UNIVERSIDAD DE GRANADA

FACULTAD DE MEDICINA

LABORATORIO DE ANTROPOLOGÍA

EL APORTE DE LA RADIOLOGÍA AL AVANCE DE LA ANTROPOLOGÍA FORENSE: PERSPECTIVA PROFESIONAL

TESIS DOCTORAL

TZIPI KAHANA

DIRECTORES:

DR. MIGUEL C. BOTELLA LÓPEZ

DRA. MARIA INMACULADA ALEMÁN AGUILERA

Granada, 2009

Editor: Editorial de la Universidad de Granada
Autor: Tzipi Kahana
D.L.: GR. 3488-2009
ISBN: 978-84-692-6389-1

AGRADECIMIENTOS

En 1984 me recibió en el laboratorio de Antropología Física de la Escuela de Medicina de La Universidad Hebrea de Jerusalén, la Profesora Patricia Smith; una de las más brillantes investigadoras en el campo de la Antropología Física y Dental. Allí hice mis primeros pinitos en Antropología. A mis compañeros de estudio y buenos amigos, Uri (Urikins), Leo, Liora, Guila, Rivka (Rivkale), y Joel (my little brother). A Pat, רבניתי מורתי, mil gracias.

En 1990, empecé la especialización en Antropología Forense en el Laboratorio de Identificación Humana de la Universidad de Arizona, que en 1987, era uno de los tres más importantes de Estados Unidos. Al jefe de este laboratorio, Walter H. Birkby, considerado uno de los fundadores de la Antropología Forense en USA, maestro incansable, hombre tierno y de disciplina férrea, siempre dispuesto a resolver las dudas de sus decenas de alumnos: Sir, Dr. Birkby, Sir!, Sempre Fi! A mis amigos de Tucson; Fulgi, Maria, Katty, Sherry y Tom– my east, my west, my weekday morning and my Sunday break.

En 1990 ingresé en el Instituto Nacional de Medicina Legal de Israel, dirigido por el Profesor Jehuda Hiss al que quiero con toda mi alma, gracias por 18 años de vida profesional plena de satisfacciones.

En 1994, me enrolé en la Unidad de Identificación de Victimas de los Laboratorios de Identificación Criminal (MAZAP) de la Policía Nacional de Israel. A mis comandantes durante todos estos años, que me han dado la oportunidad de practicar la Antropología Forense a lo largo y ancho del mundo, Profesor Iosi Almog, Dr. Shmuel Tsitrin, Dr. Avi Tsadok, y Profesor Avi Domb, jefes de MAZAP desde que me enrolé, y especialmente a Itsik Koronio, mi comandante y amigo: mis mas respetuosos agradecimientos. A mis colegas de trabajo tanto en la policía como en el Instituto, que han sido parte de mi formación profesional y compañeros en los momentos de triunfo y en horas amargas. Prof. Baruch Arensburg, Dra. Maya Freund, Dra. Nurit Bublil (Pitzi), Anat Gast, Dr. Alex Tuzov, Dr. Konstantin Zaitsev, Dra. Hadas Gips y al queridísimo Dr. Lev Goldin - Dios siempre se lleva lo mejor. A Eli Oren, Uri Argaman, David Atias, Dr. Noam Proter, Dra. Orna Rosenblat y sobre todo a mi amigo del alma: Nisim Alfi (Alfush).

A mis queridísimos amigos de toda la vida Betty, Tammy, Laura y Arie. A Irene Marchawsky por todas las horas de sillón.

A mi padre, David que en paz descanse, del que herede el amor a la enseñanza a mi madre, Miriam que mi inculco el tesón y el gusto por el arte. A mis hermanos Najman y Sue, Zahava (Tzaji), mi mejor amiga, mi compañera del alma לך יש אותי, לי יש אותך, לנו יש אותנו y Yankale אתה לי כאחי. A mis sobrinos: Natan, Yael, Tamar, Michal, Shelly, Shai y Keddy – mia bella.

Por ultimo, אחרון, אחרון חביב al Profesor Miguel Botella, destacado investigador y maestro que me acogió en su laboratorio con infinito cariño y me impartió sabias enseñanzas. A la Dra. Inmaculada Alemán amiga, compañera y maestra de la cual aprendo algo nuevo cada día. A mis amigos granainos que han hecho de Granada mi segundo hogar: Elisa– literalmente me ha dado un hogar, prenda!, Rosa, Silvia, Carmen, Fernando, Aly, Stephano y Paola.

Gracias por esta maravillosa experiencia תודה מקרב לב.

El Doctor D. Miguel Cecilio Botella López, profesor del Laboratorio de Antropología Forense de la Facultad de Medicina de la Universidad de Granada,

CERTIFICA:

Que Dª Tzipi Kahana, licenciada en Arqueología y Antropología, ha realizado bajo mi dirección los trabajos de su Tesis Doctoral " **El aporte de la radiología al avance de la antropología forense: Perspectiva profesional".**

Ha sido revisada por el que subscribe y estimo que reúne las condiciones necesarias para ser presentada a defensa pública ante Tribunal y obtener el grado de Doctor.

Granada, a 15 de Junio de 2009.

La Doctora Dª Mª Inmaculada Alemán Aguilera, profesora del Laboratorio de Antropología Forense de la Facultad de Medicina de la Universidad de Granada,

CERTIFICA:

Que Dª Tzipi Kahana, licenciada en Arqueología y Antropología, ha realizado bajo mi dirección los trabajos de su Tesis Doctoral " **El aporte de la radiología al avance de la antropología forense: Perspectiva profesional".**

Ha sido revisada por el que subscribe y estimo que reúne las condiciones necesarias para ser presentada a defensa pública ante Tribunal y obtener el grado de Doctor.

Granada, a 15 de Junio de 2009.

INDICE

I. INTRODUCCIÓN

I. INTRODUCCIÓN

La tecnología radiográfica es una herramienta eficaz en casi todas las fases de investigación medicolegal. Desde la determinación de la causa y mecanismo de la muerte, pasando por la necroidentificación en casos individuales y en desastres masivos, sin dejar de lado la estimación de la edad de individuos vivos y la documentación de traumatismos no accidentales.

La necroidentificación forma parte de toda práctica medicolegal, en la que cadáveres y restos no identificados suelen conformar un promedio del 10% de todos los casos (Cattaneo et al., 2000). Actualmente no existen estadísticas concretas respecto al numero de cadáveres no identificados dentro de la Unión Europea. En Estados Unidos, se reportan que el número de cadaveres no identificados ha aumentado considerablemente en los departamentos de Medicina Legal en la última decada, especialmente a lo largo del límite con Mexico (Hinkes, 2008). La pericia de identificación radiográfica suele realizarse por medio de la comparación de radiografías ante mortem o sea placas del individuo cuya identidad se sospecha, con radiografías post mortem, o sea radiografías del cadáver. Esta técnica esta ampliamente documentada en la literatura forense, casi desde el descubrimiento de la radiografía en 1895 (Bordas, 1896; Amoëdeo, 1898).

Además de las consideraciones humanitarias, la identificación es esencial para finalizar y certificar documentos oficiales, ya que permite completar el certificado de defunción, notificar a los familiares, permitiéndoles así tramitar testamentos y obtener beneficios de seguros.

Los restos humanos a identificar suelen variar en su estado de conservación, ya sea por los procesos químicos y físicos normales que afectan al cadáver, por el mecanismo y la causa de la muerte o por la actividad animal asociada a los restos cadavéricos.

La comparación de radiografías ante mortem y post mortem de restos en diversos estados de conservación como técnica de identificación positiva es uno de los procedimientos más comunes en Antropología Forense. Resulta sorprendente que, a pesar de su larga historia, el aporte fundamental de la radiología a las Ciencias Forenses se haya reconocido oficialmente en la literatura como una subdisciplina dentro del campo medicolegal tan sólo a finales del siglo XX (Viner, 2009).

En 1895, Röentgen hizo público su descubrimiento de los rayos X (Roentgen, 1895), el cual fue adoptado con asombrosa presteza y en cuestión de pocos años resultaba imposible imaginar la práctica de la Medicina sin el soporte diagnóstico de la radiografía.

Dentro del campo de la Medicina Forense, el uso de la radiografía como evidencia fue inmediato; en diciembre de 1895, el Sr. Holder fue condenado a 14 años de prisión en Canadá por intento de asesinato del Sr. Cunning, en base a una placa radiográfica de la pierna de la víctima en la que se podía observar la bala con la que Holder le había disparado (Cox y Kirkpatrick, 1896).

En 1896, Angerer sugirió por primera vez el uso de las radiografías de la muñeca para estimar la edad, como examen suplementario al proceso de identificación (Goodman, 1995).

El Dr. T Bordas, en 1896 enumeró entre varias utilidades de la radiografía, la posibilidad de identificar individuos por medio de la visualización de antiguas fracturas, balas y otras peculiaridades conocidas del individuo (Bordas, 1896).

En 1898, el Dr. Fovau d'Courmelles escribió " Conociendo la existencia de una fractura en una persona, que ha sido quemada o mutilada de tal forma que resulte irreconocible, se puede esperar que se le identifique por medio de una radiografía…." (Brogdon y Lichtenstein, 1998).

Durante las primeras décadas del siglo XX, la utilización de radiografías como método de identificación positiva se consolidó paulatinamente en la literatura científica; por ejemplo Schüller (1921) propuso la individualidad de los senos frontales, visibles en las radiografías. Consecutivamente, Culbert y Law (1927) ampliaron las características individualizadoras del cráneo, y hacia mediados de los 40 se extendió el uso de la radiografía al esqueleto postcraneal en busca de rasgos únicos para la identificación. En 1944, Dutra utilizó la radiografía en un estudio forense para identificar los restos de un cadáver, buscando el callo de una antigua fractura de femur que había atendido en el sujeto cuyos huesos carbonizados, se sospechaba eran de su paciente (Dutra, 1944). En 1946, Scott propuso ampliar las características individualizadoras observables en las placas radiográficas; además de las fracturas, planteó que la variación anatómica normal y las patologías eran excelentes rasgos de identificación (Scott, 1946).

En 1949, el navío Noronic naufragó frente a las costas de Canadá dejando 119 victimas mortales. La identificación de los cadáveres se llevó a cabo en su gran mayoría por métodos científicos, 78 de ellos por comparaciones de placas ante mortem y post mortem. La publicación del protocolo de identificación incluyendo el examen radiográfico de las víctimas, dió inicio a una nueva era en los estándares de identificación de víctimas de desastres masivos (Singleton, 1951).

Hoy en día, la radiología forma parte esencial del examen médico-legal de restos humanos en todos los aspectos de la investigación, pero sin duda ocupa un lugar cardinal en el campo de la identificación.

1.1. Técnica de identificación radiográfica

1.1.1 Radiación electromagnética

En 1895, Wilhem Röentgen utilizó el termino "rayos X" para describir su hallazgo puesto que no comprendía su origen, siendo "X" el símbolo de lo desconocido (Roentgen, 1896).

La radiación es una forma de movimiento de partículas en el espacio y en la materia. Se trata de fotones que tienen velocidad y por lo tanto producen energía a su paso, pero carecen de masa. La producción de rayos X se realiza dentro de un tubo de vidrio al vacío. Dentro del tubo se encuentran un ánodo (un bloque de metal, por lo general de cobre) y un cátodo (filamento de Tungsteno). El paso de la electricidad de baja tensión calienta el filamento, produciendo una nube de electrones dentro del tubo que, por atracción de opuestos se aceleran en dirección al ánodo, generando a su paso energía que se transforma en calor (99%) y en radiación (1%) (Graham y Clocke, 2007).

El calor que pasa a través del bloque de metal se dispersa en un medio oleoso mientras que la radiación pasa por una pequeñísima apertura en dirección al objeto del que se quiere formar la imagen. El haz de radiación que pasa a través de los tejidos del individuo se absorbe diferencialmente, pero en su gran mayoría los atraviesa y llega a la placa radiográfica en cuya superficie se encuentra una película de emulsión gelatinosa que contiene cristales de óxido de plata, bromuro de yodo, iones de plata intersticiales y compuestos de fósforo. Los fotones del haz de rayos X golpean los cristales en la emulsión y producen una reacción química de carga negativa, que atrae los iones de plata intersticiales y reduce a los cristales a un estado de plata pura.

La activación de los electrones produce una imagen latente en la película. Durante el proceso de revelado los cristales activados se fijan mientras que los demás se lavan; de modo que se crea una imagen radiográfica en varios tonos de gris, desde el negro puro hasta el blanco. El contraste de la imagen producida depende de la densidad de la película, del método de desarrollo químico, del tipo de exposición (tiempo de exposición y cantidad de radiación), de la forma del objeto de la radiografía, de su distancia al foco del rayo y de la resolución de la película (Bushberg et al., 2003).

Existen diferentes tipos de placas radiográficas, que varían en su tamaño y contraste en relación al objetivo de la radiografía. En odontología se acostumbra a utilizar radiografías intraorales y extraorales; entre ellas las ortopantografías (OPG), en las que se visualizan todos los dientes y tejidos óseos aledaños en una sola imagen (Ruprecht, 2008). El método de la toma de OPGs se basa en los principios de la tomografía, aplicados en una placa que gira rápidamente alrededor de la cara del paciente, mientras que el haz gira en dirección opuesta; esos giros reducen la calidad de la imagen (Howerton y Mora, 2008).

Hacia finales del siglo XX se introdujeron técnicas digitales dentro del campo de la radiología. Las imágenes digitales se forman por un conjunto de sensores discretos distribuidos de forma regular, que forman una malla sobre una superficie. La imagen esta representada por elementos pictóricos (píxeles); para ser vistos en una pantalla de ordenador se cuantifica su intensidad, de tal forma que cada píxel tiene una localización y un valor de intensidad numéricos en el sistema (Dunn y Kantor, 1993).

Toda imagen que no se recoge en una película es una imagen digital, ya sea la que se recoge directamente en un receptor de rayos X o la que se adquiere a través de una videocámara o de un escáner que graba una imagen digital de una placa radiográfica existente (Wenzel, 2002).

Existen variaciones de los sistemas para obtener imágenes digitales: placas de fósforo estimulable a los fotones de los rayos X en las que, una vez expuestas a la radiación, por medio de un haz de luz láser se emite la imagen latente a un dispositivo fotomultiplicador. Este dispositivo transforma la imagen a valores numéricos que se pueden ver como imagen reconstruida en la pantalla del ordenador. En el caso del receptor digital de imagen (RDI) un dispositivo de carga acoplada (CCD) sensible a los rayos X se conecta directamente a un ordenador, el cual procesa y optimiza la imagen capturada a través de la manipulación de los valores numéricos, por ejemplo, el contraste (Ruprecht, 2008).

Una de las ventajas de la radiografía digital es que el sensor requiere de menor cantidad de radiación que la emulsión en la película para producir la imagen, y es menos nocivo para la salud (Dunn y Kantor, 1993).

Las ventajas de la radiología digital son especialmente importantes en la producción de imágenes tomográficas, en las que una serie de tubos radiográficos giran alrededor del paciente y dirigen múltiples haces de rayos X mientras que el paciente se mueve en un plano horizontal, de tal forma que se crean imágenes radiográficas de cortes sucesivos del objeto en su eje coronal.

1.1.2 Principios básicos de identificación radiográfica forense

En Ciencias Forenses se definen los caracteres útiles para la individualización como aquellos que se atienen a dos requisitos fundamentales: variabilidad en la expresión o en la forma y consistencia a lo largo de la vida del individuo (Taroni, Mangin y Perrior, 2000).

Las características más comunes, aparentes en las radiografías, que se utilizan como indicadores de individualidad incluyen la variación anatómica normal, signos de intervención médica, patologías, e indicios de cicatrización y otros procesos de curación. La fiabilidad de estos indicadores de identidad, dentro del ámbito forense depende de cuan únicos son y de su estabilidad a lo largo del tiempo (Saferstein, 1982; Sauer et al., 1988). Algunos de los rasgos individualizadores que conciernen al campo de la Radiología Forense no se ajustan del todo al requisito de estabilidad, puesto que los cambios degenerativos en el sistema óseo tienden a magnificarse con el tiempo y algunas intervenciones médicas se sustituyen a lo largo de la vida del individuo. No obstante, la dirección de los cambios es predecible.

Investigadores en el campo de las Ciencias Forenses, principalmente de la Odontología, han intentado crear escalas de identificación en base a la calidad y cantidad de puntos concordantes en las radiografías. McKena (1986) propuso seis categorías o niveles de identificación, similares a los que se usan en la unidad de Odontología Forense de la Universidad de Adelaida en Australia:

1. Identificación positiva, cuando la identidad se ha probado por encima de lo razonable incluyendo el uso de radiografías.

2. Identidad altamente probable, al existir un alto nivel de concordancia entre la información ante y post mortem, pero no existen radiografías.

3. Consistente pero dudosa, cuando existen diferencias entre la data ante y post mortem, pero estas diferencias pueden ser explicadas.

4. Imposible de identificar, casos en los que la información ante o post mortem es mínima o insuficiente y no es posible confirmar o excluir la identidad.

5. Inconsistente, cuando existen diferencias en los datos ante y post mortem que no se pueden explicar.

6. Exclusión definitiva cuando las inconsistencias indican de una forma pormenorizada que existe una incongruencia.

Silverstein (1995) recomendó simplificar estas categorías en cuatro niveles: 1. Identificación positiva, 2. Identidad posible, 3. Evidencia insuficiente, 4. Exclusión.

Algunos investigadores han enfocado la identificación al número de rasgos requeridos para establecer la identificación positiva, siguiendo el punto de vista de la identificación por medio de huellas digitales. Keiser-Nielsen (1977) propuso doce puntos concordantes como mínimo para establecer la identidad positiva; argumentando que al ignorarse la frecuencia en la que se presentan las características dentales declina su valor identificativo (Keiser-Nielsen, 1977). De acuerdo a esta línea de pensamiento se han realizado diversos estudios epidemiológicos con el fin de establecer las frecuencias y distribución de tratamientos y patología en diversas poblaciones (Friedman, Cornwell y Lorton, 1989; Adams, 2003; Martínez Chicón, Luna del Castillo y Valenzuela Garach, 2008). Otros investigadores aceptan un numero menor, siempre y cuando las caracteristicas sean de alta concordancia (Fellingham, Kotze y Nash, 1984; Borman y Grondahl, 1990; Phillips y Scheepers, 1990; Zahrani, 2005). Varios investigadores en el campo de la Odontología Forense recogen identificaciones dentales basadas en un solo punto de concordancia (Nortje y Harris, 1986; Dailey, 1991; Slabbert, Ackermann y Altini, 1991; Villiers y Phillips, 1998).

Sin embargo, otros expertos forenses sugieren que el número de puntos concordantes no es necesariamente el problema (Hill, 1989). Locard en 1918 consideró que la evaluación de la identificación requiere más que la mera cuenta de características (Erzinclioglu, 2000; Taroni et al., 2000). En 1995, la comunidad de expertos en huellas digitales, acordó en el manifiesto de "Neurim" que no existe un número mínimo de puntos de concordancia para establecer la identidad dactiloscópica (Almog y Springer, 1995).

En el ámbito de la Radiología Forense no existe un consenso respecto al número de puntos concordantes mínimos para establecer la identidad, aunque algunos radiólogos sugieren que cuanto mayor sea el número de concordancias, mayor será el grado de certidumbre de la identificación (Mulligan et al., 1988). El hincapié en la investigación en este campo se encuentra más que todo en la calidad de los rasgos útiles para la identificación; es la experiencia del investigador la que determinará si existe la evidencia suficiente que permita establecer la identidad (Acharya y Taylor, 2003). Este aspecto de la Radiología Forense se ampliará en secciones sucesivas del presente manuscrito.

La identificación del individuo depende de la similitud entre los rasgos comparados en las radiografías ante y post mortem. Uno de los problemas fundamentales mencionado en la literatura forense es la influencia de las diferencias en la proyección geométrica del origen de los rayos X en las radiografías ante y post mortem. Alteraciones en la dirección del haz de radiación a través del objeto o cambios en la posición del objeto que se radiografía, permutarán los valores de intensidad y por lo tanto la información radiográfica (McKenna, 1999).

La posición correcta de los sujetos al tomarse la radiografía es extremadamente importante, ya que el objetivo del investigador es reproducir del modo más exacto posible las condiciones y ángulos placa – objeto respecto a la radiografía ante mortem (Fishman, 1985). Radiografías del mismo individuo pueden parecer diferentes a raíz de variaciones en la centralización del rayo, ángulo de proyección y rotación del hueso. Por lo general la experiencia del antropólogo o patólogo forense son suficientes para sobreponerse a este obstáculo (McKeena, 1999).

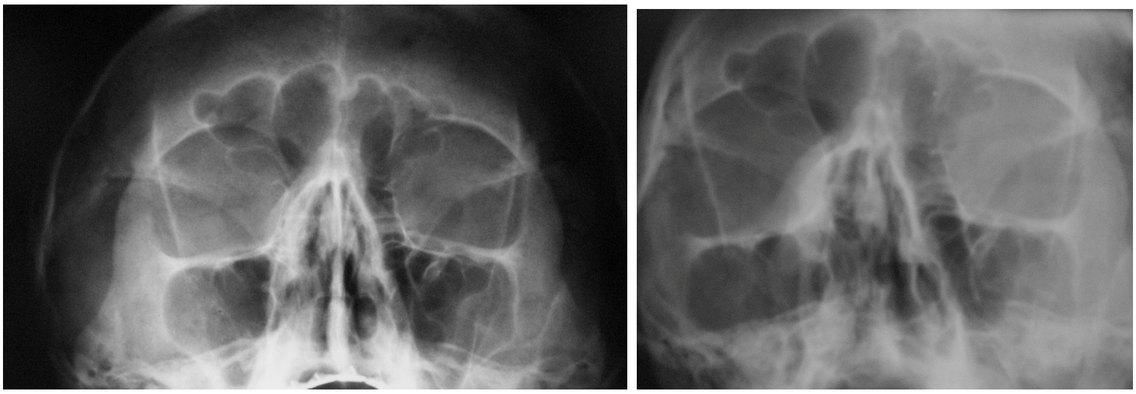


Figura 1. Radiografías ante mortem y post mortem de los senos frontales del mismo individuo. A pesar de la diferencia en el angulo del tubo, es posible comparar la configuración de los senos

1.1.3 Aplicación de la Tomografía Automática Computerizada (TAC) y Resonancia Magnética Nuclear (RMN) en el ámbito Forense

Durante la última década del siglo XX empezaron a ser sugeridas técnicas tanatológicas no invasivas como sustitutos parciales o totales a la necroscopia (Davis y Peterson, 1996; Fariñas, 1998; Cacchione et al., 2001; Sebire, 2006). Los exámenes ultrasonográficos (Pacheco Cuadros, Sendino Revuelta y Hernández Albújar, 2000) y las endoscopias post mortem (Damore et al., 2000) dieron paso a la "virtopsia" o autopsia virtual llevada a cabo por un escaneo tomográfico de la totalidad del cadáver (Donchin et al., 1994; O'Donnell et al., 2007; Rutty, 2007), que posteriormente se complementó con exámenes de resonancia magnética (RMN) (Thali et al., 2003 a - b; Yen et al., 2007; O'Donnell y Woodford, 2008).

Los investigadores forenses que abogan por la utilización de técnicas de imagen avanzadas como TAC y RMN no siempre sugieren que estas reemplacen a la autopsia, pero si que la complementen. Existen un gran número de estudios que comparan la fiabilidad de la evidencia obtenida por medio del estudio de imágenes con la derivada de la autopsia convencional, reportando resultados positivos en cuanto al TAC (Roberts et al., 2003; Thali et al., 2003 a; Yamazaki et al., 2006; Yen et al., 2005); no así respecto a la RMN, que aunque es superior a la hora de definir estructuras viscerales y delinear patologías, sufre de artefactos producidos por gases y metales presentes en el cadáver

(O'Donell et al., 2007; O'Donell y Woodford, 2008). A pesar de los avances en la tecnología de la RMN, que permiten realizar el examen de la totalidad del cadáver en menos de una hora, suele restringirse al análisis del tórax o del abdomen como complemento de la virtopsia (Hart, Dudley y Zumwalt, 1996; Bisset et al., 2003; Jackowski et al., 2006).

Dentro del campo de la Antropología Forense, las imágenes producidas por TAC y RMN se han empleado tanto para la creación del perfil antropológico del individuo no identificado (Uysal et al., 2005; Abdel Moneim et al., 2008; Akansel et al., 2008; Dedouit et al., 2008; Robinson et al., 2008; Veyre-Goulet et al., 2008; DiGangi et al., 2009) como para la comparación de caracteres para identificarlo (Haglund y Fligner, 1993; Smith, Limbird, y Hoffman, 2002; Pfaeffli et al., 2007).

Algunos autores sugieren utilizar el TAC para mejorar la exactitud de medidas antropológicas que se pueden tomar directamente en la imagen con el objeto de realizar comparaciones a la hora de identificar restos humanos (Tatlisumak et al., 2007; Santoro et al., 2008).

Las ventajas del TAC han sido subrayadas también por odontólogos forenses que afirman que al utilizar imágenes que se asemejan a radiografías dentales, reconstruidas de tomografías post mortem, se pueden superar fallos de la comparación radiográfica convencional, como baja calidad de la imagen y angulación ortorradial de la dentadura (Tohnak et al., 2007). Sin embargo, en un estudio realizado en el Instituto de Radiología Clínica de la Universidad de Munich, en el que se analizó y comparó la información dental de diez cráneos, se observó que la técnica no solo resulta ardua, sino que además se producen supraposiciones dentales que impiden definir correctamente la periferia de los empastes, especialmente los de materiales sintéticos. Los autores observaron un total de 2.9% de identificaciones erróneas y un 64.1 % de falsos negativos (Kirchoff et al., 2008).

Los beneficios del TAC y de la RMN han sido indicados de igual forma para la fase de la evaluación inicial de restos humanos en grandes catástrofes (Blau, Robertson y Johnstone, 2008) y se ha sugerido que algunos de los rasgos útiles para la identificación de victimas pueden llegar a pasar desapercibidos por limitarse a los exámenes tradicionales (Dedouit et al., 2007).

Aunque son útiles radiografías de todas las regiones del cuerpo para la identificación forense, las placas craneales, dentales, torácicas y abdominales suelen ser las que se usan con mayor frecuencia (Atkins y Potsaid, 1978).

1.2. Identificación a través de radiografías del cráneo

Las características utilizadas con más frecuencia en la radiología comparativa del cráneo incluyen las grandes estructuras anatómicas, como los senos frontales y maxilares (Culbert and Law, 1927; Atkins y Potsaid, 1978; Martin, Clark y Standish, 1991; Yoshino et al., 1987; Quatrehomme et al., 1996; Campobasso et al., 2007), variación anatómica normal (Sekharan, 1985; Mesmer y Fierro, 1986; Rhine y Sperry, 1991), dentición (De Vore, 1977) y la arquitectura trabecular alveolar (Van der Stelt et al., 1986).

1.2.1 Senos y células aéreas de la apófisis mastoides

La neumatización de los senos maxilares y etmoides progresa desde el nacimiento hasta la segunda década de la vida del individuo. Los senos frontales se desarrollan como extensiones del grupo etmoideo superior y su aparición puede variar entre los seis meses y los dos años de vida, aunque generalmente se observan con claridad en placas radiográficas hacia los siete años (Simpson y Byard, 2008). El desarrollo puede ser bilateral, unilateral o estar totalmente ausentes en el 2- 5% de la población (Cameriere et al., 2008a).

El seno esfenoidal es el ultimo en desarrollarse como una extensión de las células etmoidales posteriores. Existe una variabilidad considerable en el tiempo de aparición, tamaño final y configuración del esfenoides, de aquí su fiabilidad como elemento de identificación (Brogdon, 1998).

Las células aéreas de los procesos mastoideos comienzan a desarrollarse durante la semana 33 de gestación y continúan creciendo durante la infancia hasta aproximadamente los ocho o nueve años (Koç, Karaaslan y Koç, 2004).

La variación individual del tamaño de los senos frontales y paranasales, así como las células aéreas de los procesos mastoideos fueron mencionadas por primera vez por Schüller en 1921. En un estudio basado en una serie de 100 radiografías, incluyendo un par de placas de gemelos idénticos, el investigador concluyó que las diferencias individuales encontradas son lo suficientemente distintivas como para que puedan ser utilizadas en el campo de la identificación forense (Schüller, 1943).

Figura 2. Radiografías ante mortem y post mortem del cráneo del mismo individuo en plano "Waters" en la que se pueden observar diversos caracteres útiles para la identificación: senos frontales y paranasales, septo nasal y morfología del maxilar y de la mandíbula.

En 1927 se publicó por primera vez un caso de identificación positiva apoyada en la forma de los senos frontales de un individuo. El Dr. Culbert, que había operado a un paciente de mastoiditis, identifico sus restos esqueléticos dos años después en India en base a los rasgos morfológicos y a la existencia de restos post-operatorios en el proceso mastoideo (Culbert y Law, 1927).

Posteriores estudios en diversas poblaciones han reforzado la noción de que no existen dos individuos cuyos senos sean idénticos (Ubelaker, 1984; Harris et al, 1987; Nambiar, Naidu y Subramaniam, 1999).

En 1987, Yoshino et al. propusieron sistematizar la identificación en base a la estructura de los senos paranasales a través de una clasificación morfológica del patrón anatómico. En este estudio crearon un código numérico que se sustenta en una serie de siete variables de los senos: área total, simetría bilateral, proporcionalidad, perfil del borde superior, forma del septum, células supraorbitales y área orbital. A cada uno se le asigna un valor según su característica morfológica, que se expresa en un código cuya probabilidad de repetirse en dos individuos diferentes es muy pequeña (Yoshino et al., 1987).

En 2005, el equipo de investigación de Cameriere planteó mejorar el sistema de Yoshino (1987), reemplazando las variables continuas (área y proporcionalidad) por proporciones de las áreas del seno y de la órbita (Cameriere et al., 2005).

La fiabilidad de la comparación de los senos frontales observados en radiografías ante mortem y post mortem fue examinada por primera vez por el equipo de investigación de Kullman; se hizo a través de una investigación doble ciega, realizada por tres investigadores independientes sobre 99 pares de placas del cráneo (Kullman, Eklund y Grunding, 1990).

La influencia de la edad, sexo, causa de la muerte o el tiempo transcurrido entre las radiografías ante mortem y post mortem en la fiabilidad de los senos frontales fue examinada en una muestra de 39 casos forenses, demostrando que ninguno de estos factores afectan a la validez del rasgo (Kirk, Word y Goldstein, 2002). No obstante, diferencias en el ángulo de proyección de la radiografía pueden afectar a la apariencia de los senos, por lo que Nambiar y colaboradores (1999) propusieron que las radiografías post mortem se tomen en proyección occipito-mental para acercarse al ángulo ante mortem (Nambiar, Naidu y Subramaniam, 1999).

Posteriormente, en 2003, el equipo de investigación japonés de Taniguchi, examinó 372 radiografías del cráneo para analizar la posibilidad de aumentar la fiabilidad de este rasgo combinándola con la forma del septo nasal y crear un sistema clasificatorio. El septo nasal se clasificó como recto, inclinado hacia la izquierda, inclinado hacia la derecha, de forma sigmoidea, de forma sigmoidea inversa, y tipos raros. La forma de los senos frontales se clasificó como aplasica, simétrica, asimétrica dominante hacia la derecha, asimétrica dominante hacia la izquierda y número de lobulaciones. La combinación de estas dos categorizaciones resultó en 204 tipos diferentes, cuyas incidencias se acercan al 5% cada una. No obstante, la aplicación de este método en 24 pares de radiografías solo obtuvo resultados correctos en 75% de los casos (Taniguchi et al., 2003).

La cuantificación de los métodos de identificación permite que se ajusten a los requisitos impuestos por la comunidad forense en base a las guías de Daubert (Daubert vs Merrell Dow Pharmaceuticals, INC.- 509 US 579, 1993). De esta forma, Christensen (2004) estudió una muestra de 800 radiografías en las cuales aplicó el análisis elíptico de Fourier para ajustar el borde de cada seno que se puede representar como una suma de funciones trigonométricas. Finalmente se concluyó que la distancia euclidiana entre los pares de bordes de senos del mismo individuo, obtenidas de radiografías distintas, es menor que la de pares de individuos distintos (Christensen, 2004). La comparación de los rebordes de los senos frontales es recomendada también por el equipo de investigación de da Silva para reforzar la identificación (da Silva et al., 2009).

Recientemente Cameriere y su grupo de investigación (2008), han reiterado la fiabilidad del sistema de identificación a través de los senos frontales, y han examinado el potencial de errores de identificación cuando se comparan placas de individuos de la misma familia (Cameriere et al., 2008b).

1.2.2 Otros rasgos de variabilidad anatómica normal en el cráneo

La observación de los surcos y canales vasculares en el cráneo ha sido propuesta como indicadora radiográfica para la identificación positiva. El curso de la arteria meníngea media que es claramente visible en la mayoría de radiografías del cráneo, así como las granulaciones de Pacchioni, que se encuentran en el frontal y en los parietales, varían extremadamente tanto en apariencia como en tamaño y curso entre distintos individuos. En un estudio retrospectivo realizado por Messmer y Fierro (1986), se observó que los patrones vasculares cambian muy poco a lo largo de la vida del individuo, excepto el incremento simétrico en el tamaño, que refleja el crecimiento (Mesmer y Fierro, 1986). A pesar de que la profundización de la arteria meníngea media y del complejo venoso, es uno de los fenómenos que se han destacado en la literatura científica como indicadores de edad (Arensburg, 1989); el recorrido vascular se mantiene constante a lo largo de la vida y por lo tanto resulta útil como indicador de identificación positiva (Bass, 1989; Rhine y Sperry, 1991).

El patrón de las suturas craneales, expresado como tenues líneas grises en la placa radiográfica, ha sido propuesto como otro indicador de identidad por Sekharan en 1985, examinando su fiabilidad en una serie de 320 radiografías (Sekharan, 1989). Sin embargo, cabe indicar que a partir de los 45 años las suturas empiezan a obliterarse dejando lagunas en el patrón, lo cual influye en su fiabilidad como indicador de identidad (Schollmeyer, 1965).

Finalmente, el tamaño y la configuración de la silla turca fueron destacadas como indicadores de individualidad por Voluter (1959), característica utilizada por Singleton en la identificación de las víctimas del navío Noronic (Singleton, 1951).

Figura 3. Placa radiográfica del cráneo en posición lateral en la que se pueden observar caracteres de alta variación anatómica como la silla turca y celdas neumáticas de la apófisis mastoides.

1.2.3 Dentición

La utilización de la radiografía como elemento diagnóstico de la práctica odontológica se conoce a partir de 1898. Su uso como utensilio forense en la identificación de restos cadavéricos se menciona en el primer texto de Odontología Forense escrito por el Dr. Oscar Amoëdeo en 1898, en el que se publica una reproducción de lo que parece ser una proyección panorámica de la dentición (Amoëdeo, 1898).

Dada la naturaleza de los tejidos dentales y que algunos de los materiales utilizados para su restauración son extremadamente resistentes a los elementos químicos y físicos, la identificación dental es uno de los métodos probablemente mejor conocidos y más frecuentemente usados en la identificación de restos humanos (Petju et al., 2007).

PM **AM**

Figura 4. Radiografías dentales de una victima de desastre aéreo (PM) y de uno de los pasajeros del avión siniestrado (AM). La identificación dental de la víctima se basó en la concordancia del patrón trabecular, morfología de las raíces, y de las cavidades pulpares visibles en las dos radiografías.

La identidad dental se define como el total de las características de los dientes y las estructuras asociadas que aunque no necesariamente son únicas, cuando se consideran en conjunto proveen una totalidad exclusiva (Acharya y Taylor, 2003).

La presencia o ausencia de dientes; tratamientos y prótesis, crean un conjunto de datos única, por medio del cual se puede obtener la identificación del individuo (Mertz, 1977; Buchner, 1985), la forma de las restauraciones y la presencia de evidencia dental iatrogénica como tatuajes de amalgama, aumentan la individualidad del conjunto (Slabbert et al., 1991; Wilcher y Hulewicz, 2005).

Otras particularidades que se pueden observar en radiografías dentales incluyen la variación anatómica de las coronas y raíces, (Schwartz y Woolridge, 1976; Sopher, 1993), la morfología de los empastes, procesos patológicos en el hueso (Fischman, 1985), el patrón trabecular (Van der Stelt, 1986) y rebordes de los senos maxilares en placas periapicales (Tai, Blenkinsop y Wood, 1993).

Radiografías de tipo ortopantograma (OPG) permiten la visualización de la mayoría de las estructuras dentales y óseas en una sola placa y facilitan el proceso de identificación dental (Happonen et al., 1991).

Figura 5. Conjunto de características dentales visibles en un ortopantograma.

A pesar de que la proyección dental en este tipo de placas conlleva cierta distorsión en la zona premolar, los ortopantogramas resultan muy útiles para la identificación de restos humanos. La fiabilidad del peritaje basado en información obtenida en ortopantogramas fue examinada por el equipo de investigación coreano de Lee (2004). Utilizaron una serie de 300 placas OPG, escogidas al azar en el archivo de un centro médico, y crearon una serie de códigos en base a las características dentales presentes (Lee et al., 2004).

Una de las ventajas de los OPGs es que son visibles, no solo las piezas dentales y parte del hueso alveolar, sino que además son observables las estructuras óseas adyacentes como senos maxilares, vértebras cervicales, hioides y malares lo que hace posible examinar la diversidad de la anatomía normal. La presencia de variaciones anatómicas como las celdillas aéreas en la apófisis zigomática del temporal ha sido estudiada en una serie de 7870 ortopantogramas; esta característica esta presente en el 2.37% de los casos, y en el 70% de ellos es unilateral (Friedrich, Schulz y Scheuer, 2005).

Estudios de validación respecto al uso de la radiografía dental como herramienta de identificación, proponen investigar el efecto de algunas variables en la fiabilidad de la identificación puesto que los tratamientos terapéuticos realizados posteriormente a las radiografías ante mortem o periodos muy largos transcurridos entre las radiografías a comparar, pueden afectar la fiabilidad de la identificación (Kogon, McKay y MacLean, 1995), especialmente durante la fase de crecimiento y desarrollo dental (Borman y Grondhal, 1990).

La radiografía dental es fundamental no solo en el área de la identificación individual sino en la estimación de la edad de individuos en crecimiento y adultos; su fiabilidad ha sido demostrada por un gran número de autores (Gleiser y Hunt, 1955; Demirjian, Goldstein y Tanner, 1973; Haavikko, 1974; Smith, 1991; Liversidge et al., 1999; Nyström et al., 2000; Teivens y Mornstad, 2001; Mesotten et al., 2002; Gunst et al., 2003; Cameriere et al., 2006; Scmelling et al., 2008). Probablemente esto se debe a su baja variabilidad individual, ya que el ritmo de calcificación dental está controlado principalmente por mecanismos genéticos y esta menos afectado por factores ambientales (Demirjian, Goldstein y Tanner 1973; Chailet, Willens y Demirjian, 2004).

Los métodos de estimación del desarrollo dental se basan en la observación radiográfica de las piezas dentales y su clasificación en estadios de calcificación (Teivens y Mörnstad, 2001; Knell et al., 2009) o en medidas tomadas sobre radiografías, ya sea la longitud del diente en su totalidad, la corona o la raíz (Lilliequist y Lundberg, 1971; Mörnstad et al., 1995 ; Cameriere et al., 2008a).

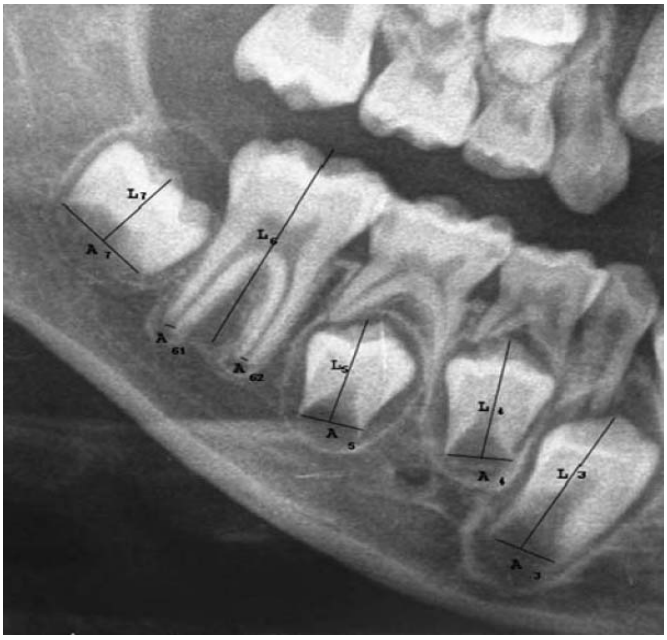


Figura 6. Odontometría de piezas dentales permanentes (Cameriere et al., 2008a)

1.3. Identificación por medio de radiografías postcraneales

Cuando se trata de radiografías postcraneales, el antropólogo forense suele comparar características de variación anatómica normal, como la morfología de los procesos vertebrales (Hyma y Rao, 1991; Valenzuela, 1997), el tamaño, forma y la relación entre las costillas (Martel et al., 1977; Murphy y Gantner, 1982), el patrón trabecular y surcos vasculares de los coxales (Moser y Wagner, 1990) y de los huesos de manos y pies (Greulich, 1960a; Kade, Meyer y Wahlke, 1967; Varga y Takacs, 1991).

Suelen utilizarse como elementos de identificación el efecto de los procesos degenerativos concomitantes al envejecimiento, como los rebordes osteofíticos vertebrales, calcificaciones del cartílago costal (Martel et al., 1977), herniaciones vertebrales, puentes óseos intervertebrales y espículas en los coxales (Rouge et al., 1993), asi como la presencia de antiguos traumatismos óseos e intervenciones medicas (Varga y Takacs, 1991).

Los cambios degenerativos se pueden observar tanto en el esqueleto axial como en el apendicular. No existe un límite claro entre los cambios que ocurren en las articulaciones a raíz del envejecimiento y los fenómenos correlacionados a la artritis degenerativa incipiente. Se trata de cambios progresivos precedidos por alteraciones del cartílago articular por el desgaste fisiológico normal. A este proceso normal se une la artritis degenerativa secundaria. Las características degenerativas de las articulaciones axiales son, en suma, el resultado de la inflamación, traumatismos, cambios metabólicos y fenómenos congénitos (Ortner y Putschar, 1985).

En la columna vertebral se pueden observar protuberancias óseas en forma de repisa en la corteza de los cuerpos vertebrales después de la tercera década de vida (Schmörl y Junghans, 1971). La formación de osteofitos principalmente derivados de células precursoras del periostio y otros factores de crecimiento de la superfamilia TGFbeta, se encuentra altamente asociada al daño del cartílago pero no de manera exclusiva (van der Kraan y van den Berg, 2007). Los osteofitos tienden a apuntar hacia el espacio intervertebral adyacente y en ocasiones se fusionan dos osteofitos de vértebras consecutivas. Los osteofitos suelen estar apuntalados por osificaciones del ligamento espinoso anterior, fenómeno que se denomina osteofitosis vertebral (Aufderheide y Rodríguez-Martin, 2005).

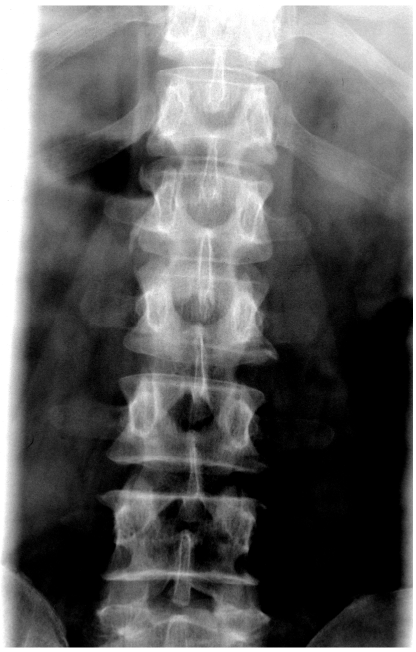


Figura 7. Radiografía de la columna vertebral en la que se observan diversos caracteres útiles para la identificación como la morfología de los procesos espinosos, deformación de los cuerpos vertebrales y osteofitos

Otros fenómenos degenerativos de la columna vertebral detectables en radiografías incluyen el estrechamiento de los espacios intervertebrales, nódulos de Schmörl y quistes. Owsley et al. (1993) demostraron la utilidad de una placa abdominal para la identificación de unos restos esqueléticos hallados en un bosque en Pennsylvania. La comparación entre la radiografía de los restos y una placa de un individuo desaparecido resultó en la concordancia de diez rasgos independientes; variación anatómica normal de dos procesos transversales, concavidad de un cuerpo vertebral, osteofitos, un arco neural abierto, radiotransparencias y radiodensidades, y la forma del contorno del acetábulo (Owsley et al., 1993).

Exostosis u osteocondromas fueron descritos por primera vez en 1787 como un desorden que forma lesiones óseas pedunculares de hueso cortical y medular contiguos al cartílago hialiano subyacente, por lo general de un grosor menor de 2 cms (Wilcher, 2008).

Exostosis en huesos largos, como resultado de procesos neoplásicos también se mencionan en la literatura científica como rasgos útiles para la identificación de restos humanos (Wilcher, 2008).

La estabilidad de las particularidades mencionadas ha sido analizada en varios estudios longitudinales. Sauer et al. (1988) examinaron los cambios degenerativos de las apófisis espinosas y de los cuerpos vertebrales de cinco individuos a lo largo de 10 y 25 años. Los resultados del estudio indican que a pesar de la gran flexibilidad y de los cambios en el tejido óseo a lo largo de la vida, los criterios utilizados por los antropólogos forenses para la identificación positiva son extremadamente estables, incluso después de más de dos décadas (Sauer et al., 1988).

La individualidad de las características cervicales fué examinada en una serie de radiografías de quince individuos, entre los cuales no se hallo ningún punto de concordancia (Owesley et al., 1993). Las calcificaciones de los cartílagos costales, su tamaño, forma y la orientación de los elementos óseos del tórax fueron examinados en una serie de nueve pares de radiografías tomadas en diferentes centros médicos en intervalos de entre uno y ocho años. En todos los casos las características fueron suficientemente indicativas de identificación (Martel et al., 1977). Atkins y Potsaid realizaron un estudio similar con una muestra mas grande (50 pares de radiografías del tórax) obteniendo resultados semejantes al estudio del equipo de Martel (Atkins y Potsaid, 1978).

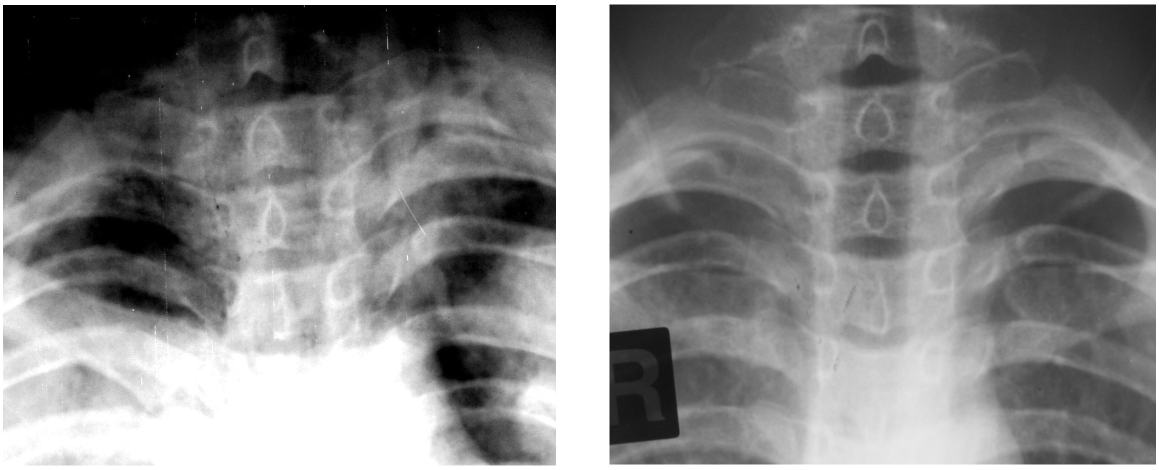


FIGURA 8. Radiografías ante mortem y post mortem del tórax de un individuo en las que se puede observar la similitud en la forma de las apófisis espinales de las vértebras.

Uno de los primeros estudios de la variabilidad individual de las características óseas del esqueleto apendicular fue realizado en 1960 por Greulich, que comparó 70 pares de radiografías de las manos de gemelos del mismo sexo. En este estudio, en el que se analizó la estructura de los huesos de la mano y la muñeca, se encontraron diferencias considerables en la morfología de los huesos (Greulich, 1960 a-b). Ubelaker, en 1990, estudió la morfología del borde lateral de la escápula en una muestra de 200 placas radiográficas, hallándola un excelente indicador de individualidad (Ubelaker, 1990).

Figura 9. Radiografía de la mano un individuo no identificado con presencia de polidactilia.

La validez de los parámetros radiográficos presentes en placas del tórax fue examinada por un grupo de investigadores forenses norteamericanos, concluyendo que se puede obtener un alto grado de certeza por medio de este tipo de identificación (Kuehn et al., 2002). La investigación de Kuehn et al. aporta además, de manera similar a la de Christensen (2005) basada en los senos frontales, un acercamiento a los requisitos legales de Daubert, adoptados en los Estados Unidos y algunos países Europeos (Kassirer y Cecil, 2002; Almog y Springer, 1995).

1.3.1 Intervención médica

La presencia de implantes ortopédicos u otros implantes médicos pueden ayudar a la identificación positiva del individuo cuando existen documentos ante mortem que permiten la comparación.

La observación de implantes en placas radiográficas que contienen a su vez información respecto a la identidad del individuo resultan especialmente útiles (Simpson et al., 2007). En países en los que se requiere anotar el número de serie del implante en los documentos médicos, es posible seguir su pista cuando se encuentran en restos humanos no identificados. Los marcapasos son un buen ejemplo de esta práctica (Saint Martin et al., 2008).

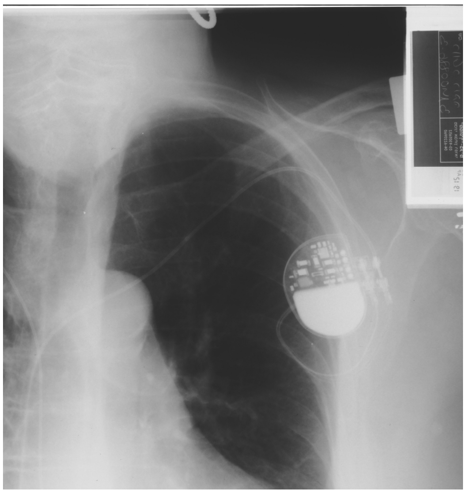
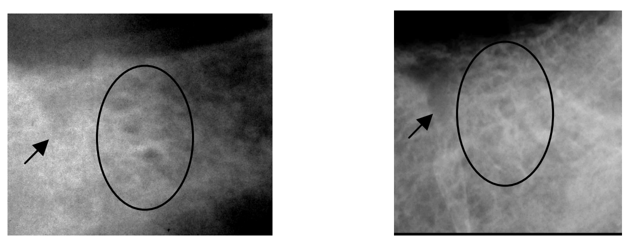


FIGURA 10. La presencia del marcapasos y su número de serie en un cadáver no identificado fue fundamental en su identificación. En la radiografía ante mortem se observa la presencia del marcapasos y el nombre del paciente.

1.4. Patrón trabecular

El hueso trabecular se halla asociado a la médula y a los espacios óseos. En el hueso adulto se encuentra principalmente en el cuerpo mandibular, en los extremos de los huesos largos y cortos, en zonas articulares, en cuerpos vertebrales y en la pelvis. Durante el desarrollo fetal y la infancia las trabéculas consisten en fibras de hueso entretejido. Hacia finales de la infancia las trabéculas están compuestas de hueso lamelar, que incluye osteocitos como en el hueso compacto pero raramente se encuentran en ellas canales vasculares u osteonas (Ortner y Putschar, 1985).

El uso de la arquitectura trabecular como indicador de identidad en radiografías post craneales fue inicialmente propuesto por Greulich en 1960 (Greulich, 1960a). Sucesivos informes en la literatura científica afirman su utilidad tanto en el esqueleto craneal como en el postcraneal (Kade; 1967, Sanders et al., 1972; Varga and Takacs, 1991; Owsly et al., 1993; Van der Stelt et al., 1986; Southard and Southard, 1994).



AM **PM**

Figura 11. Detalle de una mandíbula edéntula en donde se ve la correspondencia de lagunas en la arquitectura trabecular de las placas ante y post mortem

La reproducibilidad de las investigaciones de identidad basados en el detalle trabecular de huesos largos fue analizado por medio de un estudio de aproximadamente 40 huesos del miembro inferior en los que se definieron morfológicamente diversas morfologías; incompletas, múltiples, paralelas, en forma de "V", "H" o "S" (Mann, 1998).

La validación del patrón trabecular se sustenta metodológicamente por medio de un estudio realizado en 2005 por el grupo de investigación de Koot, ajustándolo a los requisitos legales de Daubert (Koot et al., 2005). En esta investigación, doce expertos forenses trabajaron independientemente; intentaron emparejar diez radiografías de manos previamente esqueletizadas con el fin de simular radiografías post mortem; utilizaron para ello 40 radiografías de manos de cadáveres frescos que simulaban los datos ante mortem. Los resultados demostraron una exactitud del 95%, la sensitividad y especificidad del método varió entre el 92 y el 95% respectivamente (Koot et al, 2005).

La presencia de la estructura trabecular en toda placa radiográfica, independientemente de la existencia de variantes normales poco frecuentes de ciertas estructuras anatómicas, de procesos degenerativos o de evidencia de intervención medica, hace del patrón trabecular un marcador de suma importancia en el ámbito forense.

La arquitectura trabecular puede verse comprometida en pacientes que sufren de osteoporosis. En un estudio realizado en 11 pacientes con esta enfermedad, se halló que existen diferencias morfológicas en el patrón trabecular maxilar y mandibular (White y Rudolph, 1999); por lo tanto, debe tenerse en cuenta la edad y estado de salud del individuo a la hora de cotejar la estructura trabecular.

1.5. Aplicación de la Radiología Forense a la investigación forense de desastres masivos

En general, el proceso administrativo de las víctimas fatales en grandes catástrofes se puede dividir en cuatro fases principales: rescate de los heridos, búsqueda y recuperación de cuerpos y restos fragmentados, identificación de las víctimas y proceso funerario (Blanshan y Quarentelli, 1981). La forma en que se llevan a cabo las actividades referentes a estos procesos depende de factores intrínsecos a la catástrofe como su magnitud, la cantidad y localización de las víctimas y la disponibilidad de recursos, equipo y personal especializado (Stehr y Simpson, 2002).

Cabe anotar que el establecimiento de protocolos de examen de restos cadavéricos en grandes catástrofes debe incluir un rango de flexibilidad de actuación teniendo en cuenta factores como la naturaleza del desastre en si, el estado de los restos y el número de cuerpos o fragmentos que se han de analizar (Stehr y Simpson, 2002).

Los métodos de identificación de víctimas de desastres masivos no difieren de los métodos en casos de muerte singular. Sin embargo, la identificación del cadáver basada en el reconocimiento visual de familiares o amigos no se recomienda en estas situaciones (Hiss y Kahana, 2000). La utilización de técnicas forenses como comparación de huellas dactilares, información dental, perfil de ADN e información médica durante la investigación forense de grandes catástrofes necesitan personal especializado y equipo dedicado (Kahana, Freund y Hiss, 1997).

La Radiología, desde mediados del siglo XX, se considera una herramienta importante en la identificación de víctimas de desastres masivos. En 1951 se publicó uno de los primeros protocolos de investigación forense de grandes catástrofes de acuerdo a la experiencia del equipo encargado de la identificación de las víctimas del desastre del navío Noronic, que ocurrió en 1949 en aguas territoriales de Canadá dejando 119 víctimas mortales. En este caso, la identificación de los cuerpos se basó en varios métodos científicos; cerca del 60% de los cadáveres se identificaron por medio de comparaciones de placas radiográficas ante mortem y post mortem. La publicación de este protocolo dio inicio a una nueva era en los estándares profesionales de identificación de víctimas de desastres masivos. En él se establece que a todas las víctimas se les realice una serie de 13 radiografías que cubrirán la totalidad del cuerpo, para ser utilizadas más tarde en comparaciones con placas ante mortem con el fin de establecer la identidad del individuo (Singleton, 1951).

En 1980, el departamento de Patología de la Defensa Aereoespacial Norteamericana publicó un protocolo de identificación para víctimas de desastres aéreos en el que se define el procedimiento radiográfico tanatológico como dos procesos separados pero relacionados entre si: la evaluación radiográfica de todas las víctimas y la identificación (Lichtenstein et al., 1980). Posteriormente, El Instituto de Patología de las Fuerzas Armadas Americanas evaluó la ejecución de este protocolo en un accidente aéreo en Terranova en 1985, en el que perecieron un total de 256 personas. El resultado de esta valoración produjo la formalización de la rutina radiográfica moderna, que incluye el uso de aparatos de radiografía portátiles, con recomendaciones referentes al tipo y número de tomas para la evaluación inicial, así como de procedimientos logísticos. Igualmente, este protocolo reúne de manera coherente los principios de la identificación personal radiográfica, describiendo tanto los tipos de proyecciones como los rasgos útiles para la identificación en cada una de ellas, incluyendo los grados de certeza de estos mismos rasgos (Mulligan et al., 1988).

La secuencia de operaciones necesarias para la recogida eficiente de información ante mortem fue descrita detalladamente por Moody y Busuttil (1994) tras el desastre aéreo de Lockerbie en 1988. Esta secuencia con variaciones y ajustes, se utiliza en la gran mayoría de desastres masivos y requiere, entre otras, un área especializada para la toma de fluoroscopias y radiografías, alejada del área general con el fin de proteger al personal presente (Jordan, 1999; Gill, 2006; Prieto et al., 2007). A raíz de la introducción de las técnicas tomográficas, dentro del campo de las ciencias forenses en los últimos años, se ha sugerido el empleo del TAC como reemplazo a la radiografía tradicional, aduciendo que esta tecnología podría sustituir tres fases distintas del procedimiento tanatológico como serian la evaluación inicial de los restos, la toma de radiografías del cuerpo en varias proyecciones para el examen patológico y antropológico y el registro radiográfico dental (Rutty et al., 2007; Blau, Robertson y Johnstone, 2008).

El examen rutinario y sistemático de la dentición como herramienta de identificación de víctimas de desastres masivos forma parte intrínseca de casi todos los protocolos de identificación (Beale, 1991; Van der Kuiji y Van der Pols, 1995; Kahana y Hiss, 2002b; Byard, Cooke y Leditsche, 2006; Keiser, Laing y Herbison, 2006); el examen dental del cadáver incluye la inspección ocular de la cavidad oral con la consecuente anotación detallada, la radiografía intraoral y la fotografía de la dentición (Kvaal, 2006; INTERPOL, 2009). El éxito de estos procedimientos fue comprobado en desastres de gran magnitud como el tsunami en el Océano Indico en el año 2004, en el cual 46.2% de las 3750 víctimas en Tailandia fueron identificadas por medio de la comparación dental. En este caso, para aumentar la eficacia y seguridad del personal, se diseñó un aparato de radiografía portátil de fácil manejo y muy poca dispersión (James et al., 2005; Keiser et al., 2005; Petju et al., 2007).

Figura 12. Toma de radiografías dentales de victimas del Tsunami, 2004 con un aparato portátil diseñado especialmente para desastres masivos.

El aporte de variadas técnicas radiográficas a la identificación de víctimas mortales de grandes catástrofes es patente en la literatura científica, tanto en el campo de la Patología y Antropología Forense como en la Odontología Forense.

La importancia de la Radiografía en este campo se refleja en su reconocimiento como sección separada en diversas conferencias y congresos internacionales de Radiografía (Hines, Rock y Viner, 2006). Es de esperar que, en un futuro no lejano se reconozca oficialmente la Radiología Forense como disciplina independiente dentro del ámbito de las Ciencias Forenses.

II. JUSTIFICACIÓN

II. JUSTIFICACIÓN

La Antropología Forense como disciplina independiente ha evolucionado desde principios del siglo XX a la par que los desarrollos tecnológicos del mundo científico; una de las herramientas que le ha dado un gran empuje ha sido la utilización de técnicas radiológicas para la identificación positiva de restos humanos.

Casi desde su descubrimiento, las técnicas de radiografía fueron reconocidas como instrumentos de gran importancia dentro del campo de las Ciencias Forenses (Brogdon, 1998). La aplicación de la Radiología tanto para las pericias clínicas en las que se estima la edad de individuos vivos (Shmelling et al., 2004) o se evalúa la gravedad de diversos traumatismos, como en las pericias tanatológicas (Raino et al., 2001) es parte integral del quehacer diario de patólogos y antropólogos forenses (Stein y Grünberg, 2009).

Dado el papel central de la identificación positiva de cadáveres y restos humanos que conlleva implicaciones legales de gran magnitud, los métodos utilizados para establecer la identidad, deben cumplir con los requisitos de todo procedimiento científico, para poder ser aplicados con validez a cuestiones forenses (Petju et al., 2007).

Estos requisitos suponen la transparencia y la posibilidad de verificar la data, que debe haber sido presentada a la comunidad científica por medio de publicaciones que incluyan los detalles relevantes de la metodología utilizada, y la estadística relevante. Por el contrario, métodos ambiguos o cuyo procedimiento es vago y sus aplicaciones o evaluaciones son inciertas, no son apropiados para resolver cuestiones legales cuya significación social es determinante (Ritz – Timme et al., 2000).

Uno de los principales problemas a la hora de aplicar ciertos métodos de identificación, es la falta de estudios sistemáticos que analizan la variación entre diferentes investigadores al aplicar el mismo método. Este obstáculo se acusa más en sistemas basados en evaluaciones de tipo cualitativo o semi-cuantitavo (Borman et al., 1995), como también en el empleo de nuevas tecnologías de medición aplicadas a métodos diseñados para otros procedimientos (Kollveit et al., 1998; Bosmans et al., 2005).

La presentación clara de la información relativa a la precisión de la estimación obtenida por el método a utilizar es también muy importante; esta deberá ser examinada por medio del uso de procedimientos validos de estadística claramente definidos (Cecil, 2005).

Los artículos que forman parte de esta tesis representan cambios en la perspectiva científica de la Antropología Forense ajustándose a nuevos requerimientos jurídicos, a la magnitud de las grandes catástrofes de los siglos XX y XXI y a los avances tecnológicos del mundo moderno.

Las primeras dos publicaciones que conforman este trabajo: "Positive identification by means of trabecular bone pattern comparison" y "Quantitative assessment of trabecular bone pattern identification" conciernen a aplicaciones matemáticas dentro del ámbito de la identificación positiva por medio de la comparación del patrón trabecular visible en radiografías post craneales (Kahana y Hiss, 1994; Kahana, Hiss y Smith, 1998). Estos artículos forman parte del fundamento científico necesario bajo los nuevos requerimientos jurídicos de Daubert (Cecil, 2005).

La tercera publicación incluida en esta tesis "Endoscopic autopsy" (Avrahami et al., 1995), enfoca el problema de las técnicas invasivas que forman parte de toda autopsia a las cuales se resisten tradiciones religiosas de judíos y musulmanes (Benbow y Roberts, 2003). En este artículo, el grupo de investigación del "Centro Nacional de Medicina Forense" de Israel, propuso por primera vez utilizar la laparoscopia como sustituto de la autopsia. Cabe recalcar que el artículo no fue bien recibido por la comunidad científica que criticó la sugerencia de no examinar visualmente la evidencia necroscópica, y tachó la posibilidad de utilizar cualquier sustituto de autopsia como un retroceso en las pautas científicas. A este artículo le siguieron diversas propuestas tanatológicas no invasivas (Cacchione et al., 2001; Pacheco Cuadros, Sendito Revuelta y Hernández Albujar, 2000; Fariñas Gonzales, 1996) y, si se considera la actual aceptación de la "virtopsia" (Dedouit et al., 2007; Yen et al., 2007), podría decirse que la propuesta de la laparoscopía fue pionera.

Dentro del grupo de publicaciones incluidas en esta tesis, se encuentran dos que enfocan el uso de características degenerativas visibles en radiografías post craneales: los flebolitos presentes en algunas radiografías del abdomen: "Suprapelvic and pelvic phleboliths – a reliable radiographic marker for positive identification" (Kahana y Hiss, 2002a) y varios aspectos de la columna vertebral observables en placas torácicas y abdominales "Personal Identification based on radiographic vertebral features" (Kahana, Goldin y Hiss, 2002).

La inclusión de la radiografía dentro del protocolo de identificación en desastres masivos está representada en un artículo escrito en colaboración con el equipo de Medicina Forense de Buenos Aires (Kahana et al., 1997). En este artículo: " Radiographic identification of fragmentary human remains from mass disaster" se refleja la experiencia de patólogos, antropólogos y radiólogos forenses que, por medio de una actuación coordinada, utilizan radiografías de restos humanos fragmentarios para la identificación positiva de víctimas de una gran catástrofe.

La posibilidad de comparar imágenes de TAC ante mortem con radiografías post mortem, es el tema central del artículo titulado "Identification of human remains through comparison of computerized tomography and radiographic plates" (Kahana et al., 2002b). Este procedimiento es hoy en día ampliamente reconocido por patólogos y antropólogos forenses que lo utilizan para la identificación de víctimas mortales (Dedouit et al., 2007; Tatlisumak et al., 2007).

La Radiología Forense no está oficialmente reconocida como una sub-disciplina dentro del conjunto de las Ciencias Forenses y así lo refleja el hecho de que, hasta el momento, no existen secciones separadas de Radiología en ninguno de los principales congresos forenses de Europa o de los Estados Unidos; tampoco hay secciones separadas para Radiología Forense en los congresos de Radiología; aunque organizaciones de técnicos de radiografía (radiógrafos) como "La Sociedad Internacional de Radiógrafos" del Reino Unido han creado, desde 1999, secciones separadas en sus conferencias (Viner, 2009).

Existen libros de texto (Evans, Knight y Whittaker 1981; Brogdon, 1998) que utilizan el termino "Radiología Forense" para definir la íntima relación entre la Patología y la Antropología Forenses con las técnicas radiograficas; las tres publicaciones que cierran esta tesis doctoral: "Identification of human remains: Forensic Radiology" (Kahana y Hiss, 1997), "Forensic Radiology" (Kahana y Hiss, 1999) y "Forensic Radiology" (Kahana y Hiss, 2005) son un aporte más al esfuerzo de darle a la Radiología Forense el lugar independiente que merece.

Este trabajo representa un recorrido a lo largo de ocho años en la vida profesional del antropólogo, enfocando el uso de la radiografía en diversos aspectos tanto de investigación como de aplicación de la Antropología Forense.

III. OBJETIVOS

III. OBJETIVOS

1. Analizar el papel de la Radiología dentro del campo de las Ciencias Forenses en general y en la Antropología Forense en particular.

2. Enfatizar el aporte de las técnicas radiológicas al área de la identificación positiva de cadáveres y restos humanos en casos individuales.

3. Presentar la perspectiva científica de la Antropología Forense con el apoyo de la Radiología, dada la magnitud de las grandes catástrofes de los siglos XX y XXI.

4. Sintetizar la evolución del pensamiento científico dentro del campo de la Antropología Forense en lo que se refiere a la aplicación de técnicas tradicionales bajo los nuevos requerimientos jurídicos de finales del siglo XX.

5. Exponer nuevas orientaciones en el campo de la necroidentificación y de la investigación tanatológica ajustándose a los requerimientos culturales y religiosos de diversas comunidades.

6. Señalar los diversos caracteres radiográficos útiles en la práctica de la necroidentificación y considerar su fiabilidad forense.

IV. Positive identification by means of trabecular bone pattern comparison

Kahana, T. y Hiss, J.

Journal of Forensic Sciences.

1994;39:1325-1330.

En Julio de 1992, perecieron en Jerusalén dos terroristas, al incendiarse el vehículo en que escapaban. La identificación de uno de los cadáveres incinerados se obtuvo por medio de comparación de huellas digitales, mientras que el estado de conservación del otro cuerpo no permitió obtener más que una huella parcial del pulgar derecho, la cual no fue considerada suficiente para establecer la identidad positiva por los expertos de la Unidad de Dactiloscopia sin embargo se halló indicativa de una posible identidad.

La unidad de investigación criminal de la Policía, obtuvo radiografías de las manos del individuo cuyos restos carbonizados se sospechaba, eran del presunto terrorista. En estas radiografías, tomadas dos años antes del incidente, no se observaron patologías ni traumatismos. Sin embargo, el patrón trabecular de las falanges era claramente visible. Debido al estado de conservación del cadáver, solo se pudo obtener una radiografía de su mano derecha para realizar la comparación del patrón trabecular.

Con el fin de realizar la identificación positiva se utilizó el método de comparación de densitografías desarrollado en el laboratorio de Antropología Física del Departamento de Odontología de la Universidad Hebrea de Jerusalén.

Las radiografías ante mortem y post mortem fueron digitalizadas y analizadas en el sistema de análisis de imágenes. Las líneas de referencia fueron trazadas a través de las extremidades proximales de las falanges del pulgar derecho y las densitografías comparadas por simple superimposición de imágenes y por comparación de coeficientes de correlación de Pearson.

Los resultados de la comparación entre las densitografías ante mortem y post mortem indican que las radiografías son del mismo individuo; subsecuentes exámenes del perfil de ADN del cadáver y de familiares del presunto terrorista reiteraron la identificación.

CASE REPORT

Tzipi Kahana,[1] *M.Sc. and Jehuda Hiss,*[1] *M.D.*

Positive Identification by Means of Trabecular Bone Pattern Comparison

REFERENCE: Kahana, T and Hiss, J , **"Positive Identification by Means of Trabecular Bone Pattern Comparison."** *Journal of Forensic Sciences,* JFSCA, Vol 39, No 5, September 1994, pp 1325–1330

ABSTRACT: Positive identification of human remains is often achieved by comparing antemortem and postmortem radiographs Usually, radiographs contain a number of markers that can serve as reference for comparison, one of these markers is the trabecular bone pattern depicted in the roentgenograms. In the present case, densitometric analysis of the trabecular bone pattern was used as the sole means of identification. Later on, two other methods confirmed the original positive identification

KEYWORDS: physical anthropology, trabecular pattern, positive identification, human identification

The comparison of antemortem and postmortem radiographs for positive identification of human remains is a widely used procedure in forensic anthropology [*1,2*]. The technique was first documented in the literature in 1927 by Law and Culbert [*3*], who compared the morphology of air sinuses and air cells in antemortem and postmortem cranial radiographs and established positive identification.

The reliability of identifications based on cranial and postcranial radiographic markers, has been well established since then. These markers include: gross anatomic structures [*3–6*], general degenerative changes [*7*] trauma and evidence of medical intervention [*8*] and the trabecular bone pattern depicted on the radiographs [*1,9–11*].

In this paper, a case is reported, in which positive identification was established using the trabecular bone architecture of the first metacarpal and phalanx and was later confirmed by other means of identification.

Case Report

In July 1992, two terrorists died when the stolen car in which they were traveling burst in flames. When the bodies were recovered they were extensively charred, thus precluding

Received for publication 16 Dec. 1993, revised manuscript received 7 March 1994, accepted for publication 7 March 1994.

[1] Forensic Anthropologist, Israel Police Force and Director, respectively, The L Greenberg Institute of Forensic Medicine, Tel-Aviv, Israel

visual identification. Identification and necropsy of the two burned bodies were performed at the L. Greenberg Institute of Forensic Medicine. An anthropological profile of each body was submitted to the Israeli police department together with a complete set of fingerprints of one of the bodies and a thumb print of the other. The next day, the police submitted radiographs (Fig. 1) of the right and left thumbs of a terrorist on the wanted list, who fit one of the anthropological profiles provided by the forensic anthropologist.

Postmortem radiographs of the right thumb of the body in question were taken for comparison (Fig. 2) with the radiographs supplied by the police (the left hand was extensively damaged by the fire). The visual comparison of the trabecular pattern of the first metacarpal and distal phalanx of the right hand clearly indicated that the antemortem and postmortem radiographs belonged to the same individual.

The antemortem radiographs, which had been taken two years previously, showed no evidence of trauma or special peculiarities. For this reason, detailed comparisons were made of the internal structure of the bone. In order to compare the antemortem and postmortem evidence, the radiographs were taken to the Physical Anthropology Laboratory of the Hebrew University to be densitometrically examined with an Image Analyzer.

Materials and Methods

The Image analyzer is a PC based system with the following major components: a view table for radiographs; a CCD computer controlled video camera and control card; an IBM/PC AT computer with appropriate software developed by "Galai" technologies and specially adapted by Dr. Paul Zaslansky from the Hebrew University, Hadassah Dental School.

Each radiograph was scanned and stored in the computer memory. The scanning process, performed by the camera, involves the translation of the different shades of gray of the radiograph into numbers. In this way a computer image is produced in which darker or

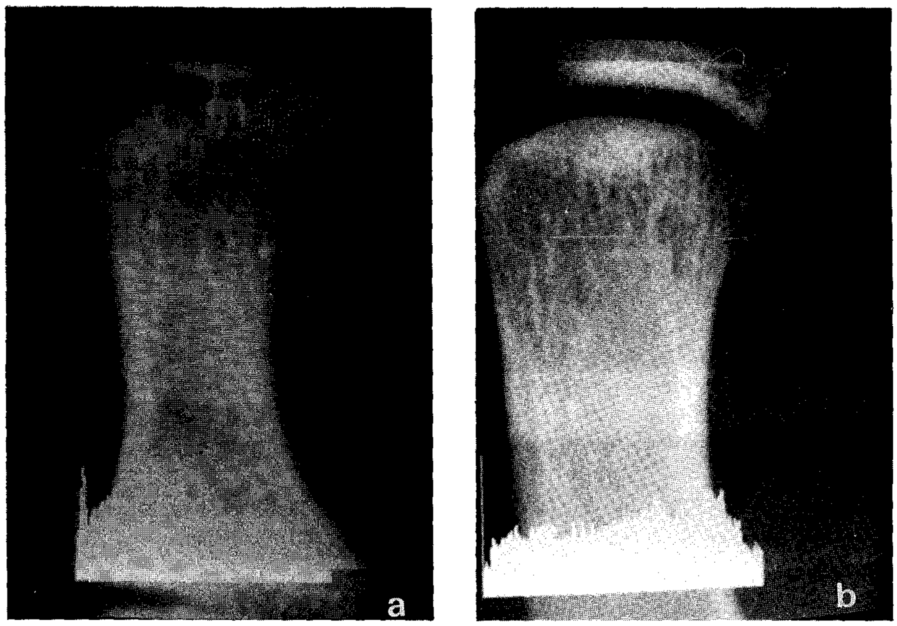


FIG. 1—*(a) Antemortem radiograph of the right proximal first phalanx; (b) antemortem radiograph of the right first metacarpal.*

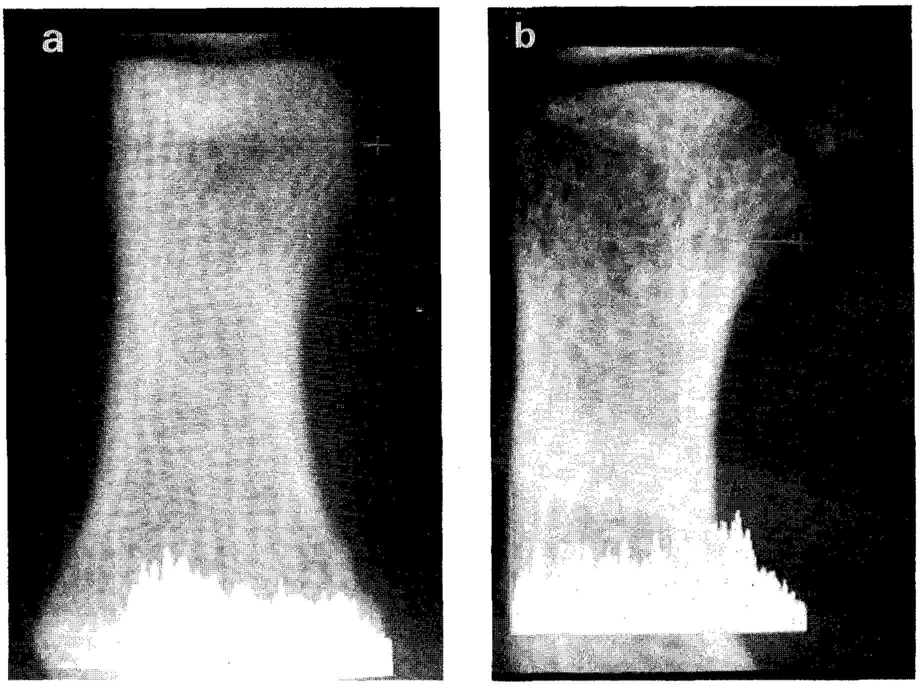


FIG. 2—*(a) Postmortem radiograph of the right proximal first; (b) postmortem radiograph of the right first metacarpal phalanx.*

lighter shades are represented by low or high values respectively (in the range of 0 to 254). Each computer image is stored as an array of numbers that can be statistically manipulated.

With the Cue4 analysis package, mathematical contrast enhancement operations were performed on the images.

Once the contrast was improved, a line along the proximal end of the first metacarpal and distal phalanx of each radiograph analyzed was selected and saved (Figs. 3 and 4). In

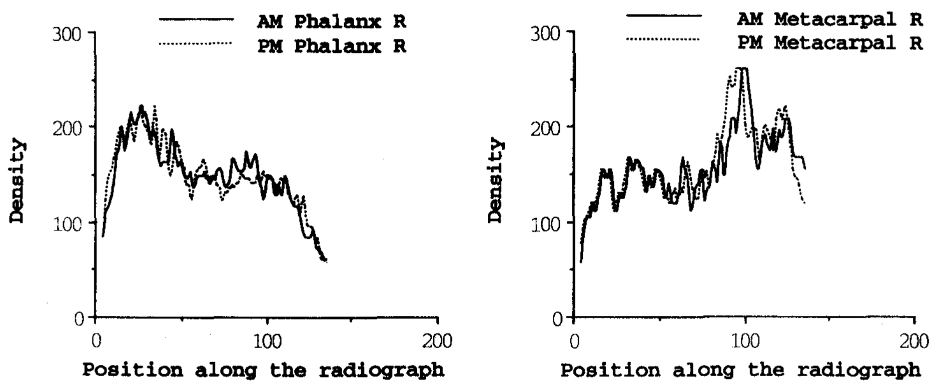


FIG. 3—*(a) Densitographs (line maps) of the antemortem and postmortem right proximal first phalanx; (b) densitographs (line maps) of the antemortem and postmortem right proximal first metacarpal.*

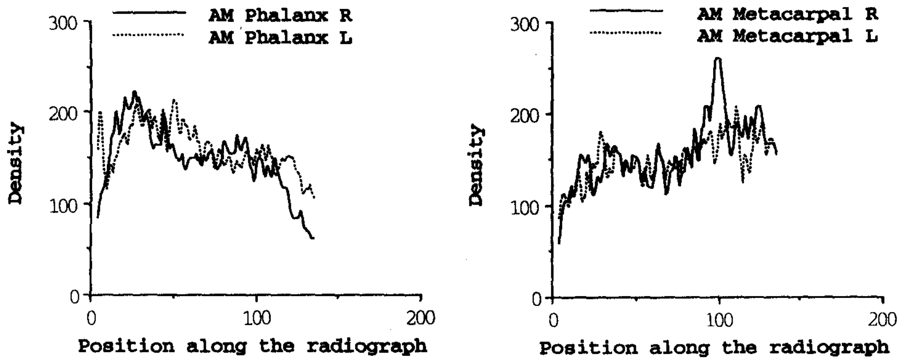


FIG. 4—*(a) Densitographs (line maps) of the antemortem left and right proximal first phalanx; (b) densitographs (line maps) of the antemortem left and right proximal first metacarpal.*

this manner, a profile of the trabecular bone pattern in each image was created. This profile (also known as a line map or a densitograph) transects distinct trabeculae [*12–13*]. The lines were selected at approximately 0.5 cm from the distal end of the first metacarpal and distal phalanx. The correlation between the different densitometric traces was examined through regression analysis.

For control purposes, the postmortem radiograph of the right hand was tested against both the right and left antemortem radiographs.

Results

Table 1 shows the correlation between the densitographs of the antemortem and postmortem radiographs of the right hand. A correlation of 0.90 was obtained for the phalanx and 0.81 for the metacarpal. The similarity between these densitographs can be evinced from the comparative graphs (Fig. 2). The correlation between the densitographs of the first metacarpal and distal phalanx of the right hand and the hand (antemortem) is also reported. The differences between the densitographs are shown on the comparative graph (Fig. 3). The correlation for both bones analyzed is less than 0.6 (the lowest correlation for densitographs of the same bone radiographed at different radiographic conditions is 0.6 [*14*].

TABLE 1—*Correlation between densitographs.*

	A.M. Right Phalanx	A.M. Right Metacarpal	A.M. Left Phalanx	A.M. Left Metacarpal	P.M. Right Phalanx	P.M. Right Metacarpal
A.M. Right Phalanx	1.0	...	...	...	...	...
A.M. Right Metacarpal	−0.272	1.0	...	...	...	...
A.M. Left Phalanx	0.507	−0.306	1.0	...	...	...
A.M. Left Metacarpal	−0.254	−0.432	−0.248	1.0	...	...
P.M. Right Phalanx	0.905	0.044	0.552	0.282	1.0	...
P.M. Right Metacarpal	0.073	0.816	0.429	0.559	0.128	1.0

Two days after the report of the positive identification by means of trabecular bone comparison was filed, the Israeli Police Department confirmed the identification by comparing the postmortem thumb print with antemortem prints that were on their files. Independently, a week later the Laboratory of Criminal Identification produced a positive identification from DNA analysis.

Discussion

Nowadays, radiographic comparisons are the most common technique used by forensic anthropologists for positive identification [*1,2*]. There are a number of reports in the literature on the markers used when making radiographic comparisons [*1–10, 15–20*]. Trabecular bone, however, is seldom used as a single marker since usually there are other remarkable features depicted in the radiographs.

In 1986 Van Der Stelt and colleagues proposed the use of trabecular bone pattern depicted in dental radiographs as a marker in forensic identifications [*9*]. Investigators comparing trabecular bone pattern from dental radiographs should be aware that the trabecular bone of the maxilla and mandible is affected by changes in the dentition, namely resorption of the alveolar bone due to extraction of teeth or periodontal disease.

Other factors that may affect comparison of the trabecular bone pattern are the radiographic conditions at which the radiographs were taken and the bone remodeling produced by age [*21*]. In a previous study designed to test the effect of the radiographic conditions on the depiction of the trabecular bone pattern [*14*], 10 radii were repeatedly radiographed under different radiographic conditions. The results of the study indicated that radiographs of the same bone taken at different settings (for example, intensity, time of exposure and angle) were more highly correlated ($R = 0.8$ to 0.6) than radiographs of different bones taken under the same conditions ($R = 0.5$ to 0.1).

Conclusion

Positive identification of the human remains is probably one of the most important steps in a necropsy. Forensic anthropologists often use radiographic comparisons for this purpose.

In this case, the only remarkable feature for comparison in the antemortem and postmortem radiographs was the trabecular bone pattern. The reliability of this marker for positive identification was tested through densitometric analysis and later confirmed by fingerprint and DNA comparisons.

References

[*1*] Atkins, L. and Potsaid, M. S., "Roentgenographic Identification of Human Remains," *Journal of the American Medical Association,* Vol. 240, No. 21, 1978, pp. 2307–2308.

[*2*] Birkby, W. and Rhine, S., "Radiographic Comparison of the Axial Skeleton for Positive Identification," *Presented at the Annual Meeting of the American Academy of Forensic Sciences,* Cincinnati, OH, 1983.

[*3*] Culbert, W. C. and Law, F. M., "Identification by Comparison of Roentgenograms of Nasal Accessory Sinuses and Mastoid Processes," *Journal of the American Medical Association,* Vol. 88, No. 4, 1927, pp. 1634–1636.

[*4*] Messmer, J. M. and Fierro, M. F., "Personal Identification by Radiographic Comparison of Vascular Groove Patterns of the Calvarium," *The American Journal of Forensic Medicine and Pathology,* Vol. 7, No. 2, 1986, pp. 159–162.

[*5*] Rhine, S. and Sperry, K., "Radiographic Identification by Mastoid Sinus and Arterial Pattern," *Journal of Forensic Sciences,* Vol. 36, No. 1, Jan. 1991, pp. 272–279.

[*6*] Marlin, D., Clark, M., and Standish, M., "Identification of Human Remains by Comparison of Frontal Sinus Radiographs: A Series of 4 Cases," *Journal of Forensic Sciences,* Vol. 36, No. 6, Nov. 1991, pp. 1762–1772.

[7] Sauer, N., Brantley, R. E., Baronders, D. A., "The Effect of Aging on the Comparability of Antemortem and Postmortem Radiographs," *Journal of Forensic Sciences,* Vol. 33, No. 5, Sept. 1988, pp. 1223–1230.
[8] Murphy, W. A., Spruill, F. G., and Gantner, G. E., "Radiographic Identification of Unknown Human Remains," *Journal of Forensic Sciences,* Vol. 25, No. 4, 1980, pp. 725–735.
[9] Van der Stelt, P., Webber, R., and Ruttimann, U., "Forensic Identification of Trabecular Patterns from Dental Radiographs," *Journal of Dental Research,* Vol. 65, Special Issue/Abstracts, 1986, p. 176 (abstract 56).
[10] Kade, H., Meyers, H., and Wahlke, J. E., "Identification of Skeletonized Human Remains by X-ray Comparison," *The Journal of Criminal Law, Criminology and Police Science,* Vol. 58, No. 2, 1967, pp. 261–264.
[11] Owsley, D. W. and Mann, R. W. "Personal Identity of Skeletonized Remains Using Abdominal and Pelvic Radiographs," *Journal of Forensic Sciences,* Vol. 37, No. 1, Jan. 1992, pp. 332–336.
[12] Israel, H. "Microdensitometric Analysis for the Study of Craniofacial Growth in the Living Subject," *American Journal of Physical Anthropology,* Vol. 27, No. 2, 1967, p. 236 (abstract 11).
[13] Israel, H., "Microdensitometric Analysis for the Study of Skeletal Growth and Aging in the Living Subject," *American Journal of Physical Anthropology,* Vol. 29, No. 2, 1968, pp. 287–294.
[14] Kahana, T., "The Reliability of the Trabecular Bone Pattern as a Bone Marker in Radiographs for Positive Identification," *Presented at the Annual Meeting of the American Academy of Forensic Sciences,* Boston, 1993.
[15] Merz, W. and Schenk, R. K., "Quantitative Structural Analysis of Human Cancellous Bone," *Acta Anatomica,* Vol. 75, No. 1, 1970, pp. 54–66.
[16] Buchner, A., "The Identification of Human Remains," *International Dental Journal,* Vol. 35, No. 4, 1985, pp. 307–311.
[17] Schwartz, T. and Woolridge, E. D., "The Use of Panoramic Radiographs for Comparison in Cases of Identification," *Journal of Forensic Sciences,* Vol. 31, No. 1, 1976, pp. 154–146.
[18] Sanders, I., Woesner, M. E., Ferguson, R. A., and Noguchi, T. T., "A New Application of Forensic Radiology: Identification of Deceased from a Single Clavicle," *American Journal of Roentgenology, Radium Therapy and Nuclear Medicine,* Vol. 115, No. 3, 1972, pp. 619–622.
[19] Ubelaker, D. H., "Positive Identification of American Indian Skeletal Remains from Radiograph Comparison," *Journal of Forensic Sciences,* Vol. 35, No. 2, 1990, pp. 466–472.
[20] Hyma, B. A. and Rao, V. J., "Evaluation and Identification of Dismembered Human Remains," *The American Journal of Forensic Medicine and Pathology,* Vol. 12, No. 4, 1991, pp. 291–299.
[21] Compston, J. E., Mellesh, R. W. E., Croucher, P., and Newcombe, R., "Structural Mechanisms of Trabecular Bone Loss in Man," *Bone and Mineral,* Vol. 6, No. 3, 1989, pp. 339–350.

Address requests for reprints or additional information to
Tzipi Kahana
Greenberg Institute of Forensic Medicine
67 Ben Zvi Blvd.
Tel-Aviv 61490
Israel

V. Quantitative Assessment of Trabecular Bone Pattern Identification

Kahana, T., Hiss, J. y Smith, P.

Journal of Forensic Sciences

1998;43:1144-1147

La arquitectura trabecular que se observa en placas radiográficas suele utilizarse como característica para la identificación. Sin embargo, su fiabilidad como marcador forense no ha sido previamente establecida, puesto que se desconoce cuan única es y cuanto cambia a través del tiempo.

El patrón trabecular es potencialmente el mejor marcador radiográfico para la identificación, ya que su presencia en la radiografía no depende de procesos patológicos o de traumatismos previos. Siempre y cuando exista una radiografía antemortem, esta se podrá comparar con una radiografía tomada de la zona correspondiente en los restos humanos y de esta manera se obtendrá suficiente data para verificar o rechazar la identificación.

El objetivo de este estudio es establecer la fiabilidad del patrón trabecular para la identificación forense, teniendo en cuenta el efecto de los cambios degenerativos del esqueleto apendicular en su arquitectura.

Se analizó una muestra de 305 radiografías de la muñeca izquierda de 103 mujeres post menopáusicas. Las radiografías se digitalizaron por medio de una videocámara y fueron estudiadas utilizando un sistema de análisis de imágenes llamado absorbsiometría o densitometría fotográfica.

Este sistema parte de la premisa de que los cambios en la densidad óptica, que se miden en la radiografía, con una escala de gris que va del 0 al 254, son inversamente proporcionales a la densidad del hueso. La densidad de cada uno de los píxeles a lo largo de una línea de referencia trazada horizontalmente en el punto ultradistal del radio se midió para crear un mapa de línea o densitografía que atraviesa las placas trabeculares. Las fluctuaciones verticales (Y) sobre el eje horizontal reflejan el grado de densidad a través del hueso, mientras que la posición relativa a lo largo del eje horizontal (X) indica la distancia entre las trabéculas cuando el sistema se ajusta de tal manera que un milímetro de placa radiográfica representa un píxel.

Las diferencias en intensidad de diversas radiografías producen gráficos cuyo punto de inicio en el eje vertical difiere. Esta posición no afecta el resultado puesto que las medidas se llevan a cabo sobre el eje horizontal.

Las densitografías obtenidas por el sistema se analizaron estadísticamente. La estabilidad del patrón trabecular se estudió comparando las densitografías del mismo individuo tomadas en años sucesivos, mientras que la densitografías del patrón se investigó comparando las densitografías de diversos individuos.

Se calcularon coeficientes de correlación de Pearson para todos los pares posibles de radiografías. El coeficiente de correlación entre pares de radiografías del mismo individuo, tomadas en diversas ocasiones (entre dos y seis años) es siempre superior a r=0.72, mientras que el coeficiente de correlación entre pares de radiografías de diferentes individuos es siempre inferior a r=0.62.

Los resultados que se presentan en este estudio demuestran que la arquitectura trabecular es individualmente única y que, a pesar de la perdida pérdida de masa ósea concomitante con la edad, existen rasgos distintivos en la arquitectura trabecular del esqueleto apendicular que permanecen estables a lo largo del tiempo. Por esta razón resulta un marcador eficiente para la identificación positiva de restos humanos.

Tzipi Kahana,[1] Ph.D.; Jehuda Hiss,[2] M.D.; and Patricia Smith,[3] Ph.D.

Quantitative Assessment of Trabecular Bone Pattern Identification

REFERENCE: Kahana T, Hiss J, Smith P. Quantitative assessment of trabecular bone pattern identification. J Forensic Sci 1998;43(6): 1144–1147.

ABSTRACT: The results of the research described in this paper demonstrate that the trabecular architecture is unique to each individual and stable enough to be used as a forensic marker for positive identification of human remains.

The trabecular bone architecture depicted on radiographs is often used as an individualizing forensic marker for positive identification of human remains.

The aim of the present study was to ascertain the reliability of the trabecular pattern in forensic identification. The trabecular pattern is potentially the best radiographic forensic marker since its presence on a radiograph doesn't depend on a previous pathology or traumatic event.

A sample of 305 radiographs of the left wrist of 103 postmenopausal women was studied using an image analyzer. The uniqueness and stability over time of the trabecular architecture was examined by creating line maps or "densitographs" of the ultra-distal point of the radius of each roentgenogram.

Pearson's correlation coefficients were calculated for all possible combinations of pairs of radiographs. The correlation coefficient of pairs of radiographs of the same individual, taken at different times (2 to 6 years apart), was always higher than 0.72, while the correlation coefficients of radiographs of different individuals was always below 0.62.

KEYWORDS: identification, X-ray, trabecula

Identification of human remains is an integral part of the medicolegal investigation of death. Beyond humanitarian considerations, identification is essential to the completion and certification of official documents, allowing them to proceed with the probate of wills and to apply for disbursement of benefits and insurance (1).

Recovered human remains vary in state of preservation either because of the normal chemical processes that affect the cadaver, the mechanism of death, or due to animal scavening. Because of this, the larger the number of methods of identification available to forensic anthropologists, the greater their probability of reaching a definitive conclusion (2).

Comparison of antemortem and postmortem radiographs is one of the most common identification procedures in forensic anthropology. Features depicted on roentgenograms often used as individualizing markers for positive identification include normal anatomical variation, signs of medical surgical intervention, pathological changes, and indications of healing processes. The reliability of these markers for forensic purposes depends on their uniqueness and stability over time (3).

The trabecular bone architecture that can be seen on radiographs is sometimes used as an individualizing forensic marker; however, its dependability for positive identification has not been previously established, since it was not known how unique the pattern is and how much it changes over time. Nevertheless, the trabecular pattern is potentially the best radiographic marker for forensic purposes since its presence doesn't depend on a rare event such as pathology, or trauma. As long as an antemortem radiograph is available, the postmortem radiograph of the corresponding area will provide enough data for verification or rejection of identification (4).

The aim of the present research was to investigate the effect of age-related bone degenerative changes in the trabecular architecture of the appendicular skeleton, and the reliability of this marker on radiographs for positive identification of human remains.

Materials and Methods

A sample of 305 radiographs of the root of the hand taken from 103 postmenopausal women was digitally analyzed. The radiographs used came from the archives of the Jerusalem Osteoporosis Institute where they were taken as part of a larger research project on osteoporosis carried out during the years 1982–1988. The participants in this project were examined annually for bone mineral status (5). The mean age of the women whose radiographs were included in the present research was 66.7 years (Table 1). They were all in good health, although 25.2% of them had been diagnosed as suffering from mild postmenopausal osteoporosis based on radiographic examination of the lumbar spine (Lumbar Spine Index 2) and 21.3% of severe postmenopausal osteoporosis (Lumbar Spine Index 3-4) (6,7) (Table 2).

The technique utilized to evaluate the reliability of the trabecular bone as a forensic identification marker is called radiographic absorptiometry or photo densitometry. This method was first devised in the early 1960's for quantitative detection of bone mineral changes (8). The density of the bones was obtained from standardized radiographs analyzed with an optical densitometer. This technique generally fell into disuse as lower radiation exposure methods such as Single and Dual photon absorptiometry were devised for diagnosis of osteoporosis (9).

Today, advances in computerized graphics permit digital quantification together with image enhancement and noise reduction of the image, allowing an accurate analysis of the trabecular bone architecture depicted on radiographs.

[1] Division of Identification and Forensic Sciences, Israel Police Headquarters, Jerusalem, Israel.
[2] The L. Greenberg Institute of Forensic Medicine, Tel Aviv, Israel.
[3] Laboratory of Physical Anthropology, Hadasah School of Dental Medicine, the Hebrew University, Jerusalem, Israel.
Received 10 Feb. 1998; and in revised form 23 April 1998; accepted 23 April 1998.

TABLE 1—*Age distribution at the time of the radiographic examination.*

Age	No.	Mean	S.D.
40–45	7	43.4	1.6
46–50	16	46.8	1.4
51–55	12	51.7	1.5
56–60	18	57.4	1.4
61–65	65	62.2	1.3
66–70	45	66.6	1.5
71–75	91	71.9	1.3
76–80	33	77.1	1.4
80+	18	81.0	0.9
Total	305	66.7	1.4

TABLE 2—*Degree of osteoporosis by age. The degree of osteoporosis was established by visual examination of lumbar spine radiographs [LSI, (6)].*

Osteoporosis (LSI)	Frequency	%	Mean Age
0	124	40.7	67.8
1	39	12.8	62.0
2	77	25.2	66.2
3	46	15.1	68.4
4	19	6.2	64.3
Total	305	100	66.7

Radiographic absorptiometry assumes that changes in optical density, when measured from roentgenograms on a gray scale ranging from 0 to 254, are inversely proportional to bone density (9).

In the present study, the radiographs were digitized and measured using a computerized image analyzer. This is a PC-based system which includes a view table, a CCD computer-controlled video camera and control card, and a computer with appropriate software developed by "Galai" technologies and especially adapted for this research.

After encoding and preprocessing the radiographic images, a reference horizontal line was selected along the ultradistal end of the radius. The gray-level value of each pixel along the line was recorded, thus producing a profile of the trabecular bone pattern (Fig. 1). This profile, also known as a densitograph or line map, transects distinct trabeculae. The vertical fluctuation (on the Y-axis) of the line maps reflects the varying density along the bone while the horizontal direction (on the X-axis) of the graph indicates the distance with the system adjusted to represent 1 mm of the film per pixel.

Differences in relative intensity between radiographs of the same bone produce graphs whose initial position on the vertical axis differs. This does not affect the analysis since the measurements are carried out along the horizontal axis (10).

The line maps obtained from the radiographs were statistically analyzed. The stability of the trabecular bone pattern was tested by comparing the line maps of the radiographs of the same individual taken at different times (between 1 to 6 years apart), while the uniqueness of the trabecular pattern was tested by comparing the line maps of the three radiographs of each individual with the correspondent radiographs of all other individuals.

The analysis was conducted with a PC-based statistical package called "Statistix." Pearson's coefficients were calculated for all pairs of line maps.

Results

The correlation coefficients between pairs of radiographs of the same individual taken at different times ranged between 0.99 and 0.72 (Fig. 2, Table 3). Higher correlation coefficients were observed in those individuals with low degrees of osteoporosis, as assessed from lumbar spine roentgenographs. While the correlation coefficients observed were never below 0.80 in individuals classified as normal or slightly osteoporotic, 31.8% of the subjects classified as suffering from mild to severe osteoporosis had correlation coefficients below 0.80; the lowest correlation was 0.72 (Table 4).

A total of 13 908 pairs of correlation coefficients were calculated between pairs of line maps of different individuals. The Pearson's correlation coefficients ranged from −0.99 to 0.62; most correlation coefficients fell between −0.40 and 0.40, with only 5.13% of the correlation coefficients being higher than 0.50 (Table 5). Lower correlation coefficients indicate that the shape of the line maps is very different, while negative correlation coefficients imply that the line maps are in opposite directions (Fig. 3).

No overlap between correlation coefficients of same and different individuals was detected, thus a cutting point at the level of $r = 0.72$ can be established for identification of human remains by means of trabecular bone pattern. In other words, if "known" or antemortem and "unknown" or postmortem radiographs from an unidentified decedent are compared in order to determine identity, a positive identification will be established when the correlation coefficient of the known and unknown line maps is higher than 0.72.

The effect of the radiographic conditions (kilovoltage and milliamperage per second) on the reliability of trabecular identification has been already reported (4). The correlation coefficients of line maps of the same bone radiographed under varying conditions are always higher than 0.73, while the correlation coefficients of line maps of different bones taken under the same conditions are always below 0.60. Thus the radiographic settings do not affect the reliability of the technique.

Discussion

The underlying hypothesis of this research was that despite age-related bone loss (11), there are distinct features of the trabecular bone of the appendicular skeleton which remain stable through time and that there is great individuality in the trabecular pattern.

The main mechanisms of microarchitectural disruption associated with aging are either a decrease in trabecular plate thickness produced by a low bone turnover and reduced bone formation at the cellular level, or perforation of plates and removal of whole trabecular units, due to high bone turnover and an excess of bone loss over bone formation. Although Silva and Gibson in 1997 (12) suggest that both mechanisms are concomitant, the findings of the present study support the notion of a low trabecular bone turnover as reflected by the lack of change in the microarchitecture of the trabecular mesh over time.

The stability of the trabecular bone assessed from radiographs of older, osteoporotic women, which are postulated as having the greatest extent of bone mineral loss, can be extrapolated to younger women and to males who have less bone mass loss (13).

The present study substantiates the scientific reliability of the trabecular bone pattern as a forensic marker for personal identification. Although this marker has been implemented for more than 30 years (14), the results of this research provide quantifiable criteria to be presented in courts of law in a way easier to judge. The equipment required to quantify the correlation between various

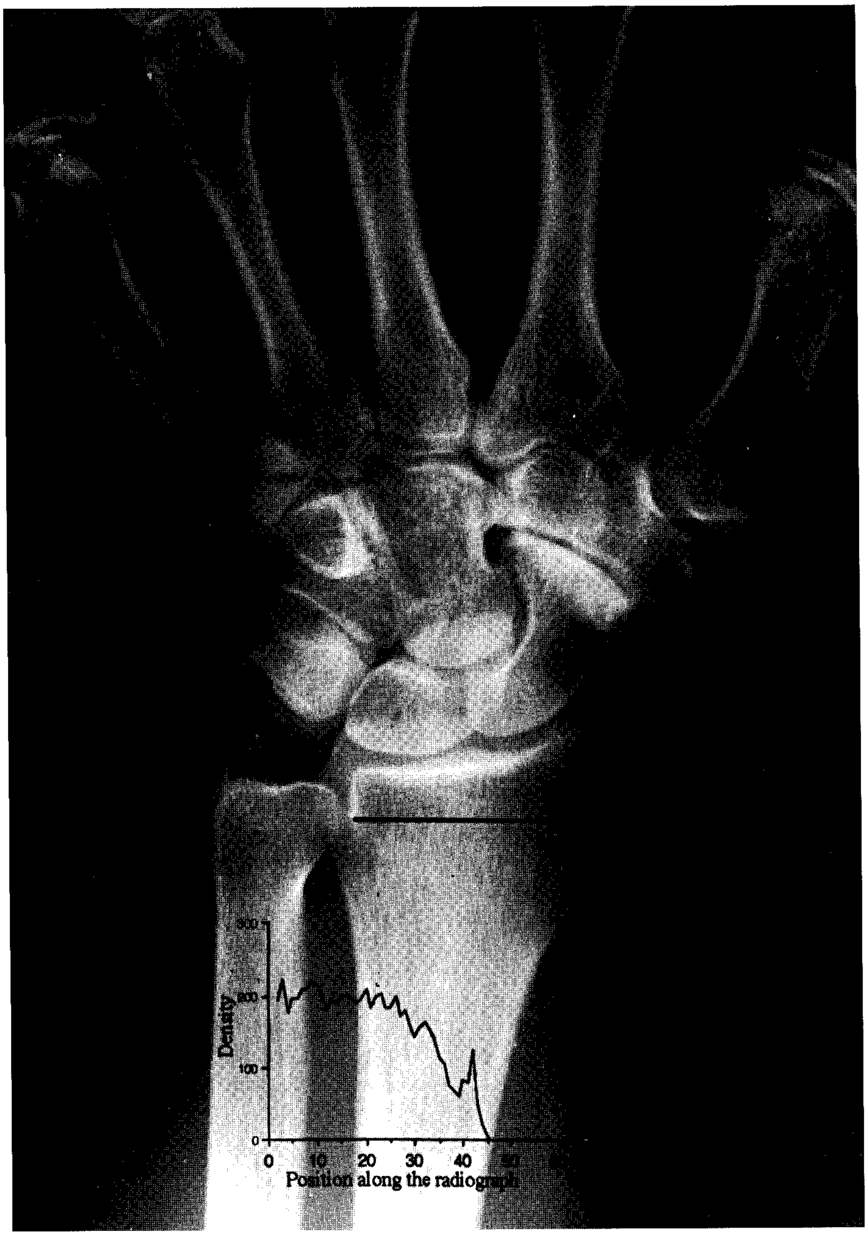


FIG. 1—*Radiograph of left hand and wrist with densitograph produced by the image analyzer.*

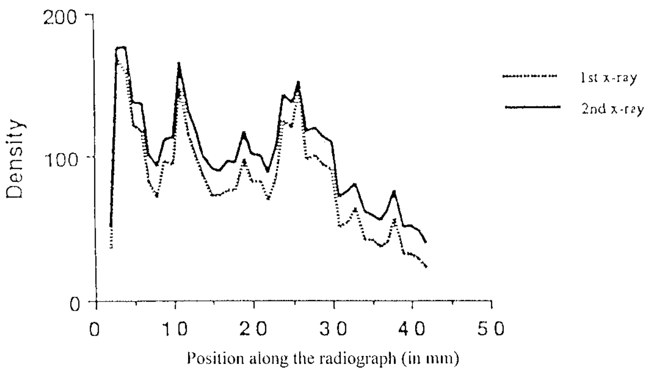


FIG. 2—*Densitographs of radiographs of the same individual taken at different times (4 years apart) (r = 0.99).*

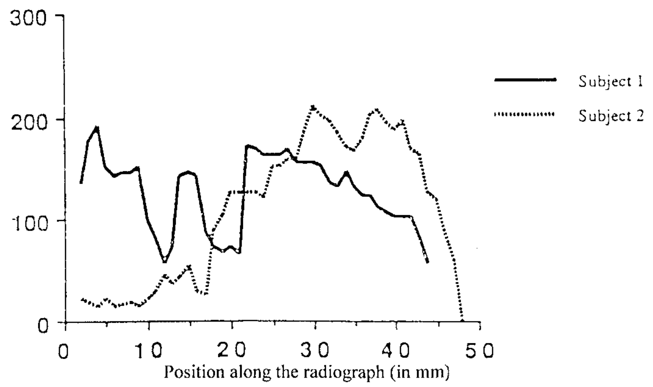


FIG. 3—*Densitographs of radiographs of different individuals (r = −0.96).*

TABLE 3—*Pearson's correlation coefficients between radiographs of the same individual taken at different times.*

	1st and 2nd X-ray		2nd and 3rd X-ray		1st and 3rd X-ray	
Correlation	Freq.	%	Freq.	%	Freq.	%
0.99–0.95	47	44.8	54	51.5	49	49.5
0.94–0.90	27	26.7	23	23.3	24	23.7
0.89–0.85	16	16.2	11	10.7	17	15.5
0.84–0.80	7	6.7	7	6.8	6	6.2
0.79–0.75	2	1.9	2	1.9	3	1.0
0.74–0.70	4	3.8	6	5.8	2	4.1
Total	103	100	101	100	101	100

TABLE 4—*Pearson's correlation coefficients by degree of osteoporosis (LSI).*

LSI/Corr.	0	1	2	3	4
0.72–0.79	0	0	0	9	10
0.80–0.85	1	6	3	8	3
0.86–0.90	3	9	15	11	1
0.91–0.95	21	36	27	4	0
0.96–0.99	77	23	45	4	3
Total	102	74	76	36	17

TABLE 5—*Pearson's correlation coefficients between pairs of line maps from radiographs of different individuals.*

X-ray/Corr.	−0.9 to −0.5	−0.49 to 0	0.1 to 0.62	Total
1st X-ray	208	1742	3303	5253
2nd X-ray	251	1710	2134	4095
3rd X-ray	152	1378	3030	4560

densitographs, i.e., a computer, a video camera and a graphics program, is common and can be found in most modern laboratories.

References

1. Fierro FM. Identification of human remains. In: Spitz WU, editor. Spitz and Fisher's medicolegal investigation of death. 3rd edition. Springfield, Illinois: Charles C Thomas, 1993;71–117.
2. Penalver JJ, Kahana T, Hiss J. Prosthetic devices in positive identification of human remains. J Forensic Identification 1997;47:400–5.
3. Kahana T, Hiss J. Identification of human remains: forensic radiology. J Clin Forensic Med 1997;4:7–15.
4. Kahana T, Hiss J. Positive identification by means of trabecular bone pattern comparison. J Forensic Sci 1994;39:1325–30.
5. Foldes I. Measurement of the bone density and early diagnosis of bone loss by Compton spectroscopy. Harefuah 1988;214:109–13.
6. Adams P, Davies GT, Sweetnam P. Osteoporosis and the effects of aging on bone mass in elderly men and women. Quart J Med 1970;34:601–15.
7. La Fianza A, Taverna E, Pistorio A, Pallavicini D, Preda L, Di Maggio EM, et al. Speed of calcaneal ultrasound attenuation in the identification of vertebral fractures in patients with senile osteoporosis. Radiol Med (Torino) 1997;93:51–5.
8. Macchiarelli R, Bondioli L. Linear densitometry and digital image processing of proximal femur radiographs: implications for archaeological and forensic anthropology. Am J Physical Anthropol 1994; 93:109–22.
9. Yates AJ, Ross PD, Lydick E, Epstein RS. Radiographic absorptiometry in the diagnosis of osteoporosis. Am J Med 1995;98: 41S–7S.
10. Beyer-Olsen EM, Eggen S. Evaluation of the reproducibility of two bitewing techniques by means of a microdensitometric recording method. Oral Surg 1983;55:103–7.
11. Christiansen C. Skeletal osteoporosis. J Bone Min Res 1993;8: S475–80.
12. Silva MJ, Gibson LJ. Modeling the mechanical behaviour of vertebral trabecular bone: effects of age related changes in microstructure. Bone 1997;21:191–9.
13. Geraets WGM, Van der Stelt PF, Netelembos WGM. A new method for automatic recognition of the radiographic trabecular pattern. J Bone Min Res 1990;5:227–33.
14. Greulich WW. Value of x-ray films of hand and wrist in human identification. Science 1960;131:155–6.

Additional information and reprint requests:
Tzipi Kahana, Ph.D.
The L. Greenberg Inst. of Forensic Medicine
67 Ben Zvi Rd.
P.O. Box 49015
Tel-Aviv 61490, Israel

VI. Endoscopic Autopsy

Avrahami, R., Watemberg, S., Daniels-Philips, E., Kahana, T. y Hiss, J.

American Journal of Forensic Medicine and

Pathology

1995;16:147-150

La fiabilidad de las técnicas endoscópicas en el campo de la cirugía clínica está ampliamente comprobada. Por medio de la endoscopia diagnóstica se evalúan exitosamente dolencias, tumores y traumatismos abdominales y toracales; por esta razón se le denomina eufemísticamente "el corte más benévolo", cuyas dimensiones no sobrepasan los dos centímetros.

Dadas las ventajas diagnosticas y cosméticas de la endoscopia, se propuso investigar la posibilidad de usar esta técnica como sustituto a la autopsia en aquellas instancias en que, por razones religiosas o culturales, resulte imposible realizar una autopsia convencional.

Con el fin de evaluar la fiabilidad de la endoscopia en el campo forense, se realizaron laparoscopias y toracoscopias en veinte cadáveres, a los que sucesivamente se les practicó autopsias convencionales.

Los casos examinados incluyen víctimas de seis accidentes vehiculares, seis de bala y ocho muertes naturales.

Los resultados de la comparación entre las dos técnicas: endoscopia y autopsia demostraron una correspondencia completa (100%) en el hallazgo de hemorragias intraperitoneales y torácicas, traumatismos hepáticos, del bazo y del diafragma. La correlación es un poco menor (60 – 80%) en hematomas del mesenterio y del retroperitoneo, traumatismos de los grandes vasos y pulmones y en aspiraciones. La endoscopia fallo en el reconocimiento de traumatismos en el retroperitoneo y en el aspecto posterior del mediastino.

Esta técnica resultó muy eficiente en la extracción de muestras de fluidos y tejidos.

Las ventajas de la autopsia laparoscópica fueron demostradas no solo en su precisión relativa y eficiencia sino en sus resultados estéticos.

The American Journal of Forensic Medicine and Pathology 16(2):147–150, 1995.

Endoscopic Autopsy

Ram Avrahami, M.D., Shalom Watemberg, M.D., Esther Daniels-Philips, M.D., Tzipi Kahana, M.Sc., and Jehuda Hiss, M.D.

In cases in which the family of the deceased objects to the performance of a conventional autopsy for religious or other reasons, or where there are no forensic pathology facilities in the vicinity of the hospital, postmortem endoscopic examination may be an advantageous and cost-effective substitute for conventional necropsy, especially when the alternative is no postmortem examination at all. To test the reliability of postmortem endoscopy, conventional and endoscopic autopsies were performed on 20 cadavers at the L. Greenberg Institute of Forensic Medicine in Israel. Comparison of the findings of the two procedures showed a very high correlation (100%) for intraperitoneal and thoracic hemorrhages and hepatic, splenic, and diaphragmatic injuries; it showed a slightly lower correlation (60–80%) for mesenteric and retroperitoneal hematomas injuries to the great vessels, blood aspiration, and lung injury. Endoscopy failed to reveal the correct site of injury in the retroperitoneum and posterior aspect of the mediastinum. Collection of body fluids and tissue samples was possible by means of laparoscopy. The technique proved to be relatively accurate, more rapid than conventional autopsy, and left the body virtually intact.
Key Words: Endoscopy—Laparoscopy—Thoracoscopy—Autopsy.

Received September 9, 1994; accepted October 19, 1994.
From the Department of Surgery B, Beilinson Medical Center, Petah Tiqva (R.A., S.W.); the L. Greenberg Institute of Forensic Medicine, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv (E.D.-P., J.H.); and the Israeli National Police, Israel (T.K.).
Address correspondence and reprint requests to R. Avrahami, M.D., Department of Surgery B, Beilinson Medical Center, Petah Tiqva 49100, Israel.

Religious and moral beliefs often preclude the performance of forensic necropsies. In Israel, both Jewish Orthodox and Muslim communities frown upon the performance of autopsies.

The reliability of endoscopy in surgical procedures is well established (1). Diagnostic laparoscopy is successful in evaluating abdominal pain (2–4), staging of malignant tumors (5,6), and evaluation of abdominal trauma (7–9). Diagnostic thoracoscopy is successful in the evaluation of trauma and malignancy (10–12). The procedure is deemed the kindest cut of all, leaving only a 1–2-cm scar (13,14).

Because of these diagnostic and cosmetic assets, endoscopic examination appears to be a feasible alternative in cases in which thoracic or abdominal cavity pathology is suspected and there is no consent for a formal autopsy. It may also provide a good alternative when no forensic pathology facility is located in the vicinity of the hospital.

To test the reliability of postmortem endoscopy, we performed the procedure on 20 cadavers prior to conventional autopsy and then compared the findings.

MATERIALS AND METHODS

A Hopkin telescope (6.5 mm, 30° angle) was utilized. The basic principle of endoscopy is to create a working space within the abdominal or thoracic cavity with carbon dioxide by means of a small trocar, through which a telescopic device of

TABLE 1. *Circumstances of death*

Cause	Male	Female	Total
Road accident	4	2	6
Gunshot wound	6	—	6
Hospital	4	—	4
Other	2	2	4
Total	16	4	20

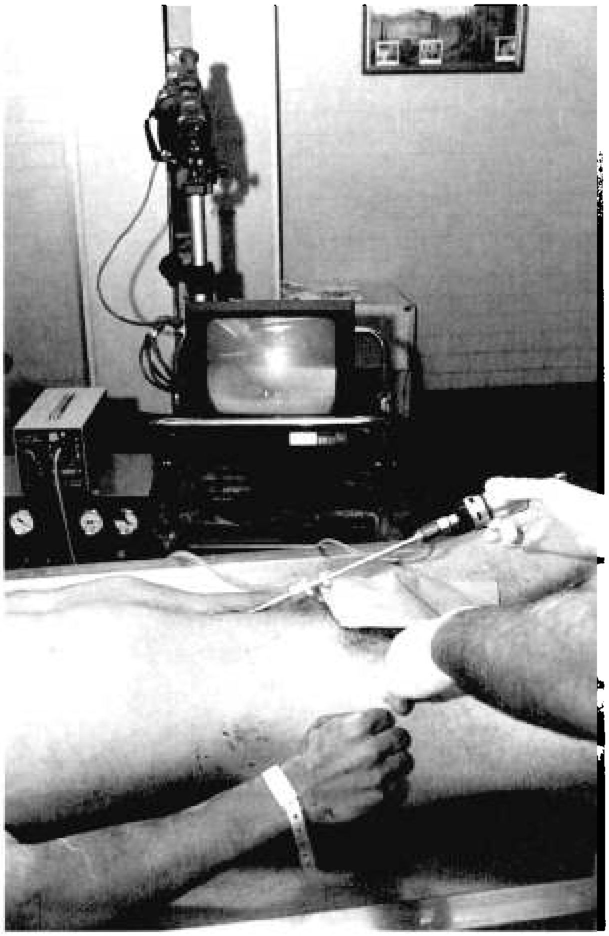


FIG. 1. The endoscopic setup.

5–10 mm is inserted. A video camera is harnessed to the telescopic eyepiece, producing a magnification of 10–15 diameters, thus providing a clear image of the operative field. Other trocars can be inserted throughout the procedure for sampling of tissues and body fluids (1).

The study samples consisted of 20 cadavers of individuals with various cause of death (Table 1). Laparoscopy was performed in all cases; thoracoscopy was done in 15 cases.

The bodies were kept under refrigeration for 6–20 h before the examination. Once the standard external postmortem examination was completed, the endoscopic examination was begun.

The endoscopy was carried out by an experienced surgeon. Laparoscopy was conducted by inserting an infraumbilical trocar for insufflation and telescopic examination (Fig. 1). Thoracoscopy was accomplished via a trocar inserted at the mid-axillary line in the fourth intercostal space. The body was shifted during the examination in order to expose different areas within the cavity.

A formal postmortem autopsy was performed by the forensic medicine staff of the institute and the findings of the two procedures were compared.

RESULTS

Comparison of the findings of the procedures in the abdominal area showed a 100% correlation in all cases of intraperitoneal hemorrhages, hepatic and splenic injury, diaphragmatic tear, gunshot wound to the peritoneal cavity, and small-bowel perforation. The correlation was 60–80% in the correct assessment of mesenteric and retroperitoneal hematomas. The laparoscopy did not reveal the correct site of injury in the retroperitoneum, perforation of the rectum, or damage to the ileac vessels (Table 2). In 11 cases, there were no pathological findings on the laparoscopic examination, whereas in only 10 cases, no abdominal pathology was found at formal autopsy. A tumor of the left kidney in an 82-year-old man who died of traumatic subdural hematoma was detected incidentally during formal necropsy.

The correlation between findings of the two methods in the thoracic cavity was 100% for intrapleural hemorrhages, gunshot wound to the pleural cavity, and diaphragmatic tear; it was 75% for injuries to the great vessels and aorta, blood aspiration, and lung injury. Thoracoscopy failed to reveal the exact location of bullet injuries to the back of the aorta, the posterior aspect of the right atrium, and the trajectory of a bullet through the lung (Table 3). Of the 15 cases, six showed no pathological findings on thoracoscopy, whereas only four were free of pathology at formal autopsy. In one instance, a pulmonary embolism was found during conventional autopsy on a victim who had been hospitalized for 2 weeks following excision of a melanoma of the right leg. In another case, massive food aspiration in a psychiatric catatonic patient was not detected during the endoscopic examination and was found only at conventional autopsy.

TABLE 2. *Laparoscopy versus formal autopsy findings*

Findings	Laparoscopy	Autopsy	Ratio
Hemoperitoneum	8	8	8/8
Splenic tear	1	1	1/1
Hepatic tear	3	3	3/3
Diaphragmatic tear	2	2	2/2
Small-bowel tear	1	1	1/1
Large-bowel tear	0	1	0/1
Bullet penetration of abdominal cavity	3	3	3/3
Abdominal wall hematoma	2	2	2/2
Retroperitoneal hematoma	2	3	2/3
Previous surgery	2	2	2/2
Hernias	1	1	1/1

TABLE 3. *Thoracoscopy versus formal autopsy findings*

Findings	Thoracoscopy	Autopsy	Ratio
Intrapleural hemorrhage	11	11	11/11
Lung parenchymal hemorrhage	6	7	6/7
Injury to great vessels	3	4	3/4
Cardiac injury	—	1	0/1
Diaphragmatic tears	2	2	2/2
Bullet penetration of pleural cavity	5	5	5/5
Bullet penetration of lung	3	5	3/5
Bullet penetration of heart	0	1	0/1

In general, the duration of the endoscopic postmortem examination was shorter than that of the conventional procedure. It was 15 versus 25 min for examination of the abdominal cavity, and 12 versus 20 min for examination of the thoracic cavity.

Samples of body fluids and tissues were taken during the endoscopic procedure. In one case, following radiological examination, a bullet was located and successfully excised from the back using the endoscope. The procedure required some dissection of the body and was accomplished with great difficulty. After the endoscopic autopsy, the body remained almost intact, with only three to six small (1-cm) incisions.

DISCUSSION

We examined the efficacy of endoscopic autopsy as an alternative to conventional necropsy in cases in which the family of the deceased refuses to sign a postmortem examination release because of religious or emotional reasons.

In Israel, as in most developed countries, forensic autopsies are indicated in all cases of sudden, unexpected death (15). When the next of kin does not consent to an autopsy, the authorities can request a court order. We suggest that when there is no court order but information may be necessary for pursuing an investigation for medical purposes (such as unexpected death after surgical procedures), postmortem endoscopic examination should be performed, since in surgical practice, the endoscopic autopsy leaves very small incisions scars. We believe this advantage makes the procedure more readily acceptable to the family of the deceased.

Diagnostic endoscopy was already in use in the early 1970s. Its obvious advantages over traditional surgery led the lay public to demand its application by physicians and surgeons. In the last 5 years, endoscopic examinations have become very popular in surgical practice as well as in the evaluation of abdominal and thoracic trauma (7,13,14,16–18).

In the present study, we found the endoscopic procedure to be highly sensitive in revealing intracavity hemorrhages, visceral injury, penetrating wounds to the thorax and peritoneal cavity, as well as tears in the small bowel. Unlike conventional autopsy, where the whole body and each organ within it is examined, these findings are not sufficiently specific to establish a definite cause of death. However, the results of the endoscopic examination are extremely reliable in the assessment of abdominal and thoracic catastrophes and—more important—in ruling them out.

Endoscopic autopsies are less sensitive for retroperitoneal and posterior mediastinal investigation. In the present study, retroperitoneal hematoma was identified in two of three cases and injury to the thoracic great vessels in three of four cases. Endoscopic examination failed to detect a gunshot wound to the posterior aspect of the right atrium in one case. Samples of body fluids and tissue were obtainable during the endoscopic autopsy.

In conclusion, we believe that although endoscopy requires special training and skills, the availability of endoscopic equipment in most hospitals (19,20) and the aesthetic advantages of the technique make the endoscopic autopsy a reliable, cost-effective, and feasible alternative to conventional autopsy in cases in which thoracic or abdominal pathology is suspected and consent for a conventional autopsy cannot be obtained from the family.

REFERENCES

1. Soper NJ, Brunt LM, Kerbl K. Laparoscopic general surgery. *N Engl J Med* 1994;330:409–19.
2. Paterson-Brown S, Eckersley JR, Sim AJ, Dudley HA. Laparoscopy as an adjunct to decision making in the 'acute abdomen.' *Br J Surg* 1986;73:1022–4.
3. Salky B. Diagnostic laparoscopy. *Surg Laparosc Endosc* 1993;3:132–4.
4. Nagy AG, James D. Diagnostic laparoscopy. *Am J Surg* 1989;157:490–3.
5. Warshaw AL, Gu ZY, Wittenberg J, Waltman AC. Preoperative staging and assessment of resectability of pancreatic cancer. *Arch Surg* 1990;125:230–3.
6. Spinelli P, Di Felice G. Laparoscopy and abdominal malignancies. *Probl Gen Surg* 1991;8:329–47.
7. Cuschieri A, Hennessy TPJ, Stephens RB, Berci G. Diagnosis of significant abdominal trauma after road traffic accidents: preliminary results of a multicentre clinical trial comparing minilaparoscopy with peritoneal lavage. *Ann R Coll Surg Engl* 1988;70:153–5.
8. Smith RS, Tsoi EKM, Fry WR, Morabito DJ, Organ CH. Laparoscopy is cost effective in the evaluation of abdominal trauma [Abstract]. *Surg Endosc* 1973;7:173.
9. Sosa JL, Sims D, Martin L, Zeppa R. Laparoscopic evaluation of tangential abdominal gunshot wounds. *Arch Surg* 1992;127:109–10.

10. Daniel TM. Diagnostic thoracoscopy for pleural disease. *Ann Thorac Surg* 1993;56:639–40.
11. Brainbridge MV. The history of thoracoscopic surgery. *Ann Thorac Surg* 1993;56:610–4.
12. Graeben GM, Jones PR. The rate of thoracoscopy in thoracic trauma. *Ann Thorac Surg* 1993;56:646–8.
13. Goldsmith MF. Future surgery: minimal invasion. *JAMA* 1990;264:272.
14. Nash JM. The kindest cuts of all. *Time* 1992March 25: 52–3.
15. DiMaio DJ, DiMaio VJ. *Forensic pathology*. New York: Elsevier, 1989:1–19.
16. Soper NJ, Stockmann PT, Dunnegan DL, Ashley SW. Laparoscopic cholecystectomy: the new "gold standard"? *Arch Surg* 1992;127:917–23.
17. The Southern Surgeons Club. A prospective analysis of 1518 laparoscopic cholecystectomies. *N Engl J Med* 1991; 324:1073–8.
18. Smith SR, Fry RW, Tsoi MKE, et al. Preliminary report on videothoracoscopy in the evaluation and treatment of thoracic injury. *Am J Surg* 1993;166:690–5.
19. Forde KA. Endosurgical training methods: is it surgical training that is out of control? *Surg Endosc* 1993;7:71–2.
20. Green FL. New York State Health Department ruling—a "wake-up-call" for all. *Surg Endosc* 1992;6:271.

VII. Suprapelvic and pelvic phleboliths – A reliable radiographic marker for positive identification

Kahana, T. y Hiss, J.

Journal of Clinical Forensic Medicine

2002; 9:115-118

Los flebolitos son coágulos calcificados que se encuentran en los vasos sanguíneos de la región pélvica en cerca de 50% de los adultos y en los del área suprapélvica en el 2%. Su posición anatómica y su morfología dependen de la forma del vaso que los contiene y de la forma del coágulo del que se han originado.

El siguiente artículo describe un caso en el que se realizó la identificación positiva de un cadáver en avanzado estado de putrefacción a través de la comparación de la localización y configuración de seis flebolitos.

La etiología y relativa frecuencia de este carácter se discute en la publicación, al igual que su fiabilidad como carácter radiográfico forense.

En el artículo se propone que, a pesar de la alta frecuencia de los flebolitos pélvicos, estos pueden ser utilizados para la identificación positiva, siempre y cuando haya una buena correspondencia en su numero, forma y posición relativa cuando se comparan placas radiográficas ante mortem y post mortem y existe algún otro indicio que confirme la identidad. En el caso de los flebolitos suprapélvicos, dada su baja frecuencia, resultan excelentes indicadores de identidad por si solos.

Journal of Clinical Forensic Medicine (2002) **9**, 115–118

doi:10.1016/S1353-1131(02)00063-9, available online at http://www.idealibrary.com on IDEAL®

ORIGINAL COMMUNICATION

Suprapelvic and pelvic phleboliths – a reliable radiographic marker for positive identification

T. Kahana,[1] J. Hiss[2]
[1]*Division of Identification and Forensic Science, Israel National Police, Headquarters, Jerusalem, Israel;*
[2]*The National Centre of Forensic Medicine, Tel Aviv, Israel*

SUMMARY. Identification of unknown human remains is often achieved by radiographic comparisons. Among the markers compared in antemortem and postmortem radiographs is the presence of concordant pelvic and supra-pelvic phleboliths which are calcified intravenous blood clots. An illustrative case is presented, where an unidentified decomposed cadaver of an elderly male was positively identified with the aid of medical data provided by the Israel National Police. Two missing persons' records were suggested as possible matches and the concordant presence of phleboliths in one of the cases was useful for the identification. The reliability of phleboliths for radiographic positive identification is discussed along with the etiology and frequency of this phenomenon. © 2002 Published by Elsevier Science Ltd and APS.

Journal of Clinical Forensic Medicine (2002) **9**, 115–118

INTRODUCTION

Identification of unknown human remains by scientific methods is one of the main endeavours of forensic sciences. This task can be accomplished by a variety of scientific techniques including imaging comparison.[1] Among the markers that are advocated in the literature as reliable indicators of identity is the presence of concordant phleboliths in both antemortem and postmortem radiographs.[2]

Phleboliths are calcified blood clots encountered in the pelvic and supra-pelvic region, the former being rather common in adults (ca. 50%)[3] while the latter are rare (ca. 2%).[4] Their anatomical position and morphology depend greatly on the individual variation of the vessel containing them and the shape of the blood clot from which they originate.

In the present study we report on a positive identification of a body in advance stage of decomposition achieved by comparison of the location and configuration of six pelvic phleboliths. Despite their relative high frequency pelvic phleboliths can be a good marker for personal identification provided that the correspondence between their number, shape, position, and relation to each other is concurrent.

CASE REPORT

In the winter of the year 2000 a decomposed body clothed only with a sweatshirt and sweatpants and bearing no identification documents was found in the basement of an abandoned building. The cadaver was transferred to the National Centre of Forensic Medicine in Tel Aviv, where following the external examination, the forensic pathologist determined that these were the remains of an elderly male whose stature was approximately 161 cm. No remarkable signs of identification were present.

The Missing Persons Unit of the Israel National Police found possible matches in two males missing from their residences for more than six weeks. The first individual was an 89-year-old man suffering from Alzheimer's disease who had disappeared from a seniors residence and the second, a 93-year-old man who disappeared from his home. Through the local Police Investigations Unit, the medical records of the missing individuals were produced.

Among the medical data, there was the diagnostic report of recent abdominal radiographs carried out in

T. Kahana PhD, Division of Identification and Forensic Science, Israel National Police, Headquarters, Jerusalem, Israel.
J. Hiss MD, The National Centre of Forensic Medicine, 67 Ben Zvi Street, P.O. Box 8495, Tel Aviv 61085, Israel.

Correspondence to: T. Kahana PhD, Tel.: +972-3-5127851; Fax: +972-3-683-3813; E-mail: tzipi.kahana@forensic.health.gov.il

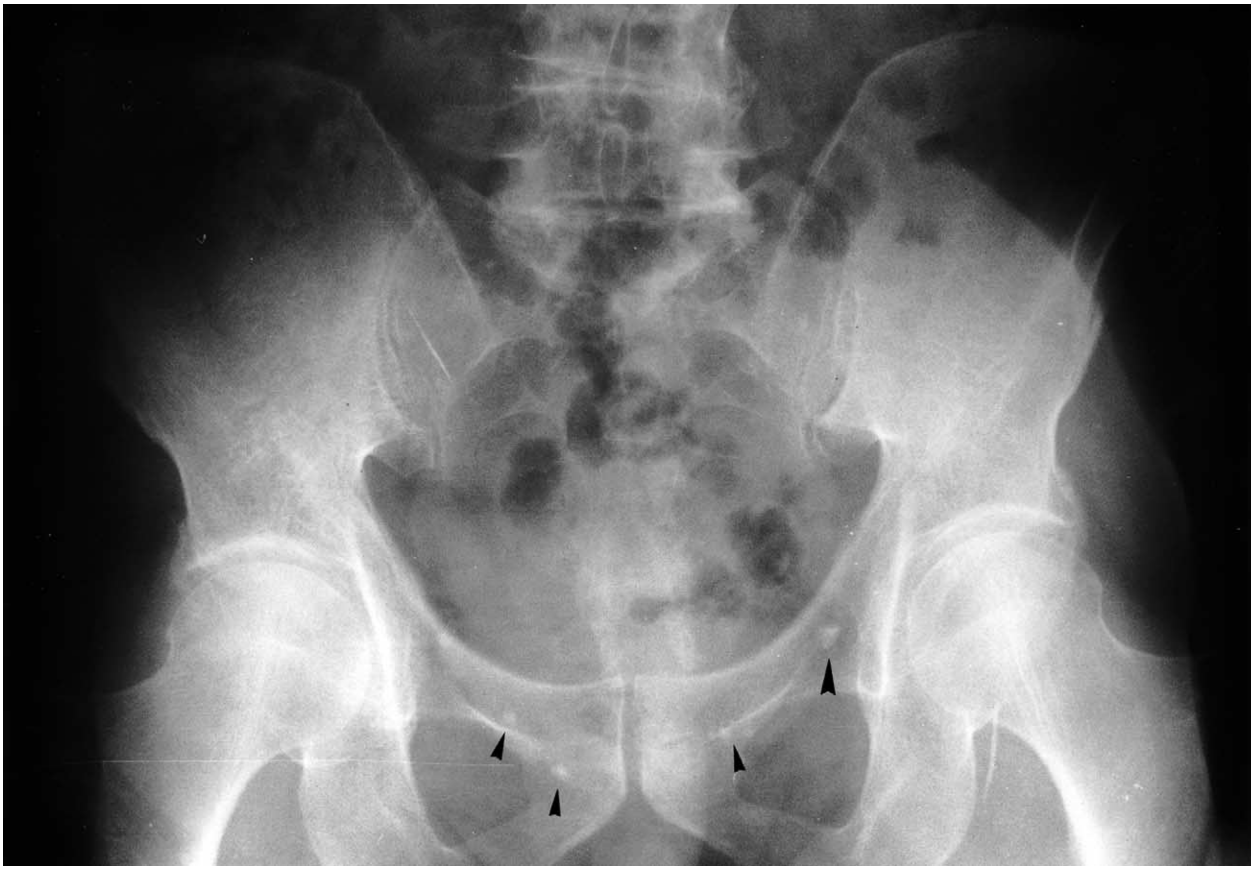


Fig. 1 Antemortem radiograph of the abdominal area of an 89-year-old missing man. Arrows points to six phleboliths in the pelvic area.

one case (the 89-year-old) due to a complaint of urinary incontinence and in the other (the 93-year-old) because of a suspected intestinal obstruction. The radiographs of both cases were requested for viewing by the forensic investigators and the presence of phlebolites in the pelvic area was detected in both sets of plates (Figs. 1 & 2). Postmortem radiographs of the lower abdomen taken in a similar projection to the antemortem X-rays disclosed a total of six radio-opaque lesions, four in the left pelvic area and two in the right (Fig. 3).

In one of the antemortem abdominal radiographs of the 89-year-old man, the location, configuration, relationship to each other, size and number of phleboliths matched almost completely the postmortem X-rays, although some minor differences due to the decay of the soft tissues in which the phleboliths are embedded were allowed. All the parameters of the phleboliths in the radiographs of the 93-year-old man were discordant. In addition the trabecular pattern of the proximal third of the femora,[5] the vertebral processes of the lower thoracic and lumbar spine[6] and degenerative changes in the vertebral bodies of the 89-year-old man were also consistent in both antemortem and postmortem radiographs. Furthermore no inconsistencies were detected. Based on these findings the remains were positively identified.

All phleboliths' parameters as well as other radiographic features of the second missing person were discordant.

DISCUSSION

Positive identification of unknown human remains is often attained by comparison of antemortem and postmortem radiographs, some of the markers frequently collated in the plates are signs of medical intervention, normal anatomical variation and evidence of healed trauma.[7,8] The presence of phleboliths has been suggested as another good indicator for positive identification.[2]

Phleboliths are calcified blood clots in pelvic veins. They are frequently multiple and are considered of clinical inconsequence except in their liability of being mistaken with uretric calculi.[3] A number of factors have been postulated as possible causes for the transformation of blood clots into phleboliths; changes in coagulation tendencies or in fibrinolytic activity, local venous damage from sudden pressure

Fig. 2 Antemortem radiograph of the abdominal area of a 93-year-old missing man. Note five phleboliths in the left lower pelvic area.

raise within the veins concomitant with abdominal straining during stool evacuation, or a combination of these factors.[3]

Pelvic phleboliths are not rare, they have been reported to occur in 44.2% of subjects aged 16–79 years of age, and the older the individual the greater the number of phleboliths detected on radiography. Their anatomic distribution is not symmetrical; they appear more often on the left than on the right side of the body suggesting the possibility of an aetiology similar to that of other venous disorders.[4]

A geographic distribution of the prevalence of phleboliths has been observed from surveys of pelvic radiographs in various communities. While in western countries they can be demonstrated in roughly half of all pelvic X-rays of individuals older than 40 years of age and in about one-third of all adults, they appear in 5–15% of Pacific Islanders and rural Africa.[9]

Suprapelvic phleboliths are significantly less frequent than pelvic ones. Abdominally located phleboliths, demonstrated as typical densities in a periureteral distribution flanking the lumbar spine, have been detected in 2% of radiographs of 783 multiparous females. The presence of pelvic masses, significant chronic hepatic disease, and altered venous flow with dilatation of gonadal veins has been associated with suprapelvic phleboliths.[4]

The reliability of radiographic features for positive identification depends on their uniqueness and stability over time. The configuration and position of phlebolithes depend mostly on the local anatomy where they are formed and the mechanism of dystrophic calcification of the individual blood clots, thus their uniqueness is as high as that of normal anatomic variation in conjunction with degenerative pathological processes commonly implemented in positive identification of human remains.

The postmortem anatomical position of pelvic and suprapelvic phleboliths varies slightly within the abdominal cavity, mostly due to decomposition phenomena such as bloating, sloughing and maggot activity. Their relative position however is stable enough to remain a reliable individualizing marker. Further investigation into the matching probability of phleboliths for personal identification would enlighten this topic.

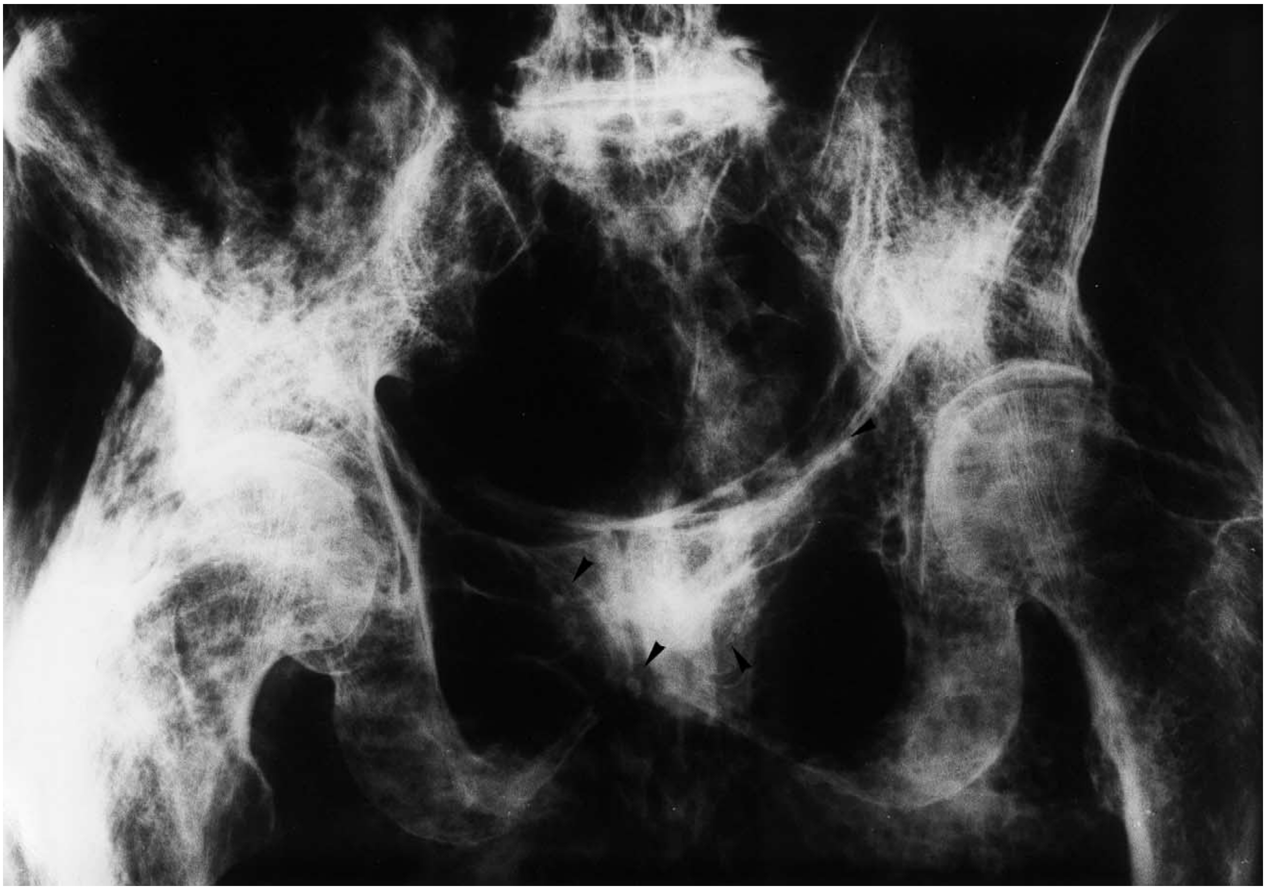


Fig. 3 Radiograph of the abdominal area of the cadaver. Note the correlation between the position, size and configuration of the phleboliths in both antemortem (Fig. 1) and postmortem plates.

Despite the relatively high frequency of pelvic phleboliths, especially in older western individuals, their concordant presence in antemortem and postmortem radiographs, i.e. number, anatomical configuration, position and size, can be an conducive to positive identification as long as there is at least another identification marker to strengthen the forensic determination. Conversely, suprapelvic phleboliths, which are rare, can be an excellent radiographic marker for positive identification of human remains without the need of additional data.

REFERENCES

1. Kahana T, Hiss J. Identification of human remains: forensic radiology. J Clin Forensic Med 1997; 4: 7–15.
2. Brogdon BG. Radiologic identification of individual remains. In: Brogdon BG (ed.) Forensic Radiology. Boca Raton: CRC Press, 1998; 149–179.
3. Burkit DP, Latto C, Janvrin SB, Mayou B. Pelvic phleboliths. Epidemiology and postulated etiology. N Engl J Med 1977; 296: 1387–1389.
4. Curry NS, Ham FC, Schabel SI. Suprapelvic phleboliths: prevalence, distribution, and clinical associations. Clin Radiol 1983; 34: 701–705.
5. Kahana T, Hiss J, Smith P. Quantitative assessment of trabecular bone pattern identification. J Forensic Sci 1998; 43: 1144–1147.
6. Kahana T, Goldin L, Hiss J. Personal identification based on radiographic vertebral features. Am J Forensic Med Pathol 2002; 23(1): 36–41.
7. Kahana T, Hiss J. Forensic Radiology. Br J Radiol 1999; 72: 129–133.
8. Kahana T, Goldstein S, Kugel C, Hiss J. Identification of human remains through comparison of computerized tomography and radiographic plates. J Forensic Identification 2002; 52: 151–158.
9. Mattson T. Frequency and location of pelvic phleboliths. Clin Radiol 1980; 31: 115–118.

VIII. Personal identification based on radiographic vertebral features

Kahana, T., Goldin, L. y Hiss, J.

American Journal of Forensic Medicine and Pathology

2002;23:36-41.

En esta publicación se presentó una propuesta de sistematización de los caracteres radiográficos de la columna vertebral útiles para la necroidentificación, con el fin de explorar la fiabilidad de los rasgos empleados en una serie de radiografías ante mortem y post mortem.

Los rasgos vertebrales que se utilizan con mayor frecuencia, en estos casos, incluyen:

1. El contorno de las apófisis dorsales.
2. La forma de los cuerpos vertebrales y sus cambios degenerativos.
3. La morfología de los arcos vertebrales y los procesos articulares, especialmente cuando presentan rastros de antiguos traumatismos.

Dentro de estos rasgos se definieron cuatro categorías y se examinó su utilidad relativa:

1. Variación anatómica normal y relaciones espaciales.
2. Cambios degenerativos:
    a. Osteofitos
    b. Discos herniados
    c. Artrodesis
    d. Trabeculación
3. Presencia de traumatismos curados:

a. Fracturas que pueden estar acompañadas de desplazamientos de fragmentos.
b. Presencia de implantes y otros aparatos ortopédicos.

4. Malformaciones congénitas:
    a. Espina bífida u otras fusiones incompletas.
    b. Presencia de hemivértebras laterales o dorsales.
    c. Sacralización de la quinta vértebra lumbar y lumbarización de la primera vértebra del sacro.
    d. Escoliosis y cifosis
    e. Agenesia de segmentos vertebrales.
5. Patologías diversas:
    a. Tumores
    b. Espondilitis anquilopoyética o postinfecciosa

Para cada categoría se analizó la posibilidad de rechazar erróneamente la identificación en base a la ausencia postmortem de rasgos visibles en las placas antemortem. Este tipo de error se puede producir por la reparación normal de traumatismos, modificación patológica del patrón trabecular o por intervenciones quirúrgicas.

En este artículo se presentaron ejemplos de identificación basada en cada una de las principales categorías.

The American Journal of Forensic Medicine and Pathology *23(1):36–41, 2002.*

Personal Identification Based on Radiographic Vertebral Features

T. Kahana, Ph.D., L. Goldin, M.D., and J. Hiss, M.D.

Personal identification of human remains constitutes about 10% of the normal caseload of any forensic medicine practice. Identification can be achieved by a variety of methods, one of which is the comparison of antemortem and postmortem radiographs. There are numerous accounts of cranial and dental radiographic features useful for identification, whereas the availability of postcranial radiographs and especially plates that depict the vertebral column is less widespread among the forensic community. The authors here review the various vertebral features instrumental in positive identification that can be identified on radiographs of the spine.
Key Words: Personal identification—Radiography—Vertebral column.

Unidentified human remains constitute about 10% of the caseload of most forensic practices. This fraction includes skeletonized, decomposed, and burnt victims along with cases of extensive mechanical trauma to the face. During the decade of the 1990s, the socioeconomic changes in the Eastern European bloc and the opening of frontiers in most European and American countries have brought large waves of illegal foreign immigrants, some of whom later become homeless and, tragically, unidentified bodies when they die. Currently, there are no comprehensive statistics detailing the number of unidentified cadavers and human remains within the European community and the Middle East, but the numbers, in our experience, seem to be increasing.

Personal identification of human remains is achieved when specific features detected on the cadaver match data recorded during the life of the individual. The procedure may be accomplished by comparison of fingerprints or of medical, dental, anthropologic, genetic, or imaging data (1).

Radiography is a common diagnostic tool for a great variety of dental and medical conditions. As a rule, radiographic plates are easily available in routine and mass disaster identification throughout the world (2). Positive radiographic identification is accomplished by meticulous comparison of the details on the film; however, unlike fingerprints there is no minimum number of points of comparison that must be concordant to determine identity. Usually one to four unique analogous features and no discrepancies are considered enough for positive identification (3).

Morphologic features depicted on radiographs must comply with two requirements to be of forensic identification value: the feature must be unique to the individual, and it must remain stable over time despite ongoing life processes (4). Osseous degenerative changes depicted on radiographs have been known to be useful markers for personal identification (5). Furthermore, healed mechanical trauma, congenital malformations, old surgical or orthopedic procedures, prosthetic devices, and certain slow-

Manuscript received March 6, 2001; accepted June 28, 2001.
From the Division of Identification and Forensic Science, Israel Police, Headquarters, Jerusalem (T.K.), and the National Centre of Forensic Medicine, affiliated with the Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv (L.G., J.H.), Israel.

Address correspondence and reprint requests to T. Kahana, Ph.D., National Center of Forensic Medicine, 67 Ben Zvi St., PO Box 49015, Tel Aviv 61490, Israel.

growing neoplasms that might be evident within the remains are invaluable individualizing features.

We here discuss the reliability of comparing various vertebral column features as markers for positive identification. The most common traits in the vertebral column that are useful for positive identification include the contour of the spinous processes and their relation to one another, the shape of the vertebral bodies and any degenerative changes that may appear on them, and the morphology of the arches and articular processes, especially if they show signs of healing trauma (5).

MATERIALS AND METHODS

Over 12 months, a total of 294 unidentified bodies (13% of the total caseload) were submitted to the Israeli National Center of Forensic Medicine. One hundred and four were identified during the first 24 hours, usually through visual identification by close relatives or with the help of the Automatic Fingerprint Identification System. These cases include mostly individuals who had collapsed in the street. The remaining 190 unidentified bodies required extensive police investigation to produce antemortem data to be used for positive identification. These were victims of suicide, accident, or violence involving extensive injuries to the head, or were decomposed, skeletonized, and burned bodies.

Out of those 190 unidentified bodies, 111 were buried without positive identification; they comprised 5 fetuses and 39 adult homeless individuals along with 67 skeletal remains, including many archaeologic specimens and some nonhuman bones.

Seventy-nine bodies were identified through the application of one of the standard identification techniques: 44 fingerprint matches, 19 cranial and postcranial radiograph comparisons, and 16 dental identifications. From the 19 radiographic comparisons, 8 subjects (10.1% from all positive identifications) were identified by contrasting various radiographic features of the vertebral column.

The postmortem radiographs were produced as closely as possible to duplicate the angulation, beam centering, and depiction of the antemortem films available for comparison.

The various morphologic features that could be studied for identification purposes were divided into four major categories: normal anatomic variation, aging degenerative processes, healed trauma, and congenital malformations.

RESULTS

Normal Anatomic Variation

Because each vertebra develops from three primary and five secondary ossification centers, there is great variation in the eventual size and configuration of the various components of each vertebra and between the parts of the spinal column as a whole (6). This variability affords the investigator an invaluable identification tool, mainly the outline of the spinal and transverse processes as depicted on radiographs. The morphology of the processes can be easily traced on anteroposterior and lateral radiographic films of the thorax and abdomen and of the cervical area. The shape of the features on the known films are compared with corresponding plates of the unidentified cadaver, taken on a projection as similar as possible to that of to the antemortem film (3).

Each process in itself, and the combination of the totality of processes, provide ample data for positive personal identification as long as no inconsistencies are detected.

Case History

The charred bodies of four women were submitted to the Center for identification. They were found at the site of an arson scene after a zealot had burned the house of ill repute in which their procurer kept them captive. The police investigation disclosed that these women were illegal immigrants from Eastern Europe. Three of them had arrived in the country recently, and the fourth had been living in Israel for some time. An anteroposterior radiograph of the thoracic and lumbar vertebral column of the last woman was retrieved from one of the local hospitals. This radiograph was compared with similar radiographs of all four cadavers. The configuration of the spinal processes on the antemortem radiograph exactly matched that of one of the burnt cadavers, whereas all other three were different (Fig. 1).

Aging Degenerative Processes

The vertebral column as a whole, and each particular vertebra, are affected by normal and pathologic aging processes and by environmental factors associated with posture and physical activity.

Common features resulting from aging that can be useful for identification include the appearance of lipping of the vertebral body margins, degenerative spurring, and dishing and wedging of the vertebral bodies. Ossified intervertebral ligaments and herniated disks are also invaluable individualizing markers (7).

By their very nature, degenerative changes lack the stability expected of identification markers. Nevertheless, their change is unidirectional and none of these conditions revert to normal, although herniated disks can be surgically removed and osteophytes impinging on nerve roots or on the spinal cord are often dissected. Occasionally the involved vertebrae are surgically fused. These interventions are always documented by appropriate imaging (8).

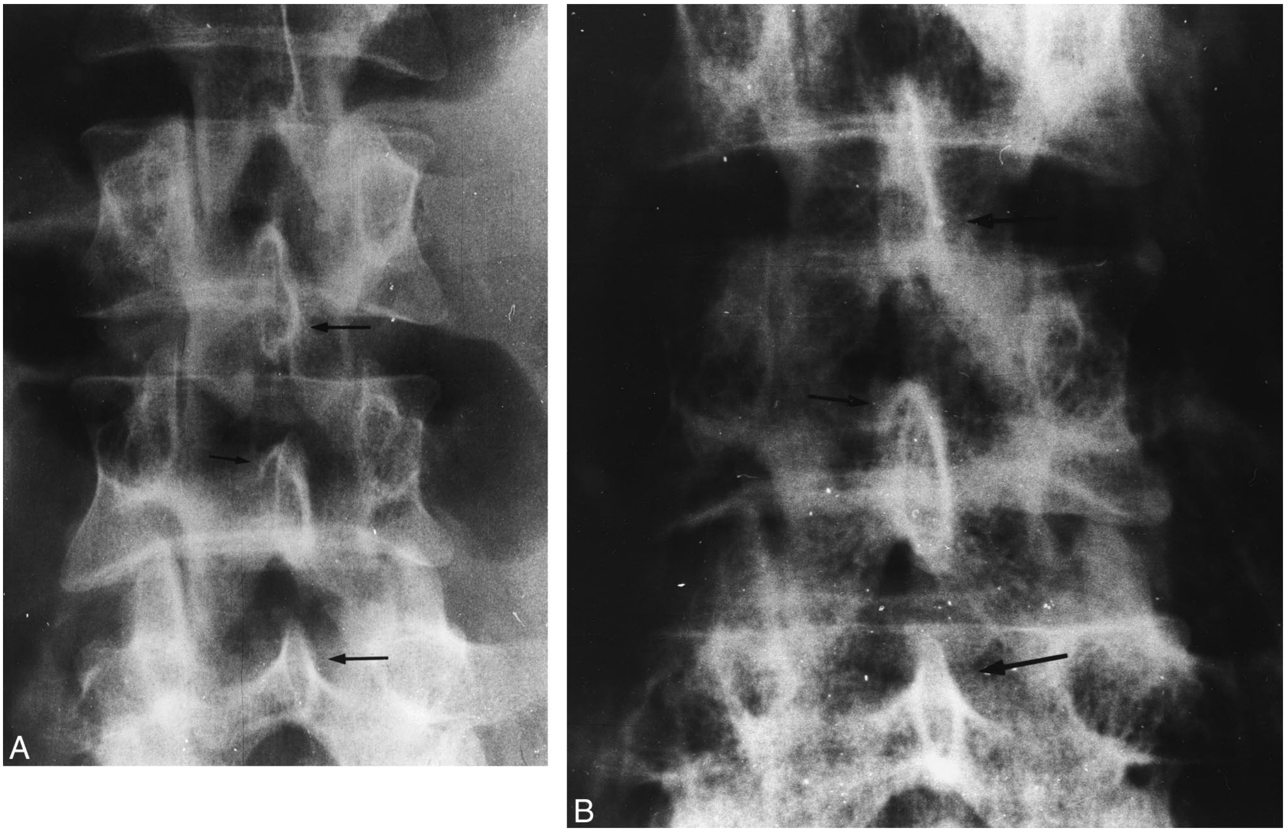


FIG. 1. (A) Antemortem radiograph of anteroposterior view of lumbar spine. **(B)** Postmortem radiograph of anteroposterior view of lumbar spine. Arrows indicate the unique morphologic characteristics of the vertebral processes instrumental in the identification.

Although the trabecular bone pattern depicted on radiographs of the appendicular skeleton has proved very useful in the identification of unknown human remains (4,6), we do not recommend that identifications be based on vertebral trabeculation. The trabecular architecture has been reported to be very susceptible to resorption processes even in the early stages of osteoporosis, especially in women (9). Thus, differences encountered between antemortem and postmortem radiographs may not necessarily rule out the identity of the cadaver.

Case History

A 91-year-old emaciated and senile man disappeared from a geriatric ward of one of the major medical centers in Israel during the summer months. His decomposed and partially mummified body was discovered three weeks later in the shaft of one of the service elevators of the hospital.

The cadaver was examined at the National Center of Forensic Medicine, where positive identification was accomplished by comparing postmortem radiographs of the subject with anteroposterior lumbar radiographs recently taken at the hospital and depicting a mosaic of degenerative vertebral changes (Fig. 2).

Healed Trauma

Radiologically, spinal fractures are considered either compression or hyperextension fractures, dislocations, or fractures of the appendicular structures. They may involve the vertebral body, the arches, and the spinous, transverse, or articular processes, either singly or in unpredictable combinations. Their healing process results mostly in spondylolisthesis or vertebral slipping, which can be detected on antemortem films, usually on lateral projections. The condition is sometimes corrected by posterolateral fusion along with excision of the posterior elements. Concomitant deformations such as trapezoid and sclerotic bodies, along with dome-shaped sacrum and the healed surgical intervention, are useful identification features (8).

Bone remodeling of the fracture callus can, over time, smooth its appearance to such a point that the residual bony exuberance may not be manifest on a radiograph. Furthermore, when vertebral body fractures occur during childhood and are properly treated, the result in adulthood will be minimal evidence or no evidence of the defect. The forensic investigator should bear this in mind before ruling out the identification (10).

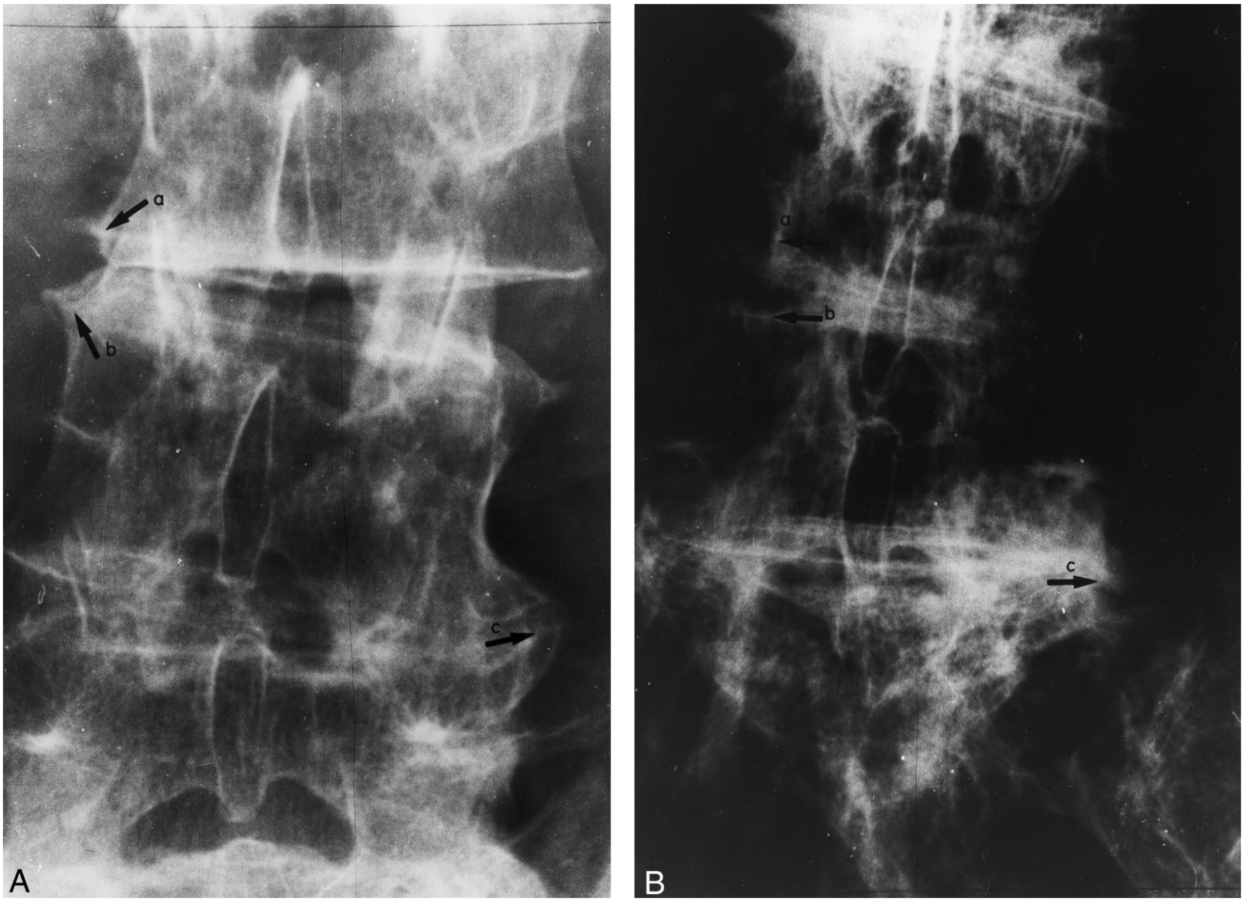


FIG. 2. (A) Antemortem radiograph of a 91-year-old man with advanced degenerative changes (a and b, lipping; c, ossification of ligaments). **(B)** Postmortem radiograph of the same man with similar aging degenerative features. Note also the morphologic similarity of the spinous processes.

Congenital Malformations

Spina bifida is a common congenital condition that occurs in various frequencies depending on the population. The main characteristic of this condition is the complete lack of closure of the neural canal in a vertebral segment, so that the two halves of the spinous process and neural arches point laterally (complete spina bifida) (Fig. 3A). The incomplete bony fusion of one or several spinous processes is known as spina bifida occulta and is more frequent than complete spina bifida, especially in the sacral area (Fig. 3B).

Lateral or dorsal hemivertebrae, which can cause abnormal curvature of the spine (scoliosis or kyphosis), fusion of vertebral segments (particularly in the cervical area—Klippel-Feil syndrome), sacralization of the fifth lumbar vertebra, lumbarization of the first sacral vertebra, and failure of the sacrum and coccyx to develop are some of the congenital vertebral features easily detected on radiography (11).

In some instances, scoliosis and kyphosis of the vertebral column may be hard to ascertain in postmortem radiographs because of the difficulty of positioning the cadaver (6).

Case Report

Skeletal remains were recovered from an abandoned dry well in the Golan Heights in the area where two 20-year-old soldiers had disappeared 3 and 5 years earlier, respectively.

No dentition was found among the partially recovered human remains, and the only remarkable feature was complete spina bifida of the sacrum. Because this condition was recorded on the medical records of one of the missing soldiers, a pertinent radiograph was requested from his family. Radiographic comparison of the malformation in the remains and in the missing soldier excluded the identification (Fig. 3).

DISCUSSION

Correct radiographic identification of the deceased depends greatly on the similarity between the antemortem and postmortem films. Positioning of the questioned anatomic specimens before radiography is of paramount importance for comparison, because the investigator strives to duplicate as closely as possible the antemortem angulation between the object and the film (3). Two

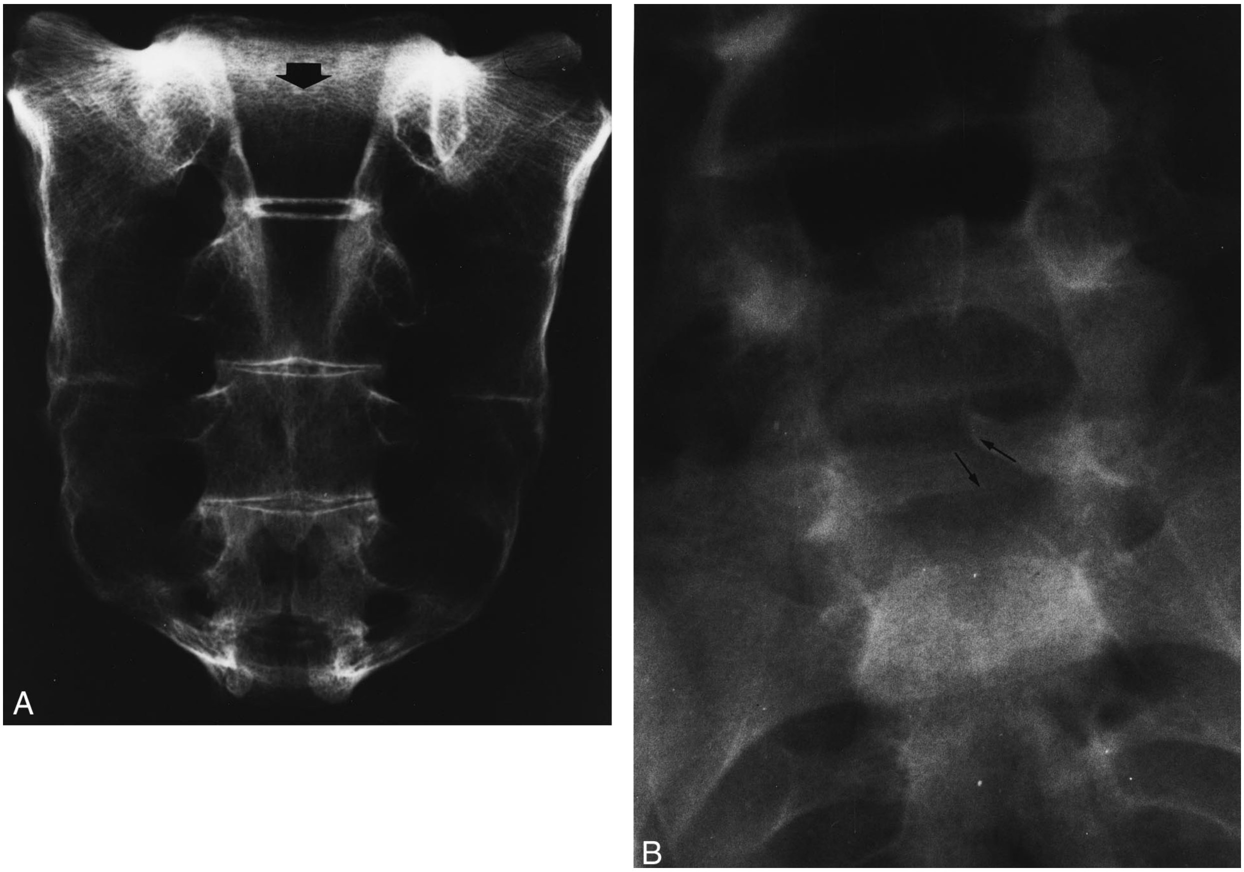


FIG. 3. (A) Postmortem radiograph of the sacrum with complete spina bifida in S1–S2. Arrow indicates the superior opening of the defect. **(B)** Antemortem radiograph of the lumbar and sacral vertebrae. The fifth lumbar spinous process is unfused. Arrows indicate the margin of the defect, i.e. lack of vertebral arch and processes. The identification was ruled out based on the morphologic expression of the condition.

comparative radiographs of the same bone may appear different because of discrepancies in beam centering, angulation, and bone rotation. Usually the experience of the forensic anthropologist is enough to overcome this obstacle.

Manipulation of the radiographs is very common in modern roentgenography. With digitalization of all kinds of radiographic equipment and the easy availability of image-processing software, it is not an unusual practice to enhance and correct the image, especially for clinical purposes. In the forensic milieu, digital image processing is very useful; contrast enhancement, brightness correction, and segmentation of images are all acceptable procedures to facilitate radiographic identification. However, any manipulations that distort radiologically visible structures by changing their angular relationship are inadmissible, and the use of drawing tools that can retouch, accentuate, or fade out contours should be avoided (12,13).

Often no pathologic condition is evident on either antemortem or postmortem radiographs. However, anatomic variation of osseous features like a sternal foramen, the outline of the frontal sinuses (14), or the unique pattern of the trabecular bone can be used to achieve positive identification (4,15).

Less common but valuable identification markers include systemic conditions like ankylosing spondyloarthritis, bone tumors, and lesions both malignant and benign. Pathologic conditions like osteoporosis, which results in abnormal loss of bony structures, are not recommended for identification.

In this study, the various vertebral features used for personal identification are discussed, not only pathologic conditions like healed trauma of the vertebrae, physiologic and infectious degenerative processes evinced on the radiographic plates, and congenital malformations but also the normal anatomic variations of the vertebral structures.

REFERENCES

1. Murphy WA, Spruill FG, Gantner GE. Radiographic identification of unknown human remains. *J Forensic Sci* 1980;25: 725–35.
2. Kahana T, Freund M, Hiss J. Suicidal terrorist bombings in Israel: Identification of human remains. *J Forensic Sci* 1997; 42:259–63.

3. Fischman SL. The use of medical and dental radiographs in identification. *Int Dent J* 1985;35:301–6.
4. Kahana T, Hiss J, Smith P. Quantitative assessment of trabecular bone pattern identification. *J Forensic Sci* 1998;43: 1144–7.
5. Sauer N, Brantley RE, Barondess DA. The effect of aging and the comparability of antemortem and postmortem radiographs. *J Forensic Sci* 1988;33:1223–30.
6. Brogdon BG. Radiological identification of individual remains. In Brogdon BG, *Forensic Radiology*. Boca Raton, FL: CRC Press, 1998:149–88.
7. Kahana T, Ravioli JA, Urroz CL, Hiss J. Radiographic identification of fragmentary human remains from mass diaster. *Am J Forensic Med Pathol* 1997;18:40–4.
8. Rosier RN. Orthopedics. In Schwartz SI. *Principles of Surgery*. 6th ed. New York: McGraw Hill, 1994:1861–965.
9. Scane AC, Masud T, Johnson FJ, Francis RM. The reliability of diagnosing osteoporosis from spinal radiographs. *Age Aging* 1994;23:283–6.
10. Rosenberg A. Bones, joints, and soft tissue tumours. In Cotran RS, Kumar V, Collins T, eds. *Robbins Pathologic Basis of Disease*. 6th ed. Philadelphia: W.B. Saunders, 1999:1215–68.
11. Ortner DJ, Putschar WCJ. Skeletal malformations. In *Identification of Pathological Conditions in Human Skeletal Remains.* Washington, DC: Smithsonian Institution Press, 1985: 346–64.
12. Du Chesne A, Benthaus S, Brinkmann B. Manipulated radiographic material: Capability and risk for the forensic consultant? *Int J Legal Med* 1999;112:329–32.
13. Richardson ML, Frank MS, Stern EJ. Digital image manipulation: What constitutes acceptable alteration of a radiologic image? *Am J Roentgenol* 1999;164:228–9.
14. Ribeiro F de A. Standardized measurements of radiographic films of the frontal sinuses: An aid to identifying unknown persons. *Ear Nose Throat J* 2000;26:32–3.
15. Mann RW. Use of bone trabeculae to establish positive identification. *Forensic Sci Int* 1998;98:91–9.

IX. Radiographic identification of fragmentary human remains from a mass disaster

Kahana, T., Ravioli, J. A., Urroz, C. L. y Hiss, J.

American Journal of Forensic Medicine and Pathology

1997;18:40-44

La Asociación Mutua Israelita Argentina (AMIA) presta servicios sociales a personas de pocos recursos de la comunidad judía de Buenos Aires y al público Bonaerense en general.

El 18 de Julio de 1994, explotó un coche-bomba aparcado en la puerta de las dependencias de AMIA, en el centro de Buenos Aires. De los escombros del edificio siniestrado, un equipo de rescate conformado por expertos argentinos e israelíes, rescataron durante diez días, 104 heridos y 85 cadáveres en distintos estados de conservación.

En esta publicación se describe el sistema de trabajo realizado en la morgue judicial por el equipo forense del Cuerpo Judicial de Buenos Aires y la recogida de datos ante mortem llevada a cabo por miembros de la comunidad judía, asesorados por la unidad de identificación de víctimas de desastres de la Policía de Israel.

El protocolo de escrutinio radiográfico que se usó para identificar a las víctimas del desastre se ilustra por medio de la presentación de un caso. El artículo concluye con una serie de recomendaciones a seguir en casos de identificación de víctimas fragmentadas a raíz de los efectos de la honda expansiva de la explosión y el subsiguiente derrumbe del edificio.

Wolters Kluwer Health | Lippincott Williams & Wilkins

The American Journal of Forensic Medicine and Pathology

Radiographic Identification of Fragmentary Human Remains from a Mass Disaster

Author(s): Kahana, T. M.Sc.; Ravioli, J. A. M.D.; Urroz, C. L. M.D.; Hiss, J. M.D.

Issue: Volume 18(1), March 1997, pp 40-44

Publication Type: [Articles]

Publisher: © Lippincott-Raven Publishers.

Institution(s): From the Israel National Police (T.K.), Jerusalem, and the L. Greenberg Institute of Forensic Pathology (J.H.), Tel Aviv, Israel; and the Forensic Medical Corps Federal Judicial Morgue (J.A.R., C.L.U.), Buenos Aires, Argentine Republic. Forensic Anthropologist (T.K.); Forensic Pathologist (J.A.R., J.H.); Forensic Radiologist (C.L.U.); Director, L. Greenberg Institute (J.H.).

Received April 10, 1995; revised and accepted September 27, 1995.

Address correspondence and reprint requests to T. Kahana, L. Greenberg Institute of Forensic Medicine, 67 Ben Zvi Boulevard, PO Box 49015, Tel Aviv 61490, Israel.

Keywords: Argentina, Bombing, Mass disaster, Radiology, Identification, positive, Terrorism

Table of Contents:

ABSTRACT

Positive identification of human remains is one of the most important tasks in mass disaster management. Here we report on the use of radiography for positive identification of fragmentary human remains recovered from the scene of a terrorist bombing in the Jewish-Argentine Mutual Association Center in Buenos Aires, Argentina, in July 1994. Radiographic examination of all human remains from mass disaster scenes is recommended for identification purposes. Establishing a computerized data bank of antemortem information on missing persons and postmortem findings in disaster victims greatly facilitates and expedites the identification process.

Key Words: Argentina; Bombing; Mass disaster; Radiology; Identification, positive; Terrorism

---

Human remains are often positively identified by comparing antemortem and postmortem radiographs (1,2), a technique that has been previously reported in the scientific literature and is deemed very reliable (3). Depending on the anatomic area depicted on the radiographic plates, different markers can be examined. Sinus pattern and dental morphology and restorations are the most common features for comparison in the cranium, along with cranial suture patterns and mastoid air cells (4-12). In the postcranial skeleton, gross anatomic structures such as morphology of vertebral bodies and ribs, trabecular bone patterns of different bones, general degenerative changes, and evidence of healed trauma and of medical intervention can be used as reference points (13-20).

The use of radiographs of the vertebral column for identification purposes has been advocated in isolated cases (2,14,17,21-23) as well as in mass disaster investigations (24-27). We present a case in which distinct features of the thoracic and lumbar vertebral column provided definitive evidence for positive identification of one of the 85 casualties in a terrorist bombing in Buenos Aires.

CASE REPORT

On July 18, 1994, the explosion caused by the car bomb leveled the seven-story building of the Asociacion Mutual Israelita Argentina (AMIA) in Buenos Aires, the Federal Capital of Argentine, wounding 104 and killing 85 individuals.

A joint Argentinian-Israeli rescue team extracted dozens of bodies from the rubble over a 10-day period. The Argentinian Forensic Medical Corps from the Federal Judicial Morgue, together with experts from the Israeli National Police, examined the human remains.

FIG. 1. Anatomically catalogued radiographs from the mass disaster.

MATERIALS AND METHODS

The primary issue addressed by the forensic team was positive identification of the deceased. A total of 91 persons were listed as missing in the AMIA disaster by the Argentinian Federal Police. A number of steps were taken to ensure the correct identification of all cadavers and fragmentary remains:

1. For each missing individual, a personal file was compiled by the Israeli National Police Identification Team, following the Interpol Guidelines for Mass Disaster Identification. The files included a thorough description of the physiognomic and individualizing features, medical and odontologic data, and personal effects and garments worn at the time of disappearance.
2. The identification number of official documents such as passport and national identification card were recorded to be cross-referenced by the Argentinian Federal Police for retrieval of fingerprints, which are registered for all Argentinian adult citizens.
3. The families were asked to produce all available antemortem radiographic records of the missing relatives, together with the names of their physicians and dental practitioners.
4. All of the antemortem information was stored on a computerized database for swift retrieval.

5. Complete necroscopic examination was carried out on all of the cadavers by the forensic scientists from the Buenos Aires Judicial Corps.
6. All body fragments were described, photographed, and radiographed, and tissue samples were taken for DNA analysis.
7. The radiographs were anatomically catalogued in order to facilitate their comparison with antemortem data (Fig. 1).

From the 91 individuals listed as missing, 84 were positively identified by fingerprint comparison. In addition, 323 various human fragments were recovered at the explosion site.

RESULTS

Ten days after the explosion, all but seven individuals from the missing persons list had been identified. The missing ones either were completely dismembered, were not recovered by the rescue teams, or were missing for reasons unrelated to the AMIA explosion.

From the antemortem personal files of these seven persons, two sets of vertebral radiographs were studied for possible identification. One set showed good correspondence with a decomposed fragmented torso recovered at the site. The following pathologic and anatomic variants were observed in both antemortem and postmortem radiographs (Figs. 2 and 3 and Table 1):

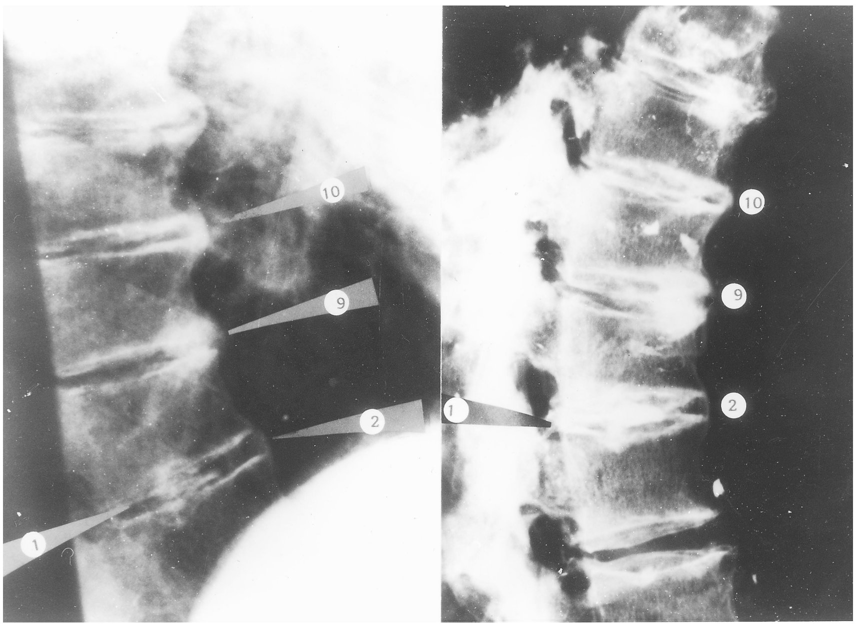


FIG. 2. Antemortem (right) and postmortem (left) lateral radiographs of the thoracic spine (numbering corresponds to that in the text).

1. Severe calcification of the anterior longitudinal ligaments between T9 and T10.
2. Calcification of the anterior longitudinal ligaments between T10 and T11.
3. Slight calcification of the anterior longitudinal ligaments between T11 and T12.
4. Intervertebral disk calcification between T11 and T12.
5. Beak-shaped osteophyte in the lower anterior border of the vertebral body of L1.
6. Triangular osteophyte in the upper anterior border of the vertebral body of L2.
7. Round osteophyte in the lower anterior border of the vertebral body of L2.
8. Horizontal osteophyte protruding from the upper anterior border of the vertebral body of L3.
9. Spur formation in the upper anterior border of the vertebral body of L4.

Based on these nine points of the morphologic pattern of the bone (Table 1), the torso was identified as belonging to one of the remaining seven missing persons: a 76-year-old woman.

CONCLUSION

Positive identification of human remains is often the crucial issue in mass disaster management not only because of the social and religious considerations but also because of related legal implications (2,25).

From a total of 91 individuals listed as missing in the AMIA bombing, 85 bodies (93.4%) were positively identified. In one instance, the comparison of antemortem and postmortem radiographs of the vertebral column at the thoracic and lumbar levels resulted in positive identification of a missing person.

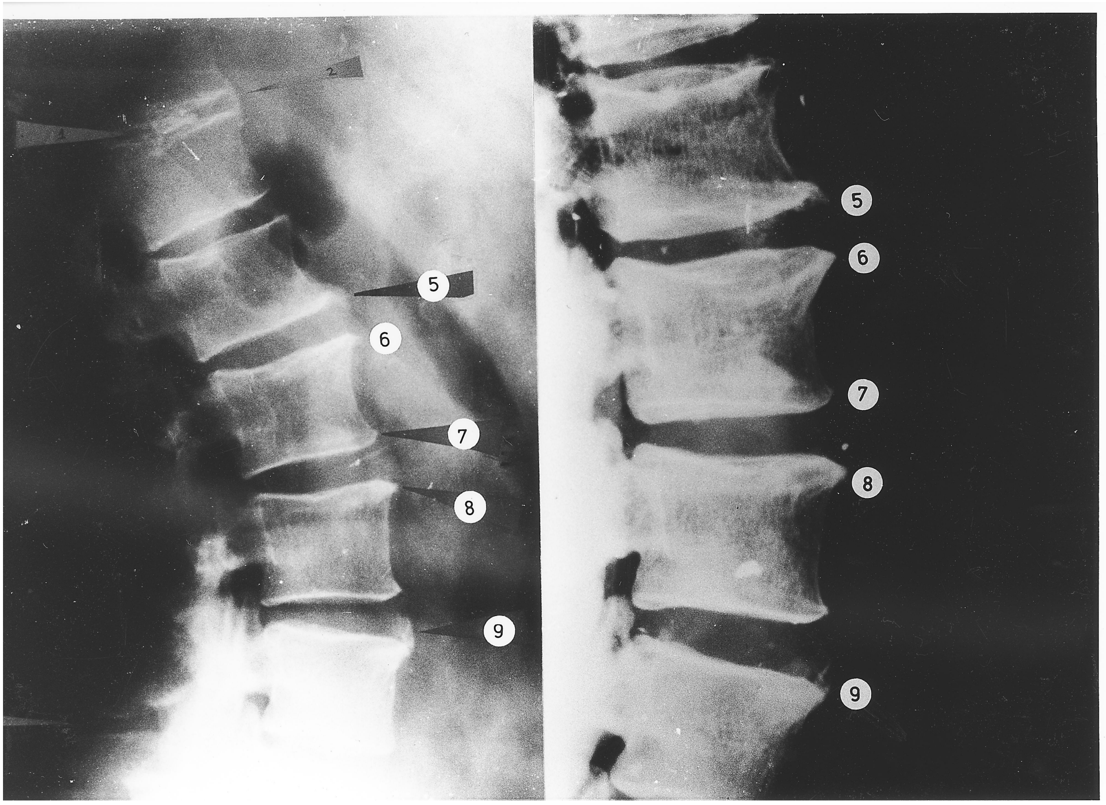


FIG. 3. Antemortem (right) and postmortem (left) lateral radiographs of the lumbar spine (numbering corresponds to that in the text).

The radiologic criteria used in this case included evidence of age-related specific degenerative changes: calcification of ligaments and the intervertebral disk and osteophytic formation. The complete correspondence between the antemortem and postmortem radiographs in which these morphologic features were depicted enabled the positive identification of the body.

In mass disaster investigations, a computerized data bank that contains the antemortem information about all allegedly missing persons should be promptly established and include (a) The anthropologic data along with all particular physiognomic features. (b) Medical information, that is, radiographic records, dental charts, and surgery notes, together with the names of the medical personnel who treated the person in the past. (c) The identification number of various official documents, such as driver's license, passport, and birth certificate, for cross-reference.

Most importantly, all tissue fragments recovered from the scene should be examined radiographically. These radiographs not only provide documentation of the material recovered, but can be used to identify skeletal injuries or locate loose dentition that may be overlooked during gross visual examination.

TABLE 1. Anatomic features of the thoracic and lumbar spine depicted in antemortem and postmortem radiographs

Points of morphologic concordance		
Calcifications	ALL	T9-T10
	ALL	T10-T11
	ALL	T11-T12
	ID	T11-T12
Osteophytes	L1	
	L2 X 2	
	L3	
	L4	

ALL anterior longitudinal ligament and ID intervertebral disk

Additionally, tissue samples should be collected and preserved for creation of DNA profiles, thereby providing a means for the reassociation of fragmented and comingled remains that cannot be identified by anthropologic or radiologic techniques.

REFERENCES

1. Atkins L, Potsaid MS. Roentgenographic identification of human remains. JAMA 1978;240:2307-8.

2. Birkby W, Rhine S. Radiographic comparison of the axial skeleton for positive identification. Presented at the Annual Meeting of the American Academy of Forensic Sciences, Cincinnati, OH, 1983

3. Fierro MF. Identification of human remains. In: Spitz WV, ed. Fisher's medicolegal investigation of death. Springfield, IL: Charles C Thomas, 1993:71-117.

4. Culbert WC, Law FM. Identification by comparison of roentgenograms of nasal accessory sinuses and mastoid processes. JAMA 1927;88:1634-6.

5. Messmer JM, Fierro MF. Personal identification by radio-graphic comparison of vascular groove patterns of the calvarium. Am J Forensic Med Pathol 1986;7:159-62.

6. Rhine S, Sperry K. Radiographic identification by mastoid sinus and arterial pattern. J Forensic Sci 1991;36:272-9.

7. Marlin D, Clark M, Standish M. Identification of human remains by comparison of frontal sinus radiographs: a series of 4 cases. J Forensic Sci 1991;36:1762-72

8. Ubelaker DH. Positive identification from the radiographic comparison of frontal sinus patterns. In: Rathbun TA, Buikstra JE, eds. Human identification: case studies in forensic anthropology. Springfield, IL: Charles C Thomas, 1986.

9. Marlin DC, Clark MA, Standish SM. Identification of human remains by comparison of frontal sinus radiographs: a series of four cases. J Forensic Sci 1991;36:1765-72.

10. Phillips VM, Scheepers CF. A comparison between fingerprint and dental concordant characteristics. J Forensic Odontostomatol 1990;8:17-9.

11. Buchner A. The identification of human remains. Int Dent J 1985;35:307-11.

12. Schwartz T, Woolridge ED. The use of panoramic radiographs for comparison in cases of identification. J Forensic Sci 1976;31:146-154.

13. Sanders I, Woesner ME, Ferguson RA, Noguchi TT. A new application of forensic radiology: identification of deceased from a single clavicle. Am J Roentgenol Radium Ther Nucl Med 1972;115:619-22.

14. Sauer N, Brantley RE, Baronders DA. The effect of aging on the comparability of antemortem and postmortem radiographs. J Forensic Sci 1988;5:1223-30.

15. Murphy WA, Spruill FG, Gantner GE. Radiographic identification of unknown human remains. J Forensic Sci 1980;25:725-35.

16. Ubelaker DH. Positive identification of American Indian skeletal remains from radiograph comparison. J Forensic Sci 1990;35:466-72.

17. Hyma BA, Rao VJ. Evaluation and identification of dismembered human remains. Am J Forensic Med Pathol 1991;12:291-9.

18. Kahana T, Hiss J. Positive identification by means of trabecular bone pattern comparison. J Forensic Sci 1994;39:1325-30.

19. Kade H, Meyers H, Wahlke JE. Identification of skeletonized human remains by x-ray comparison. J Crim Law Criminol Police Sci 1967;58:261-4.

20. Owsley DW, Mann RW. Personal identity of skeletonized remains using abdominal and pelvic radiographs. J Forensic Sci 1992;37:332-6.

21. Rouge D, Telmon N, Arrue P, Larrouy G, Arbus L. Radiographic identification of human remains through deformities and anomalies of post-cranial bones: a report of two cases. J Forensic Sci 1993;38:997-1007.

22. Stewart TD. Traits peculiar to the individual. In: Essentials in forensic anthropology. Springfield, IL: Charles C Thomas, 1979:247-51.

23. Ripert T, Rittner C, Ulmcke D, Ogbuihi S, Schweden F. Identification of an unknown corpse by means of computed tomography (CT) of the lumbar spine. J Forensic Sci 1995;40:126-7.

24. Krogman WM, Iscan MY. Radiographic analysis. In: Iscan MY, ed. The human skeleton in forensic medicine. Springfield, IL: Charles C Thomas, 1986:82-126.

25. Singleton AC. The roentgenological identification of victims of the Noronic disaster. Am J Roentgenol Radium Ther Nucl Med 1951;66:375-84.

26. Mulligan ME, McCarthy MJ, Wippold FJ, Lichtenstein JE, Wagner GN. Radiologic evaluation of mass casualty victims: lessons from the Gander, Newfoundland, accident. Radiology 1988;168:229-33.

27. Sanders I, Woesner ME, Fergeson RA, Noguchi TT. A new application of forensic radiology: identification of deceased from a single clavicle. Am J Roentgenol Radium Ther Nucl Med 1972;115:619-22.

X. Identification of human remains through comparison of computerized tomography and radiographic plates

Kahana, T., Goldstein, S, Kugel, C. y Hiss, J.

Journal of Forensic Identification

2002;52:151-158

En el siguiente caso se presenta la comparación de imágenes de TAC ante mortem con radiografías post mortem y se analizan los caracteres radiográficos usados para la identificación.

Un cadáver no identificado, en avanzado estado de putrefacción fue admitido en el Centro Nacional de Medicina Legal de Israel. Los datos obtenidos por medio del perfil antropológico y del examen radiográfico fueron remitidos a la Unidad de Investigación Criminal de la Policía que propuso posibles candidatos para la identidad del individuo en cuestión.

Los principales indicios para la identificación incluían una trepanación rectangular en el parietal izquierdo de 9 x 6 cms y dos grapas quirúrgicas en el cuarto superior izquierdo del abdomen a la altura de la onceava vértebra torácica.

De la lista de pacientes de los hospitales de la zona de Tel Aviv que coincidían con la craniotomía parietal, dos individuos se hallaban con paradero desconocido. La comparación de las imágenes del TAC postoperatorio y de una radiografía del tórax de uno de estos pacientes concluyo en su identificación.

Este tipo de comparación es hoy en día plenamente reconocido por patólogos y antropólogos forenses.

Case Report

Identification of Human Remains Through Comparison of Computerized Tomography and Radiographic Plates

T. Kahana[1]
S. Goldstein[2]
C. Kugel[2]
J. Hiss[2]

Abstract: Scientific identification of human remains is frequently accomplished by comparing antemortem and postmortem radiographic (X-ray) data. Positive identification of a decomposed cadaver was achieved by comparing: (1) antemortem computerized tomography (CT) images of the head with postmortem cranial radiographs, and (2) antemortem with postmortem radiographs depicting staples within the abdomen.

Introduction

The identification of human remains is one of the most essential aspects of forensic medicine. Beyond the humanitarian considerations of such a task, identification is cardinal for the completion and certification of official documents, such as death certificates, probates of wills, and disbursements of benefits and insurance [1]. Scientific identification of human remains might be accomplished by fingerprint, dental, anthropological, genetic or radiological examination [2]. There may be variations in the state of preservation of human remains due to factors such as normal biochemical processes affecting the cadaver, the mechanism of death, or animal

1- Division of Identification and Forensic Sciences, Israel Police Headquarters, Jerusalem, Israel.

2- National Centre of Forensic Medicine, Tel Aviv, Israel.

scavenging. The skeleton usually survives both environmental and physical processes, and, therefore, can usually be examined radiographically. Similarly, radiographs obtained for clinical purposes always include skeletal features. Therefore, it is generally possible to obtain antemortem and postmortem radiographs for identification.

Today, radiographs are a common diagnostic tool, widely utilized in dental practices, hospitals, and health services throughout the world. Storage facilities exist in most health institutions, which tend to keep radiographs for long periods of time. Computerized record keeping, available in most hospitals, expedites the retrieval of individual x-ray films, making radiographic comparison one of the most common techniques used by forensic anthropologists to establish positive identification of unknown remains [3,4]. In 1980 it was reported that approximately 60% of the scientific identifications at the St. Louis Medical Examiner's Office were obtained by comparing antemortem and postmortem plates [2]. With the availability of DNA techniques in most modern facilities, this percentage has changed. Positive identification of victims is obtained through genetic techniques when fingerprints or medical data are not available. During the last wave of suicidal terrorist attacks in Israel (November 2000 through December 2001), the National Centre of Forensic Medicine identified 18% of the 234 victims and perpetrators through radiographic data, 9% through genetic techniques, and the rest were identified either by fingerprints or particular signs, such as tatoos.

Computerized simulation using a CT scanner has been proposed for postmortem x-ray images [5], although this technique is hardly ever pursued since it requires sophisticated equipment seldom available in a standard autopsy room, and highly experienced personnel.

This report presents an unusual case where positive identification of a victim was accomplished by comparing antemortem CT cross-sectional images of the head with radiographs obtained during autopsy. The identification was substantiated with findings from antemortem and postmortem chest radiographs.

Case report

Residents of an apartment building complained to the police about a strong smell coming from one of the residences. The police found a body in an advanced state of decomposition on a couch facing a turned on television set. The investigation disclosed that the apartment had been recently rented and none of the neighbors knew the identity of the tenant.

The cadaver was brought to the National Centre of Forensic Medicine for examination and identification. The body was found to be that of a middle-aged male, 176 cm long and weighing 55 kg. Upon external examination, a 16.2 cm by 0.3 cm longitudinal scar along the abdominal midline was detected. Palpation of the decomposed head revealed a depression on the left parietal area.

Radiographic examination of the cranium disclosed a 9 cm by 6 cm radiolucent rectangular defect on the left parietal with smooth, clearly defined margins (Figure 1). On the anteroposterior chest image, two 1.5 cm by 0.1 cm linear radiopaque surgical staples were seen on the upper left abdominal quadrant at the height of the eleventh thoracic vertebra (Figure 2). These findings were compatible with a recent craniotomy and intraperitoneal surgery. No other remarkable findings were revealed during an internal examination of the intracranial, intrathoracic and intra-abdominal organs.

A swift search through the major neurosurgical wards in the greater Tel Aviv area resulted in a list of eight male patients who, during the preceding year, had undergone a left parietal craniotomy. From this list, six were excluded because they were found still living. A seventh man was excluded based on data from the anthropological profile because the estimated age and stature of the cadaver didn't fit the patient. The medical file of the remaining patient, including a radiographic study, was submitted to the forensic team for examination.

The postoperative computerized tomography of the parietal bones 3.0 cm below the vertex (Figure 3) showed a large cranial defect similar in position, shape, and size to the defect observed on the postmortem radiograph (Figure 1). This trephine was the result of the resection of a parasagittal parietal meningioma. The staples detected on the postmortem chest x-ray (Figure 2) were also observed on the patient's antemortem chest x-ray in a similar location (Figure 4). The slight difference in the positions of the

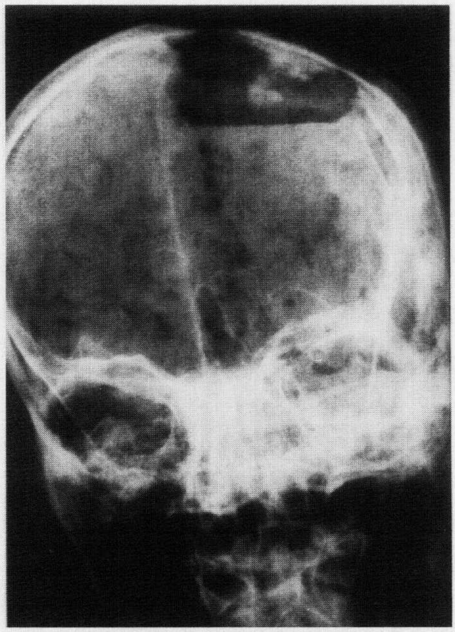


Figure 1. Postmortem radiograph of the cranium showing large radiolucent defect on the left parietal.

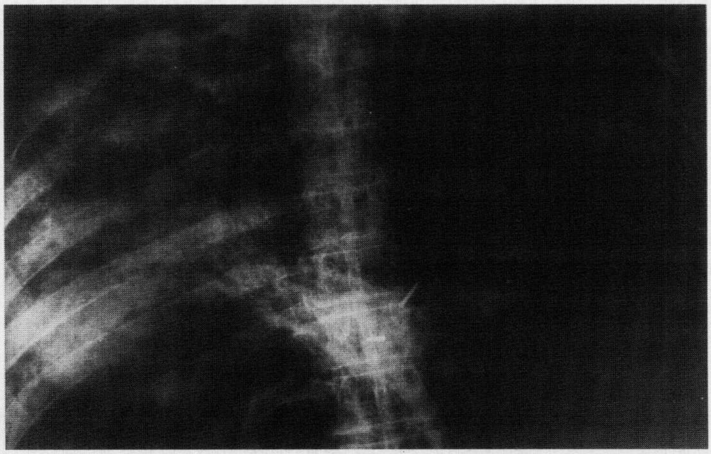


Figure 2. Postmortem anteroposterior radiograph of the chest showing two metallic surgical staples.

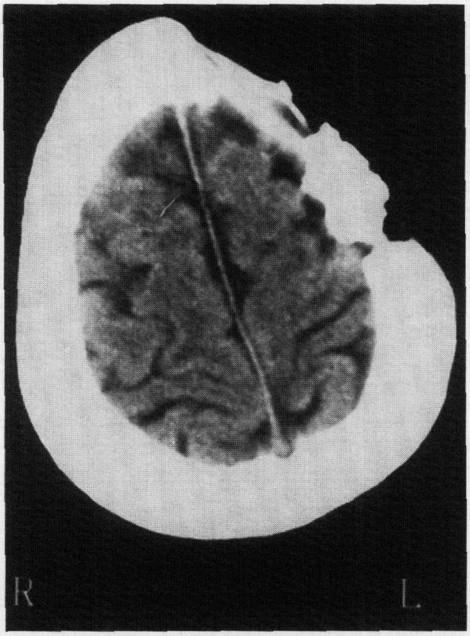


Figure 3. Antemortem CT of the parietal bones 3.0 cm below the vertex. (Note large defect on the left parietal.)

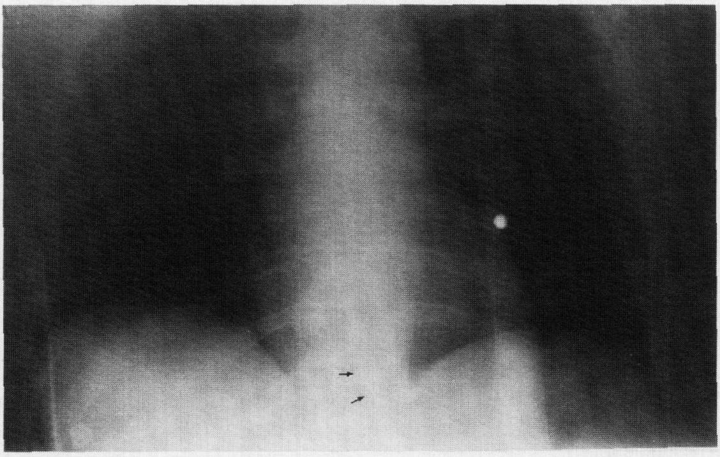


Figure 4. Antemortem anteroposterior radiograph of the chest. (Arrows on the lower part of the photograph at the level of the 11th thoracic vertebra point to two metallic surgical staples.)

staples was attributed to postmortem changes. Based on the radiographic antemortem and postmortem comparisons, the victim was positively identified.

Discussion

The use of radiographs for identification of human remains is common in mass disasters, as well as in daily forensic practice throughout the world [6]. The potential value of comparison between antemortem and postmortem radiographs in forensic medicine is fully appreciated now. Similar comparisons between antemortem and postmortem CT images can yield successful personal identifications [7]. However, this type of comparison is less feasible since CT equipment is seldom available in forensic facilities.

Positive radiographic identification is accomplished by meticulous comparison of the details present in the radiographs. However, there is no minimum number of points of comparison that must be present to determine identity. Usually, 1 to 4 unique concordant features and no discrepancies are considered enough evidence for positive identification [8].

Morphological features depicted on radiographs must comply with two requirements in order to be of forensic identification value: (1) the feature has to be unique to each individual, and (2) it should remain relatively stable over time despite ongoing life processes [9].

Radiographic identification can be accomplished when there is a lead as to the possible identity of the victim. Usually, this is the result of comparing an anthropological profile (gender, age, stature, and ethnicity) with police or military missing persons reports. Identifications of the deceased are facilitated when the antemortem and postmortem radiographs are similar (e.g., position and intensity). However, in another identification case, normal anatomic variation of the frontal sinus pattern was depicted in antemortem CT scans and postmortem radiographs, yet a comparison was made, yielding positive identification of the remains [10-11]. Unfortunately, CT imaging that is available to the forensic investigator is oftentimes disregarded because of the difficulty of reproducing a similar image from the cadaver.

The importance of careful record keeping in medical facilities and private practices for as long as feasible should be emphasized. In some countries, radiographs pertaining to inactive patients' files are stored for as short a time as 5 years [12]. When space for storage is limited, the radiographic information can be stored on a magnetic media [13], which would allow saving data for 20 years.

For further information, please contact:

Tzipi Kahana, Ph.D.
National Centre of Forensic Medicine
67 Ben Zvi St.,
PO Box 49015,
Tel Aviv 61490,
Israel.

References

1. Fierro, M. F. Identification of Human Remains. In *Medicolegal Investigation of Death*, 3rd ed.; Spitz, W.U., Ed.; CC Thomas: Springfield, Illinois, 1993; pp 71-117.
2. Murphy, W. A.; Spruill, F. G.; Gantner, G.E. Radiographic Identification of Unknown Human Remains. *J. For. Sci.* **1980**, *25* (4), pp 727-735.
3. Atkins, L.; Potsaid, M.S. Roentgenographic Identification of Human Remains. *J.A.M.A.* **1978**, *240*, pp 2307-2308.
4. Kahana, T.; Hiss, J. Identification of Human Remains: Forensic Radiology. *J. Clinical For. Med.* **1997**, *4*, pp 7-15.
5. Riepert, T.; Rittner, C.; Ulmcke, D.; Ogbuihi, S.; Schweden, F. Identification of an Unknown Corpse by Means of Computed Tomography (CT) of the Lumbar Spine. *J. For. Sci.* **1995**, *40* (1), pp 126-127.
6. Di Maio, D. J.; Di Maio, V. J. *Forensic Pathology*, Elsevier: New York, 1989; pp 332-333.
7. Rouge, D.; Telmon, N.; Arrue, P.; Larrouy, G.; Arbus, L. Radiographic Identification of Human Remains Through Deformities and Anomalies of Post-cranial Bones: A Report of Two Cases. *J. For. Sci.* **1993**, *38* (4), pp 997-1007.
8. Fischman, S. L. The Use of Medical and Dental Radiographs in Identification. *Inter. Dental J.* **1985**, *35*, pp 301-306.
9. Kahana, T.; Hiss, J.; Smith, P. Quantitative Assessment of Trabecular Bone Pattern Identification. *J. For. Sci.* **1998**, *43* (6), pp 1144-1147.

10. Reichs, K.J.; Dorion, R.B.J. The Use of Computed Tomography (CT) Scans in the Comparison of Frontal Sinus Configurations. *Can. Soc. For. Sci. J.* **1992**, *25* (1), pp 1-16.

11. Haglund, W. D.; Fligner, C.L. Confirmation of Human Identification Using Computerized Tomography (CT). *J. For. Sci.* **1993**, *38* (3), pp 708-712.

12. Mason, J. K. Radiology in Forensic Medicine. *Forensic Medicine for Lawyers*, 2nd ed.; Butterworths: London, 1983; pp 285-290.

13. Berlin, L. Malpractice Issues in Radiology. Storage and Release of Radiographs. *Amer. J. Radiology* **1997**, *168*, pp 895-897.

XI. Identification of Human Remains: Forensic Radiology

Kahana, T., Hiss, J.

Journal of Clinical Forensic Medicine

1997;4:7-15

La identificación de restos humanos es sumamente importante en la investigación medicolegal.

La comparación de radiografías antemortem y postmortem es una de las principales técnicas utilizadas para obtener la identificación.

Durante la primera mitad del siglo XX el papel de la radiografía dentro del campo de las Ciencias Forenses se presentó, en la mayoría de las publicaciones en la literatura científica, a través de descripciones de casos.

En 1994 la organización de médicos policiales del Reino Unido, inició la publicación de una revista científica cuya finalidad era difundir los principios de la Medicina Legal dentro de la comunidad de médicos clínicos. En 1997, esta revista publicó el articulo " Identificación de restos humanos – Radiología Forense." El objetivo de esta publicación fue presentar una reseña detallada del uso de diversas características radiográficas tanto en la práctica tanatológica diaria como en situaciones de desastres masivos.

Esta publicación hace hincapié en la importancia del mantenimiento de archivos clínicos por un tiempo prolongado con el fin de obtener fácilmente la valiosa información que contienen.

Finalmente, el artículo recalca la importancia del aporte de los conocimientos diagnósticos de los radiólogos, cuya habilidad y experiencia puede ser instrumental a la hora de realizar identificaciones forenses.

Journal of Clinical Forensic Medicine (1997) **4**, 7–15

REVIEW

Identification of human remains: forensic radiology

T. Kahana*, J. Hiss†
**Division of Identification and Forensic Science, Israel National Police, Headquarters, Jerusalem*
†The L. Greenberg Institute of Forensic Medicine, 67 Ben Zvi St., P.O. Box 49015, Tel-Aviv 61490, Israel

SUMMARY. The identification of human remains is of paramount importance in medicolegal investigations. The comparison of antemortem and postmortem radiographic records is one of the main techniques used to achieve a positive identification. The purpose of this paper is to present a comprehensive review of the use of roentgenography in forensic medicine with special emphasis on the nature of the radiographic markers often utilized for identification. Clinical radiologists should be aware of the importance of storing radiographs over prolonged periods of time and of efficient record keeping methods to enable prompt retrieval of X-ray films in mass disaster situations. Furthermore, because of his skills in radiographic evaluation, the radiologist's expertise might prove invaluable in forensic consultations.

Journal of Clinical Forensic Medicine (1997) **4**, 7–15

INTRODUCTION

The identification of human remains is one of the most essential aspects of forensic medicine. Beyond the humanitarian considerations of such a task, identification is essential for the completion and certification of official documents such as death certificates, probates of wills and disbursements of benefits and insurance.[1] Scientific identification of human remains might be accomplished by fingerprint, dental, anthropological, genetic or radiological examinations.[2] There may be variations in the state of preservation of human remains due to factors such as normal chemical processes affecting the cadaver, the mechanism of death or animal scavenging. The skeleton usually survives both natural and unnatural processes and therefore can nearly always be examined radiographically. Similarly, radiographs obtained for clinical purposes always include skeletal features. Therefore, it is commonly possible to obtain antemortem and postmortem radiographs for identification.

The use of radiographs in routine and mass disaster identification has long been in effect and its application in necroidentification is effective, swift and relatively easy. Antemortem and postmortem radiographic comparison is a common procedure in the identification of unknown human remains in most forensic facilities throughout the world.[3]

We present here a review of the use of radiography for identification purposes and its versatility within forensic medicine.

Radiological identification was first reported in 1926 by Culbert and Law[4] who stated that, by comparing the morphology of sinuses and mastoid air cells in antemortem and postmortem radiographs, they could establish positive identification. The reliability of identifications based on the comparison of cranial and postcranial radiographs is well established.[5,6] Forensic investigators and radiologists concur that 'many parts of the human skeleton can serve as bony prints for the identification of human remains, and in certain respects bones have an uniqueness similar to that of fingerprints.'[7]

Today, radiographs are a common diagnostic tool, widely used in dental practices, hospitals and health services throughout the world. Storage facilities exist in most health institutions which keep radiographs over long periods of time. Computerized record keeping, available in most hospitals, expedites the retrieval of individual X-ray films, making radiographic comparison one of the most common techniques used by forensic anthropologists in order to establish positive

Tzipi Kahana MSc, Jehuda Hiss MD, The L. Greenberg Institute of Forensic Medicine, 67 Ben Zvi St., P.O. Box 49015, Tel-Aviv 61490, Israel. Tel:+972 3 5127878. Fax:+972 3 6833813.

Correspondence to: Tzipi Kahana

identification of unknown remains.[7,8] In fact, it has been reported that some 72% of the identifications in modern forensic science are obtained by comparing antemortem and postmortem radiographs.[2]

Although all regions of the body have been reported to be of use in positive identification, radiographs of the skull, dental, chest and abdominal areas are the most frequently used.[2] This is probably because the individuality and uniqueness of the features in these areas have been tested in the past. Positive radiographic identification is accomplished by meticulous comparison of the details present in the radiographs. However, there is no minimum number of points of comparison that must be present to determine identity. Usually one to four unique concordant features and no discrepancies are considered enough evidence for positive identification.[9]

Morphological features depicted on radiographs must comply with two requirements in order to be of forensic identification value: on the one hand the feature has to be unique to the individual and on the other hand it has to remain stable over time despite ongoing life processes.[10]

RADIOGRAPHIC IDENTIFICATION TECHNIQUE

Radiographic identification can be accomplished when there is a lead as to the possible identity of the victim, usually this is the result of comparing an anthropological profile (gender, age, stature and ethnic affinity) with police or military missing persons reports.

The correct radiographic identification of the deceased depends greatly on the similarity of the antemortem and postmortem radiographic films. Positioning and exposure of the radiographs for comparison is important, since the forensic expert ideally strives to duplicate as closely as possible the antemortem angulation, beam centring and depiction.[9] Computerized simulation using a CT scanner has been proposed for reproduction of antemortem X-ray images.[6] This method can accurately reproduce the focus-object distance, object-film distance, brightness and contrast of the image, although most modern forensic facilities in the world do not yet own such sophisticated equipment. Radiation exposure time can be judged by trial and error. For instance, skeletonized remains should receive approximately one half of the standard exposures.[9]

The effect of the radiographic conditions on the reliability of the identification has been tested in a number of investigations.[2] The results show that considerable variance in projection and film quality do not preclude the correct identification. Furthermore, the correlation between radiographs of the same bone taken under different radiographic conditions was considerably higher ($r = 0.60–0.90$) than the correlation between radiographs of different bones taken under the same conditions ($r = 0.0–0.40$).[10]

USE OF CRANIAL RADIOGRAPHS IN POSITIVE IDENTIFICATION

Radiographs of the head are an important source of antemortem information. They provide an objective record of anatomical structures, as well as evidence of pathological conditions, previous trauma and surgery. Specifically, cranial and facial structures visible in the various types of extraoral radiographs commonly used today, may provide numerous features for comparison with appropriate postmortem X-rays of these same structures. The most frequent bone markers compared in cranial roentgenograms include gross anatomic structures such as maxillary and frontal sinuses,[4,7,11] normal anatomic variations[12,13] and dental restorations,[2,14] as well as trabecular architecture.[15]

The individual variations of size and configuration of the frontal and sphenoid sinuses as well as the mastoid air cells were first noted by Schuller in 1921 and their uniqueness was tested in ensuing years.[16] The reliability of comparing antemortem and postmortem radiographic depictions of the frontal sinus was tested by Kullman et al,[17] based on a double blind test, where three independent observers successfully matched 99 pairs of cranial radiographs.

Radiographically apparent vascular grooves, in the inner table and diploe of the skull which represent arterial and venous channels, can also be used for forensic purposes. In a retrospective study conducted by Messmer and Fierro in 1986[12] it was observed that the vascular groove patterns undergo little significant change with growth and development, except for minimal symmetrical increases in size reflecting modest growth in the cranium during life. Although deepening of the middle meningeal artery and venous plexus into the inner table, common in the elderly, has been proposed for estimating age in older individuals,[18] the vascular groove patterns remain constant throughout life and can be used as a marker for positive identification.[13] Similarly, the ectocranial suture pattern, which begins to fuse in the fourth decade of life, has also been proposed as a highly individual and reliable marker for positive identification.[19]

The teeth are the most durable of the human tissues, and the materials used in dental restoration are also extremely resistant to destruction by chemical and physical elements. The innumerable combinations of missing teeth, carious lesions, restorations and

Fig. 1 (A) Antemortem: Fracture of 1st metacarpal. (B) Postmortem: evidence of healed trauma.

prostheses involving the 100 surfaces of the deciduous dentition and 160 of the adult dentition, along with anatomical variations of teeth and jaws, form the basis for dental identification.[14,20]

Panoramic radiographs, which enable the visualization of most structures of the jaws and related areas on a single film and have a high reliability factor,[21] have been advocated for mass screening, such as screening of military personnel. In fact, since 1973, the Israeli Defence Forces have routinely taken panoramic radiographs and dental charting, along with 10 finger dactiloscopic records, as part of the enrolment procedure for their identification database.[14]

USE OF POSTCRANIAL RADIOGRAPHS FOR POSITIVE IDENTIFICATION

One of the earliest large studies on individual variations in appendicular bone markers was conducted in 1960 by Greulich.[22] In this investigation, 70 pairs of hand radiographs of same-sexed twins were compared. Structural features of the 27 bones of the hand and the distal ends of the radius and ulna were found to be different in all sets of twins.[22] More recently, the morphology of the lateral border of the scapula was examined in a similar test using a larger sample ($n = 200$), and the feature was reported to be a good individualizing trait.[23]

In postcranial radiographs of the axial and appendicular skeleton, the forensic anthropologist often uses normal anatomic variation including the following: vertebral body shape and configuration of the transverse and spinous processes of the vertebrae,[24] the size and shape of the ribs and their relationship to one another,[25] the shape and length of the xyphoid process,[26] the trabecular and vascular grooves of the innominate bones[27] and of hands and feet.[22,28] Similarly, general degenerative changes such as osteophytic lipping and vertebral body crushing,[24] costal cartilage calcifications,[29] disk herniations, bony bridges between vertebrae and bony spiculae on the innominate,[26] evidence of healed trauma (Fig. 1) and medical intervention[30] (Fig. 2) are used as individualizing markers.

The forensic reliability of post-cranial radiographic features, that is the uniqueness and stability over time

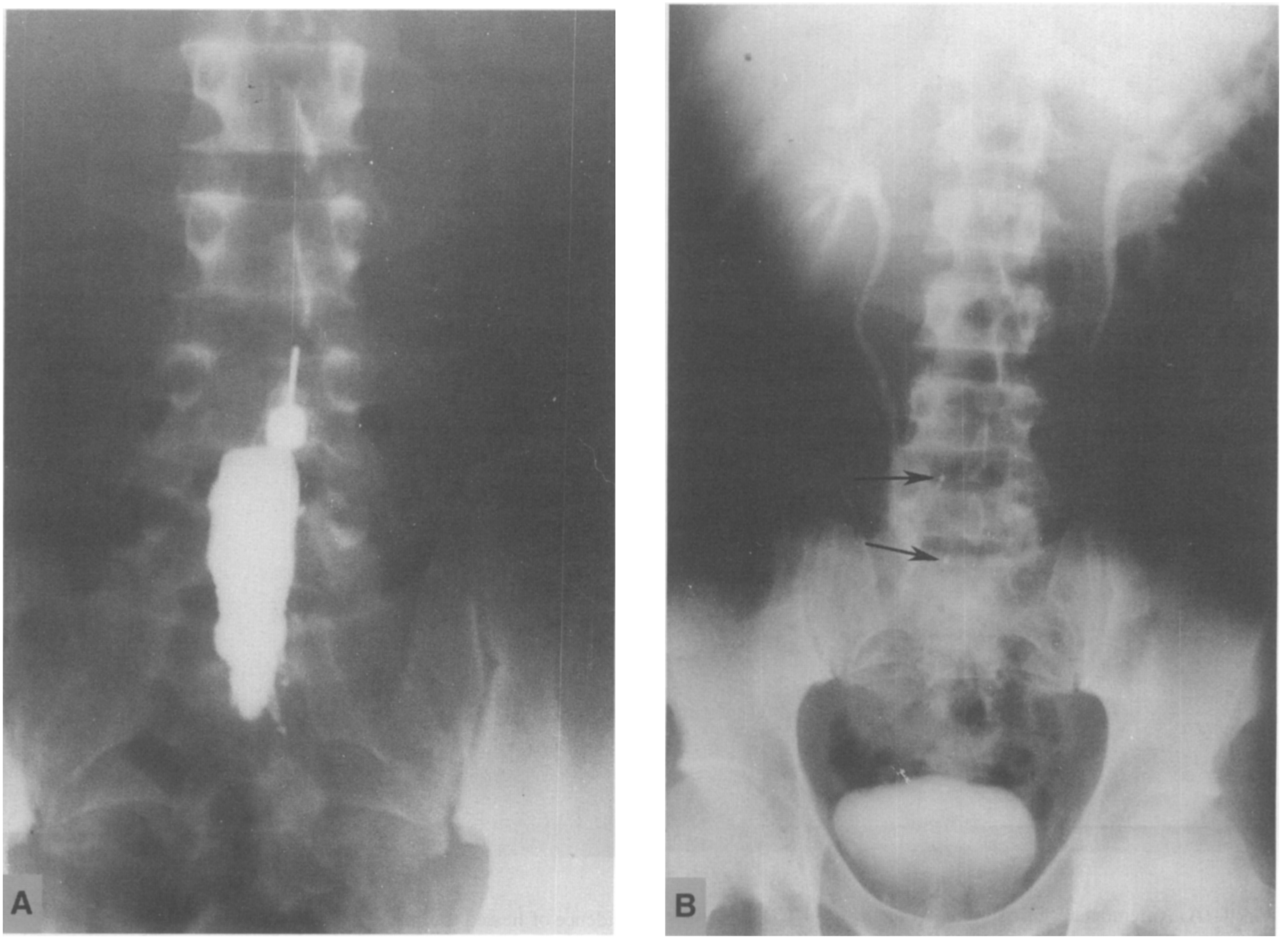
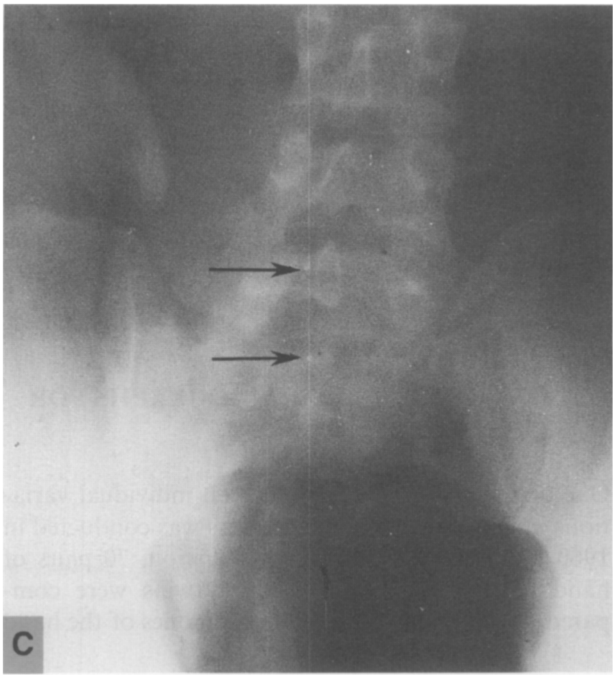


Fig. 2 (A) Radiograph during myelography. (B) Antemortem: residual contrast medium following myelography, seen during intravenous phielography. (C) Postmortem: evidence of residual contrast medium used during myelography.



(as much as two decades), has been established in several pilot studies.[31,32]

An illustrative case is the identification of a cadaver found floating in the Colorado River. The body was that of a caucasian male, 20–30 years old, of medium build and an estimated stature of 175 cm, who had been shot with a shotgun, had been stabbed 57 times in the chest, had been beheaded and had had his hands amputated. The head and hands were never recovered.

Based on the preliminary anthropological profile, the County Police suggested a possible match with a missing individual. The identification procedure was hindered by the lack of crucial postmortem data such as fingerprints or dental information.

The medical records of the missing individual included two X-rays of the upper and lower extremity. On the right hand radiograph (Fig. 3A) a small radiopaque area in the distal end of the radius could be observed, consistent with a thickening of the trabeculae, possibly due to a green stick fracture.

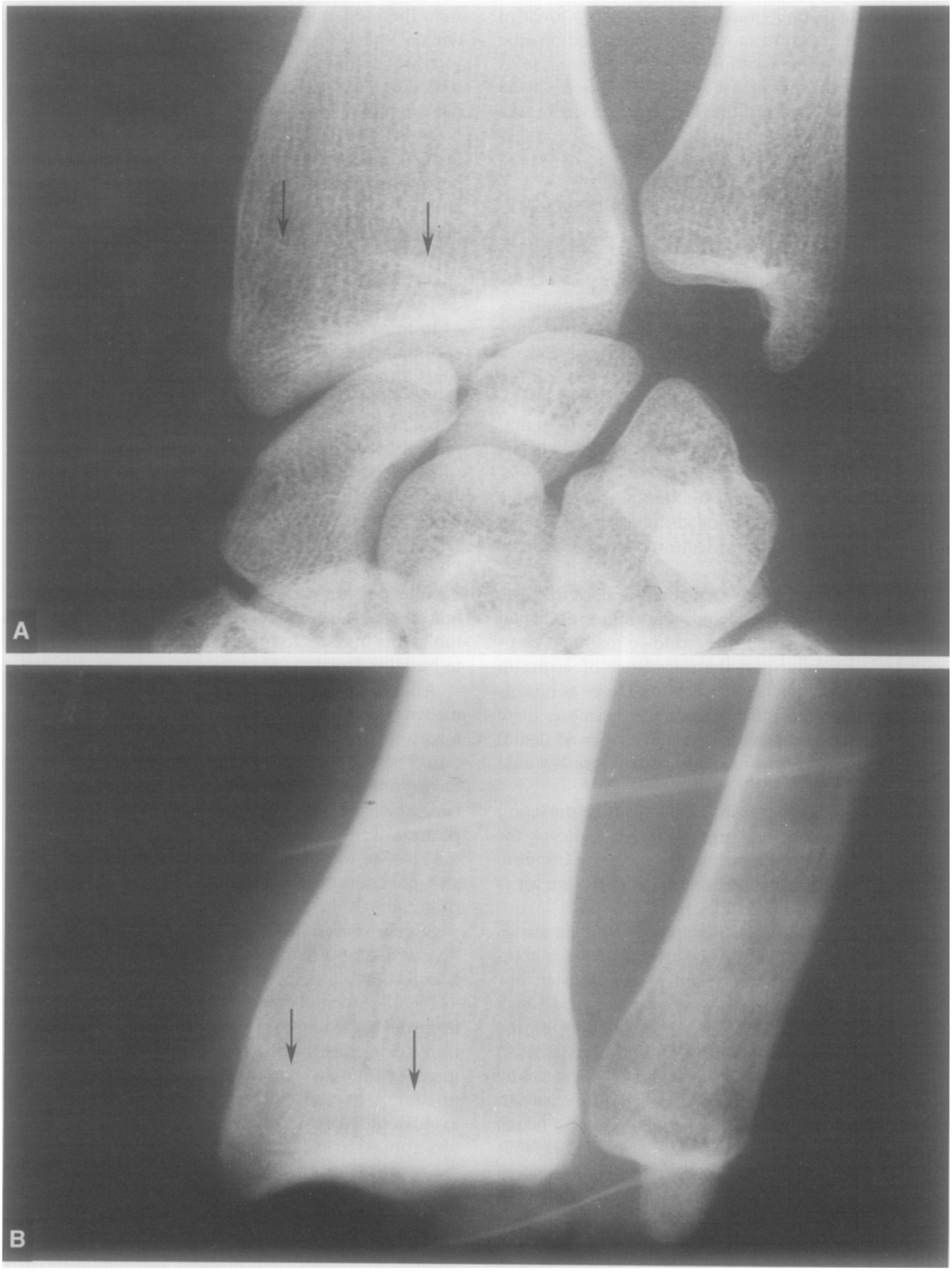


Fig. 3 (A) Antemortem: radiopaque area in distal end of radius, following a green stick fracture. (B) Postmortem: similar radiopaque area in forearm stump of the cadaver.

Postmortem radiographs of the right forearm stump of the victim showed a similar radiopaque feature, in the same location and of the same size as the antemortem radiograph (Fig. 3B). Based on the anthropological and radiological data the victim was positively identified.

RADIOGRAPHIC IDENTIFICATION IN MASS DISASTERS

In reviewing the experience from mass disasters, it is apparent that in most countries major emphasis is placed on forensic odontology for identification purposes. In an analysis of ten mass disasters in which British forensic odontologists undertook the identification procedures an average of 55% of the cadavers were identified using a variety of dental comparisons. However, in one instance (Thai International Airline Bus crash) only 6.24% of the victims could be identified by dental radiographic comparison.[33] A number of difficulties associated with this method of identification were consistently encountered.

Some of the problems that forensic odontologists have faced for decades include the failure of dental practitioners throughout the world to maintain comprehensive records[34] and the prevalence of errors in dental charts, which has been reported to be as high as 45% in a sample of 50 records.[35] Furthermore, there are many individuals who have never received dental treatment meaning that no antemortem records would be available.

In mass disasters, such as public transportation accidents, terrorist bombings, military actions or the collapse of architectural structures, reliance on more than one identification technique for each cadaver is essential in order to preclude errors.[24,34–37]

One of the most difficult tasks in these situations is the identification of individuals that have been completely dismembered as a result of the disaster. For instance, on July 18th 1994 an explosion caused by a car-bomb, levelled the seven storey building of the Jewish Argentine Mutual Association Centre (AMIA) in Buenos Aires, Argentina, wounding 104 and killing 85 individuals. Following a 10 day exhaustive investigation, conducted by a joint Argentinian and Israeli team, all but seven victims from the missing persons list were identified. The team assumed that these seven individuals were possibly completely dismembered, unrecovered by the rescue teams or missing for reasons unrelated to the AMIA disaster.

A total of 323 body fragments were recovered at the site and catalogued, photographed and X-rayed for identification purposes. Among these remains were the radiographs of a decomposed, fragmented, female torso. They were compared to antemortem vertebral column radiographs from the missing persons files. One particular set of X-rays of a 71-year-old woman showed good correspondence with the postmortem torso plate (Fig. 4). Several radiographic features were present in both the antemortem and the postmortem plates, such as calcification of ligaments and of intervertebral disks, osteophytes and spur formations of the same shape, size and location. Based on the radiographic comparison, the torso recovered at the scene was positively identified as belonging to one of the missing persons.

In most mass disasters, 90% of identifications are accomplished either by fingerprint or dental comparison,[36] although in some countries antemortem fingerprints are not available for the majority of the civilian population. In these cases, identification is accomplished by a combination of the description of personal effects and individualizing medical findings.[37] In June of 1995 the 'Angin Madras', a Korean ship, collided in the South China Sea with the 'Mineral Dampier', a Belgian cargo ship. The 'Mineral Dampier' sank immediately, causing the 27 crew members to drown. The Israeli government sent a marine rescue team to locate and recover the bodies of the sailors in order to bring nine Israeli crew members to burial in Israel.

After four sessions of diving to a depth of 60 metres over a 2-year period, six of the nine Israeli seamen were recovered in various stages of decomposition. The first three bodies were identified by means of fingerprint and dental comparisons. The following two, which were in a more advanced state of decomposition were identified by dental means only, while the last one was identified by comparing antemortem and postmortem chest radiographs of the sternum (Fig. 5A,B).

Similar eversion of the xyphoid process was observed on both the antemortem and postmortem lateral chest plates, positively identifying the remains.

In 18 suicidal terrorist bombings that have occurred in Israel over the last 2 years the identification team has been faced with extremely fragmentary human remains produced by the close proximity of the victims to the epicentre of the explosion. A variety of identification techniques was applied in each case, depending on the availability of antemortem data and of postmortem findings.[38] Similar conditions arise in military actions where identification is complicated by large numbers of unidentified victims, possibly in mass graves, absence of antemortem medical and dental records and the lack of the means to carry out sophisticated methods of identification.[39]

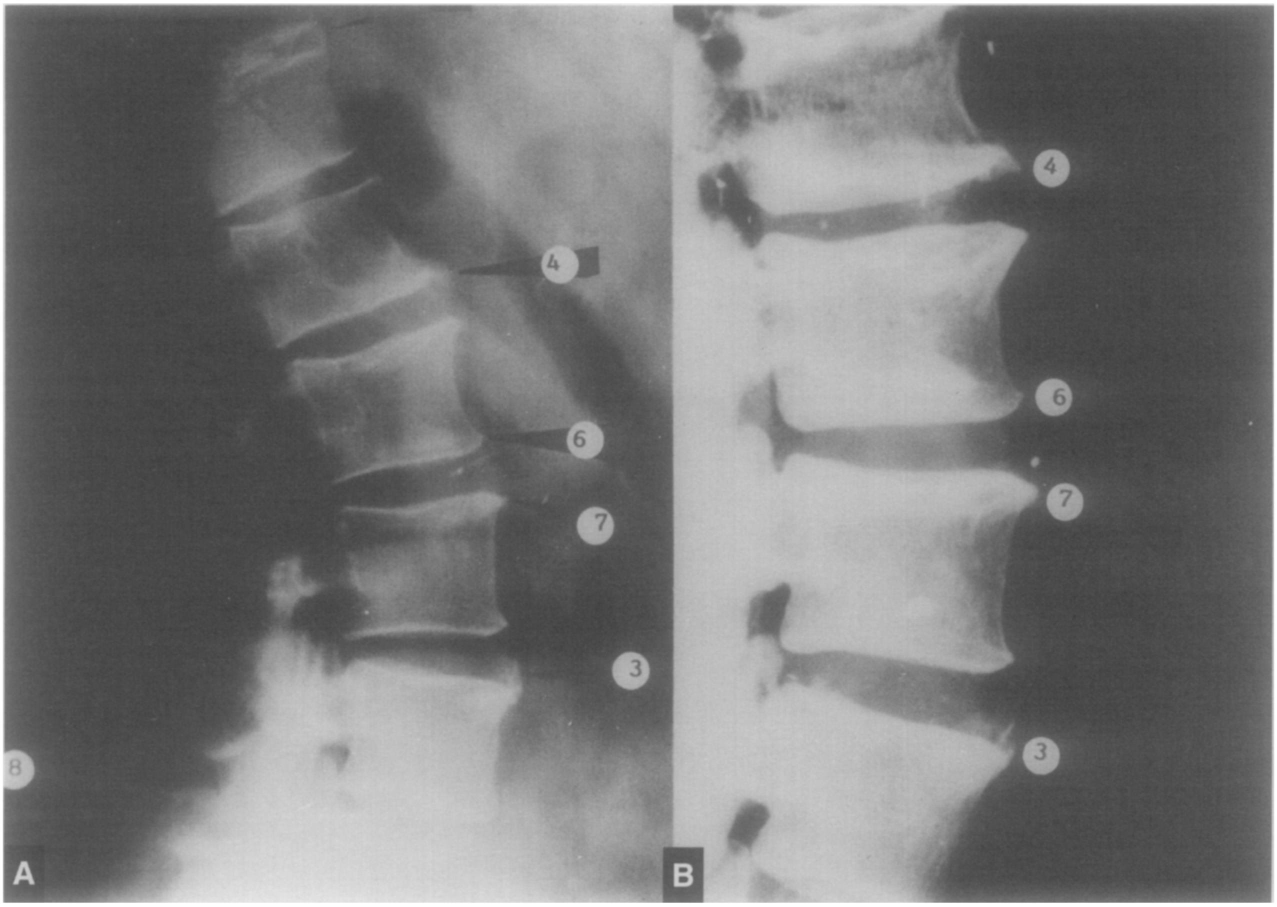


Fig. 4 (A) Antemortem: radiograph of thoracic and lumbar spine showing age related morphological features. (B) Radiograph of torso found within the rubble in the 'AMIA' disaster, showing similar characteristics.

CONCLUSION

The use of radiographs for identification of human remains is common in mass disasters as well as in daily forensic practice all over the world.[3] The potential value of comparison between antemortem and postmortem radiographs in forensic medicine is nowadays fully appreciated, although more extensive research into the uniqueness and stability of the features used for identification is necessary.

The availability of medical and dental radiographs and the high reliability of the markers depicted on X-rays make this technique extremely useful. In fact, some 72% of forensic cases in which the identity of the deceased is unknown are resolved by means of radiographic comparisons.[2]

Careful record keeping in medical facilities and private practices retained for as long as it is feasible is extremely important. In most countries, radiographs pertaining to the inactive files of patients are stored for at least 5 years.[40] In the USA, medical records are usually retained until the statute of limitations for acts of medical malpractice has run. This guideline may require a paediatrician to keep the record for up to 6 years after the age of majority.[41] In Israel because of the multiplicity of mutilated victims from terrorist attacks and military actions, the National Institute of Forensic Medicine has recommended to extend the present ministerial instruction of medical record keeping from 5 to 20 years. This measure would require saving the information on magnetic media.

The effectiveness and usefulness of any identification technique greatly depends on the rapidity with which the antemortem data can be obtained. The authors' experience from practising in the US, the UK and Israel has shown that on average 10% of the medicolegal cases are unidentified remains. Of these, some 80% are identified by radiographic means. Radiologists should be aware of this alternative use for diagnostic roentgenograms. Because of his training

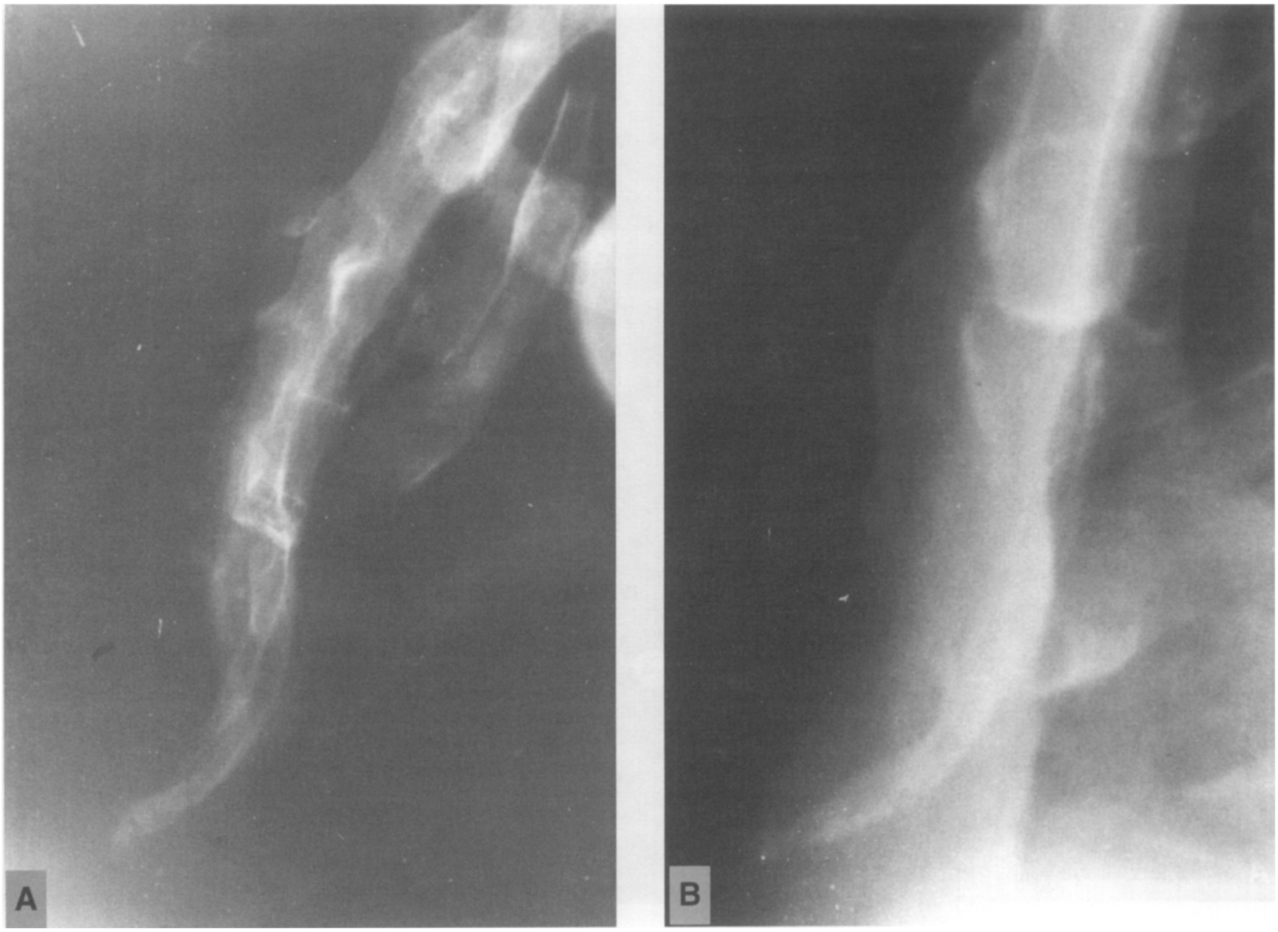


Fig. 5 (A) Antemortem: everted xyphoid process as seen on lateral-medial plate of chest. (B) Postmortem: same anatomic variant seen on X-ray of the recovered victim.

in the evaluation of radiographic studies of normal anatomy, its variants and the effect of pathological conditions or surgical interventions on them, the radiologist's expertise might prove invaluable in consultations of a medicolegal nature.

REFERENCES

1. Fierro MF. Identification of human remains. In: Spitz WU (Ed) Medicolegal investigation of death. 3rd ed. Springfield, Illinois: Charles C Thomas 1993: 71–117
2. Murphy WA, Spruill FG, Gantner GE. Radiographic identification of unknown human remains. J Forensic Sci 1980; 25: 725–735
3. Di Maio DJ, Di Maio VJ. Forensic pathology. New York: Elsevier. 1989: 332–333
4. Culbert WC, Law FM. Identification by comparison of roentgenograms of nasal accessory sinuses and mastoid processes. Journal of the American Medical Association 1927; 4: 1634–1636
5. Lichtenstein JE, Fitzpatrick JJ, Madewell JE. The role of radiology in fatality investigations. American Journal of Radiology 1988; 150: 751–755
6. Riepert T, Rittner C, Ulmcke D, Ogbuihi S, Schweden F. Identification of an unknown corpse by means of computed tomography (CT) of the lumbar spine. J Forensic Sci 1995; 40: 126–127
7. Atkins L, Potsaid MS. Roentgenographic identification of human remains. Journal of the American Medical Association 1978; 240: 2307–2308
8. Birkby WH, Rhine S. Radiographic comparison of the axial skeleton for positive identification. Paper presented at the American Academy of Forensic Sciences, 1983
9. Fischman SL. The use of medical and dental radiographs in identification. Int Dent J 1985; 35: 301–306.
10. Kahana T. The reliability of the trabecular bone pattern as a bone marker in radiographs for positive identification. Paper presented at the American Academy of Forensic Sciences, 1993
11. Marlin DC, Clark MA, Standish SM. Identification of human remains by comparison of frontal sinus radiographs: A series of four cases. J Forensic Sci 1991; 36: 1765–1772
12. Mesmer JM, Fierro MF. Personal identification by radiographic comparison of vascular groove patterns of the calvarium. Am J Forensic Med Pathol 1986; 7: 159–162
13. Rhine S, Sperry K. Radiographic comparison by mastoid sinus and arterial pattern. J Forensic Sci 1991; 36: 272–279
14. Buchner A. The identification of human remains. Int Dent J 1985; 35: 307–311
15. Van der Stelt P, Webber R, Ruttimann U. Forensic identification of trabecular patterns from dental radiographs. J Dent Res 1986; 65: 176
16. Schuller A. A note on the identification of skulls by X-ray pictures of the frontal sinuses. Med J Aust 1943; 1: 554–556
17. Kullman L, Eklund B, Grundin R. The value of frontal sinus identification of unknown persons. Journal of Forensic Odontostomatology 1990; 8: 3–10

18. Arensburg B. Methods for age identification on living individuals of uncertain age. Canadian Society of Forensic Science Journal 1989; 22: 147–157
19. Sekharan PC. Identification of skull from its suture pattern. Forensic Sci Int 1985; 27: 205–214
20. Wood RE, Tai CCE, Bleinkinsop B, Johnston D. Digitized slice interposition in forensic dental radiographic identification: An in vitro study. Am J Forensic Med Pathol 1994; 15: 70–78
21. Schwartz S, Woolridge ED. The use of panoramic radiographs for comparison in cases of identification. J Forensic Sci 1976; 31: 145–146
22. Greulich WW. Skeletal features visible on the roentgenograms of the hand and wrist which can be used for establishing individual identification. AJR 1960; 83: 756–764
23. Ubelaker DH. Positive identification of American indian skeletal remains from radiograph comparison. J Forensic Sci 1990; 35: 466–472
24. Kahana T, Ravioli JA, Urruz CL, Hiss J. Radiographic identification of fragmentary human remains from mass disaster. Am J Forensic Pathol 1997; In press
25. Murphy WA, Gantner GE. Radiologic examination of anatomic parts and skeletonized remains. J Forensic Sci 1982; 27: 9–18
26. Rouge D, Telmon N, Arrue P, Larrouy G, Arbus L. Radiographic identification of human remains through deformities and anomalies of post-cranial bones: A report of two cases. J Forensic Sci 1993; 38: 997–1007
27. Moser RP, Wagner GN. Nutrient groove of the ilium, a subtle but important forensic radiographic marker in the identification of victims of severe trauma. Skeletal Radiol 1990; 19: 15–19
28. Kahana T, Hiss J. Positive identification by means of trabecular bone pattern comparison. J Forensic Sci 1994; 39: 1325–1330
29. Martel W, Wicks JD, Hendrix RC. The accuracy of radiologic identification of humans using skeletal landmarks: A contribution to forensic pathology. Radiology 1977; 124: 681–684
30. Varga M, Takacs P. Radiographic personal identification with characteristic features in the hip joint. Am J Forensic Med Pathol 1991; 12: 328–331
31. Sauer NJ, Brantley RE, Barondess DA. The effect of ageing on the comparability of antemortem and postmortem radiographs. J Forensic Sci 1988; 33: 1223–1230
32. Owsley DW, Mann RW, Chapman RE, Moore E, Cox WA. Positive identification in a case of intentional extreme fragmentation. J Forensic Sci 1993; 38: 985–996
33. Clark DH. An analysis of the value of forensic odontology in ten mass disasters. Int Dent J 1994; 44: 241–250
34. Clark DH. Dental identification problems in the Abu Dhabi air accident. Am J Forensic Med Pathol 1986; 7: 317–321
35. Prinz JF. A forensic dental identification system with error tolerant algorithms and a review of the prevalence of errors occurring in dental records. Med Sci Law 1993; 33: 4–10
36. Mulligan ME, McCarthy MJ, Wippold FJ, Lichtenstein JE, Wagner GN. Radiologic evaluation of mass casualty victims: Lessons from the Gander, Newfoundland, accident. Radiology 1988; 168: 229–233
37. Gregersen M, Jensen S, Knudsen PJT. The crash of the Partnair Convair 340/580 in the Skagerrak: Identification of the deceased. Aviat Space Environ Med 1995; 66: 158–163
38. Kahana T, Freund M, Hiss J. Suicidal terrorist bombings in Israel – Identification of human remains. J Forensic Sci 1997; 42: 259–263
39. Strinovc D, Skavic J, Kostovic I, Henigsberg N, Judas M, Clark D. Identification of war victims in Croatia. Med Sci Law 1994; 34: 207–212
40. Mason JK. Radiology in Forensic Medicine. In: Forensic Medicine for Lawyers. 2nd ed., London: Butterworths 1983: 285–290
41. Lewis MA, Warden CD. Law and ethics in the medical office. 2nd ed. Philadelphia: FA Davis Company 1988: 93–101

XII. Forensic Radiology

Kahana, T. and Hiss, J.

British Journal of Radiology

1999;72:129-133.

El objetivo de esta publicación, es describir las diferentes aplicaciones de la radiología en el mundo medicolegal. La publicación está dirigida a radiólogos clínicos, cuya experiencia es inestimable a la hora de interpretar y contrastar información radiográfica.

En comparación con los radiólogos, los patólogos y antropólogos forenses suelen estar menos preparados para observar e interpretar pequeños detalles radiográficos. Sin embargo, en su práctica diaria se ven en la tarea de interpretar evidencias de estudios radiográficos, para adelantar la investigación medicolegal. Ocasionalmente, investigadores forenses deben consultar con radiólogos.

El papel de la Radiología en la práctica medicolegal se presenta en secciones separadas:

1. Examen necroscópico.
2. Traumatismos no accidentales en niños.
3. Antropología Forense.

En ellas se describen no solo las técnicas radiográficas convencionales y su interpretación sino que se resume además, el aporte de otras tecnologías: TAC, RMN e incluso angiografías; al mismo tiempo se discute su aplicación dependiendo del tipo de caso que se atiende.

Las dos últimas secciones del artículo contienen recomendaciones de tipo legal, y en ellas se enfatizan algunos puntos que pueden ser útiles al radiólogo clínico a la hora de participar en pericias judiciales:

1. Mantenimiento de archivos. 2. Testimonio de experto.

The British Journal of Radiology, 72 (1999), 129–133

Review article

Forensic radiology

[1]T KAHANA, PhD and [2]J HISS, MD

[1]*Israel National Police, Division of Identification and Forensic Science, Headquarters, Jerusalem, and*
[2]*The L. Greenberg Institute of Forensic Medicine, 67 Ben Zvi Street, PO Box 49015, Tel-Aviv 61490, Israel*

Abstract. Imaging techniques are a powerful tool in forensic science. Medical examiners and forensic anthropologists are less versed in the finer points of radiology than radiologists; nevertheless they are required to interpret findings from imaging studies to further medico-legal investigations. The forensic investigator often should call upon the radiologist whose expertise might prove invaluable in forensic consultations. The radiologist should be aware of the importance of storing radiographs over prolonged periods of time and of efficient record keeping methods, because various legal problems may require the radiographs for additional interpretation or for their presentation in court. Some of the main issues that might be encountered in forensic radiology are discussed in this review.

The importance of radiographic techniques in clinical forensic medicine is widely recognized. Radiographs are taken on post-mortem examinations to locate foreign bodies or document fractures and other types of injuries. Radiological examinations play a significant role in diagnosing non-accidental injuries of children, in medical negligence and in establishing biological aging in disputed cases. Finally, in forensic anthropology and odontology the comparison of ante-mortem and post-mortem radiographs is one of the cornerstones of positive identification of human remains.

The aim of this review is to cover the various uses of radiology within forensic medicine. Clinical radiologists and forensic experts should be aware of the responsibility incurred when offering an expert testimony in a court of law. Some suggestions related to storage and record keeping of radiographs will be offered, although regulations of each country differ widely.

Necroscopic examinations

Post-mortem radiological examination is fairly common in most modern forensic facilities. The stage at which radiology is implemented during autopsy will vary according to the individual circumstances, but usually it will be after the external examination and prior to the dissection [1].

Foreign bodies such as bullet fragments or glass may be seen and analysed by radiographic means. This is important not only for their detailed examination but also for retrieval of the objects as evidence. When localizing bullets, it is important to remember that they might migrate from the entry track; thus the examination should include the whole body for their precise location. The type of bullet (high or low velocity) might produce different injuries to bone and soft tissue.

Pneumothorax, pneumoperitoneum, barotrauma injuries and air embolism after abortion are detected and localized on radiographs. Vertebral angiography is recommended when a traumatic subarachnoid haemorrhage is suspected [1].

Radiographs for detection of fractures are not routinely required, except in cases of suspected neck pressure where the involved structures are relatively fragile and might be broken during direct examination, and in child abuse cases.

Other imaging techniques such as MRI, ultrasound and CT are often used in post-mortem examinations. The correlation between ante-mortem and post-mortem MRI signal changes, as well as CT attenuation changes, has not been adequately evaluated, perhaps because few radiology departments can afford scanner time for examination of a deceased person [2].

Non-accidental injuries of children

Radiology plays an important role in diagnosing child abuse. In fact, more than 80% of all identified child abuse related injuries in the United States are detected through medical imaging [3]. A complete radiographic skeletal survey should include the

Received 1 March 1998 and in final form 26 August 1998, accepted 14 September 1998.

Address correspondence to Tzipi Kahana, PhD, The L. Greenberg Institue of Forensic Medicine, 67 Ben Zvi Street, PO Box 49015, Tel-Aviv 61490, Israel.

Figure 1. Oblique diaphyseal fracture on the left femur of a baby. This injury in itself is considered pathognomonic of non-accidental injury.

Figure 2. Torsion-type fracture of tibia with small metaphyseal "corner" fracture, due to forceful pulling and twisting of the leg at the same time.

entire axial and appendicular skeleton. A single radiograph of the entire child ("babygram") is considered diagnostically inadequate [4]. Skeletal scintigraphy is highly sensitive in the detection of rib, spinal and diaphyseal fractures but has a low sensitivity for cranial fractures. This technique should be considered as a supplemental examination in suspected cases of non-accidental injuries [5].

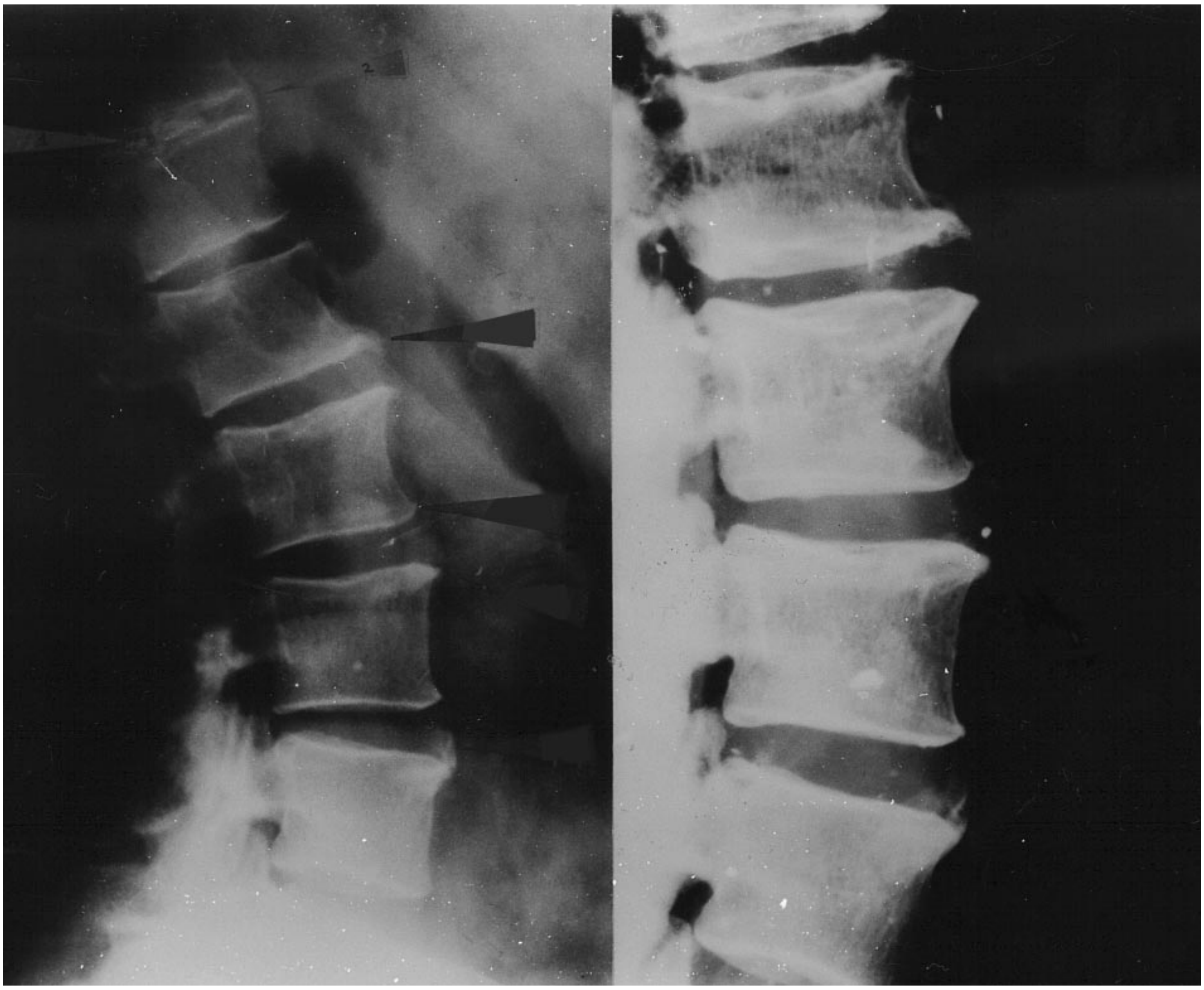
The mechanisms of trauma associated with the various types of fractures have been discussed in the literature [4–7]. Only the most prominent clinical findings will be emphasized in the present review.

The most common fractures associated with non-accidental injuries of children are diaphyseal, spiral-oblique or transverse fractures (Figure 1). Metaphyseal-epiphyseal fractures are less common. All these are considered diagnostic of non-accidental injury because the forces necessary to produce such fractures cannot be generated from simple falls or other accidents (Figure 2). Caffey (1946) [6] coined the term "bucket-handle" fracture to describe the metaphyseal fractures of long bones which are typical in abused children.

Another pathognomonic sign of abuse is the presence of multiple rib fractures, found in 5–27% of abused children. These are rarely seen in motor-vehicle accidents or in resuscitation attempts [6]. These rib fractures may be difficult to diagnose on radiographs in the acute setting and may be best detected with bone scanning [7].

Accidental cranial fractures in infants are usually simple, linear and unilateral, affect the parietal bone and do not branch or cross sutures. In general, injuries resulting from falls from beds, sofas, nappy changing chests or stairs (commonly referred to as "short falls") produce relatively minor trauma [8]. Abusive fractures are often complex, wide at the time of presentation, multiple or depressed and bilateral [5, 9]. There are some descriptions in the literature of fatal "short falls" but the majority of experts concur that these are unlikely [10].

Subdural haemorrhages are a common sequel to violently shaking an infant. The relatively large, heavy and poorly supported head is predisposed to violent acceleration and deceleration forces in the "whiplash shaken syndrome", causing disruption and bleeding of the bridging veins into the subdural space. Diagnosis of the syndrome is made by CT [6] and MRI [4]. There is no universal consensus as to the best imaging procedure for detection of non-accidental cranial injuries. Forensic radiologists suggest different techniques for specific head injuries. CT is recommended for detection of subarachnoid haemorrhages while MRI is superior in revealing subdural haematomas, concussive injuries and shear injuries.



(a) (b)

Figure 3. Torso recovered within the rubble in a mass disaster. (a) Ante-mortem radiograph of thoracic and lumbar spine showing age related morphological features. (b) Post-mortem radiograph showing similar characteristics.

CT and MRI are equally efficient for demonstrating epidural haematomas and CT is advocated for detection of fractures [8].

Age assessment of cranial injuries is rather imprecise. As a rule cranial CT is considered to be both sensitive and specific in defining acute (up to several days old) extracerebral blood collections [11]. Fresh subdural blood collections are of high density on CT. The density gradually diminishes over the first week following the injury [12].

MRI is superior to CT in depicting subacute (a few weeks old) and chronic (more than 3 months) extracerebral bleeding [12] and deep cerebral injuries [11]. Subacute and early chronic subdural blood produces a distinct high signal intensity with T_1 weighted images (short echo time (TE) and short relaxation time (TR)). As subdural blood evolves, it manifests increasing signal intensity with T_2 weighted images (long TE and long TR) [12].

A histopathological study is required for more accurate age determination.

Post-traumatic brain swelling can be detected on head CT as early as 1 h and 17 min after the injury [13].

Forensic anthropology

Establishing biological age and identification of human remains are issues addressed by forensic anthropologists.

The question of biological age can be raised in courts of law in a variety of situations: to establish if a defendant should be tried in juvenile court, to verify legal age for marriage, or to determine cases of statutory rape.

Biological age of the living cannot be correctly estimated in adult individuals older than 25 years. The most common radiographs used for establishing age up to 16 years old are dental radiographs and hand radiographs [14]. Post-cranial radiographs of specific ossification centres, depending on the reputed age of the individual, are useful for estimating older ages.

The use of radiographs for identifying human remains is common in mass disasters as well as in daily forensic practice [15]. The effectiveness and usefulness of any identification technique largely depends on the availability and rapidity with which the ante-mortem data can be obtained. The authors' experience from practising in the US, Great Britain and Israel has shown that an average of 10% of medico-legal cases are on unidentified remains. Some 80% of these are identified by radiographic means.

Although all regions of the body have been reported to be of use in positive identification, radiographs of the skull, dental, chest and abdominal areas are the most frequently used [16]. Positive radiographic identification is accomplished by meticulous comparison of the details present in the radiographs. However, there is no minimum number of points of comparison that must be present to determine identity. Usually one to four unique concordant features and no discrepancies are considered enough evidence for positive identification [17].

Panoramic radiographs, which visualize most structures of the jaws and related areas on a single radiograph, have been advocated for mass screening, such as of military personnel [18]. Since 1973, the Israeli Defence Forces routinely take panoramic radiographs and dental charting, along with 10 finger dactiloscopic records, as part of enrolment procedure for their identification database [19].

One of the most difficult tasks in mass disaster situations is the identification of individuals who have been completely dismembered (Figure 3). On average, 55% of the cadavers from major catastrophes are identified using a variety of radiological comparisons. The suicidal bombings trend implemented in Israel by various fundamentalist groups over the last 5 years has presented the identification team with extremely fragmentary human remains produced by the close proximity of the victims to the epicentre of the explosion. Implementations of radiographic and various other techniques have been instrumental in the positive identification of all victims and perpetrators [20].

Record keeping

Careful record keeping in medical facilities and private practices for as long as feasible is extremely important. In most countries, radiographs pertaining to inactive patients' files are stored for at least 5 years [21].

Radiographs are generally regarded as the property of the hospital or office in which they were produced, although the law guarantees patients' access to them. Radiographs can be released to patients or other physicians, upon valid authorization of the patient [22]. Some facilities tend to release only copies and retain the originals. In some countries, radiographs are given to the patient for safekeeping, thus releasing the medical department from any legal responsibility in case of loss.

In the United States, all states have enacted laws that govern the retention of radiographs and other medical records. This time period varies between 5 and 30 years after patient discharge or last treatment [23]. If litigation is pending, radiographs must be saved until the statute of limitations for acts of medical malpractice have run. This guideline may require a pediatrician to keep the record for as long as 6 years beyond the age of majority.

Because of the multiplicity of mutilated victims from terrorist attacks and military actions in Israel, the National Institute of Forensic Medicine has recommended that the present ministerial instruction of medical records keeping should be extended from 5 to 20 years. This measure would require saving the information on magnetic media due to space constraints. It is important to remember that only originals and not magnetic and optical data are not accepted in courts of law in some countries. This consideration should be taken into account when planning storage facilities [22].

Expert testimony

When appearing as an expert, it is advisable to consult with the lawyers involved in the case in order to outline the information to be presented.

It is important to remember to present the radiological data both in scientific and in layman terms. Before submitting the data, the radiologist should explain how and under which circumstances the radiographs were produced. The expert should know if the radiograph is the original or a copy and the whereabouts of the radiograph at all times.

Finally, a word of caution: be composed but not supercilious, present what you know and don't go beyond what has been radiologically established without question and can be supported on the basis of professional experience and knowledge. Avoid expanding the interpretative conclusions beyond the limits of validity. The opposing lawyer might try to discredit the expert by personal provocation. Above all, avoid becoming angry or participating in an argument, but maintain a professional attitude at all times [24].

References

1. Knight B. Autopsy radiology. In: Forensic pathology (2nd edn). London: Arnold, 1996:31–2.

2. Donchin Y, Rivkind AI, Bar-Ziv J, Hiss J, Almog J, Drescher M. Utility of postmortem computed tomography in trauma victims. J Trauma 1994;37:552–6.
3. Brown T. Radiography's role in detecting child abuse. Radiol Technol 1995;66:389–90.
4. Merten DF, Carpenter BLM. Radiologic imaging of inflicted injury in the child abuse syndrome. Orthop Clin North Am 1990;37:815–37.
5. Carty H. Non-accidental injury: a review of the radiology. Eur Radiol 1997;7:1365–76.
6. Hobbs CJ, Hanks HGI, Wynne JM. Clinical aspects of sexual abuse. In: Child abuse and neglect. A clinical handbook. Edinburgh: Churchill Livingston 1993:139–94.
7. Cramer EC. Orthopedic aspects of child abuse. Orthop Clin North Am 1996;43:1035–51.
8. Brogdon BG. Child abuse. In: Forensic radiology. Boca Raton: CRC Press, 1998:281–314.
9. Hiss J, Kahana T. The medicolegal complications of bilateral cranial fractures in infants. J Trauma 1995;38:1–5.
10. Reiber GD. Fatal falls in childhood. How far must children fall to sustain fatal head injury? Report of cases and review of the literature. Am J Forensic Med Pathol 1993;14:201–7.
11. Sato Y, Yuh WTC, Smith WL, Alexander RC, Kao SCS, Ellerbrock CJ. Head injury in child abuse: evaluation with MR imaging. Radiology 1989;173: 653–7.
12. Mimkin K, Kleinman PK. Imaging of child abuse. Pediatr Clin North Am 1997;44:615–35.
13. Willman KY, Bank DE, Senac M, Chadwick DL. Restricting the time of injury in fatal inflicted head injuries. Child Abuse Negl 1997;21:929–40.
14. Tanner JM, Whitehouse RH, Cameron N, Marshal WA, Healy NJR, Goldshetein H. Assessment of skeletal maturity and prediction of adult height (TW2 Method) (2nd edn). London: Academic Press, 1991:1–3.
15. Fischman SL. The use of medical and dental radiographs in identification. Int Dent J 1985;35:301–6.
16. Murphy WA, Spruill FG, Gantner GE. Radiographic identification of unknown human remains. J Forensic Sci 1980;25:725–35.
17. Di Maio DJ, Di Maio VJ. Forensic pathology. New York: Elsevier, 1989:332–3.
18. Schwartz S, Woolridge ED. The use of panoramic radiographs for comparison in cases of identification. J Forensic Sci 1976;31:145–6.
19. Kahana T, Freund M, Hiss J. Suicidal terrorist bombings in Israel: Identification of human remains. J Forensic Sci 1997;42:260–4.
20. Kahana T, Hiss J. Identification of human remains: forensic radiology. J Clin Forensic Med 1997;4:7–15.
21. Mason JK. Radiology in forensic medicine. In: Forensic medicine for lawyers (2nd edn). London: Butterworths, 1983:285–90.
22. Berlin L. Malpractice issues in radiology. Storage and release of radiographs. AJR 1997;168:895–7.
23. Brenner RJ, Westenberg L. Film management and custody: current and future medicolegal issues. AJR 1996;167:1371–5.
24. Aronson ME, Friedman PS. Forensic roentgenology. In: Tedeschi CG, Eckert WG, Tedeschi LG, editors. Forensic medicine. A study in trauma and environmental hazards. Philadelphia: WB Saunders, 1977:1154–9.

XIII. Forensic Radiology.

Kahana, T. y Hiss, J.

Forensic Pathology Reviews

2005;3:443-460.

En esta publicación se resume el aporte de diversas técnicas radiográficas a la Antropología y Patología Forenses. El artículo se divide en secciones que hacen mención a las principales aplicaciones forenses de las técnicas roentgenológicas:

1. El examen necroscópico, 2. La identificación de restos humanos, 3. La estimación de la edad en individuos vivos y 4. El examen de traumatismos no accidentales, típicos del abuso infantil.

El examen necroscópico se suplementa por lo general con radiografías de distintos tipos, que permiten reevaluar la evidencia recogida durante la autopsia, así como también presentarla ante las Cortes de Justicia. No solo en casos de muerte natural, en los que la radiografía es instrumental en la detección de embolismos, neumotórax, neumoperitoneo y barotrauma, sino en casos de muerte por armas de fuego, explosiones y diversos accidentes.

El aporte de la radiografía a la necroidentificación se extiende desde la creación del perfil antropológico hasta la comparación de rasgos individuales tanto de variación anatómica, como de intervención médica. En la sección que describe la utilidad de las técnicas radiográficas en el campo de la identificación, se discuten los avances de la digitalización y el cuidado que se debe tener a la hora de manipular las imágenes para mantener su valor forense.

El uso de la radiografía en la estimación de la edad de individuos vivos es crucial para establecer el estadio de desarrollo dental y esquelético del individuo. En esta sección se discuten las circunstancias en las que se requiere esta pericia, así como las consideraciones antropológicas que se deben tener en cuenta durante el dictamen.

El papel de las técnicas radiológicas en el diagnóstico de traumatismos no accidentales se examina en una sección separada. Las fracturas mas comúnmente asociadas al abuso infantil, su frecuencia y mecanismo se describen en detalle. El aporte de otras tecnologías como el TAC y la RMN y su eficiencia en demostrar diversas hemorragias craneales patognomónicas del abuso se revisan en esta publicación.

Finalmente, se sugieren algunas recomendaciones referentes al manejo de archivos radiológicos para facilitar su acceso en casos forenses.

13

Forensic Radiology

Tzipi Kahana, PhD *and Jehuda Hiss,* MD

Contents

Summary

Imaging techniques are powerful tools in forensic sciences. Medical examiners, forensic pathologists, and anthropologists are required to interpret findings from imaging studies to further medicolegal investigations. Often, the forensic investigator calls on the radiologist, whose expertise might prove invaluable in forensic consultations. Radiological studies are instrumental in medicolegal investigations involving the location of foreign bodies within the body (i.e., bullets, gas emboli), documentation of fractures, and other mechanical injuries. Virtual autopsy (virtopsy), which involves a full-body computed tomography and magnetic resonance imaging examination to obtain two-dimensional and three-dimensional documentation has been proposed as an alternative to conventional autopsy in cases when the next of kin oppose

From: *Forensic Pathology Reviews, Vol. 3*
Edited by: M. Tsokos © Humana Press Inc., Totowa, NJ

the necroscopy and as a complementary tool for better visualization of postmortem findings. Antemortem and postmortem radiographic comparison is a common procedure in the identification of unknown human remains in most forensic facilities throughout the world. Computerized record keeping, available in most hospitals, expedites the retrieval of individual x-ray films, making radiographic comparison one of the most common techniques used by forensic pathologists and anthropologists to establish positive identification of unknown remains. The use of radiographs in routine and mass disaster identification has long been in effect, and its application in necroidentification is efficient, swift, and relatively easy. Age estimation of the living as well as of cadavers relies heavily on data regarding growth and developmental stages of the individual as obtained from dental and skeletal radiographs. Medical practitioners should be aware of the importance of storing radiographs for prolonged periods of time and of efficient record keeping methods because of various legal problems that might arise requiring the films for later interpretation or for their presentation in court.

Key Words: Forensic radiology; forensic anthropology; imaging techniques; identification; age estimation; mass disasters; nonaccidental injury; physical child abuse.

1. Introduction

The importance of imaging techniques in forensic medicine is widely recognized. Forensic anthropologists and odontologists routinely rely on the comparison of antemortem and postmortem radiographic plates to establish identity. The location of foreign bodies and gas emboli, and the documentation of fractures and other types of injuries make x-rays an integral element of most medicolegal procedures. Furthermore, radiographic studies of the body are crucial in early recognition of hazardous objects because exploding bullets that penetrated the body unactivated, undetonated explosive material, and retained sharp souvenirs (foreign bodies) can cause severe injuries to the forensic investigators if undetected before the autopsy. Necroscopic as well as clinical radiological examination plays a significant role in the diagnosis of nonaccidental injury in children and adults, in establishing medical negligence, and estimating biological age in disputed cases. Finally, there is an increasing demand for noninvasive techniques to replace the conventional autopsy in cases in which cultural and religious demands ban invasive postmortem procedures. The aim of this review is to describe the various uses of radiology within the medicolegal realm.

2. Necroscopic Examinations

Postmortem radiological examination is fairly common in most modern forensic facilities. The permanent nature of x-ray plates makes them available for reevaluation and reinterpretation as additional evidence accumulates regarding the case investigated. The objective and noninflammatory character of radiographic records makes them a valuable tool for presenting evidence in court. The stage at which radiology is implemented during autopsy will vary according to the circumstances surrounding a particular case. Generally, radiographs will be taken after the external examination and before the dissection, except in medicolegal investigation of bombings and charred bodies.

In natural death cases as well as in investigations of assumed medical malpractice, the implementation of various imaging techniques is the most adequate method for detecting pathological features such as pneumothorax, pneumoperitoneum, barotrauma injuries, and air embolisms. Moreover, when traumatic subarachnoid hemorrhage is suspected, vertebral angiography, if available, is recommended *(1)*. When the body to be examined is badly decomposed, for instance, in exhumed cadavers, it is highly recommended to conduct a full body radiographic study that might help visualize otherwise hidden injuries and pathological findings.

As a rule, in all gunshot wound cases it is strongly recommended that x-rays are taken. This includes instances where the bullet is known to be in the body as well as those in which it has allegedly exited (Fig. 1*[2]*). This relatively easy task can sometimes fail—a bullet can be overlooked even by experienced radiologists because of "professional blinkers phenomenon" *(3)*. In localizing bullets, it is important to remember that they might migrate; thus, the radiographic examination should include the whole body. The path of the bullet can be observed as a cloud of minute metallic particles detached from the projectile, the so-called "lead snowstorm" *(4)*, or by using more sophisticated imaging techniques such as computed tomography (CT *[5]*).

The type of bullet (high or low velocity) might be deduced by the pathologist through the different injuries detected on radiographs, whereas the determination of the type of weapon and the distance from the target should be left to the ballistics experts. Establishing the bullet's caliber from a radiograph should be avoided because angulation and distance from the beam can distort the image.

Radiography is useful not only to locate a projectile but also in determining whether metallic fragments are present within the body because even very small fragments of a bullet's jacket may suffice for a ballistic identification.

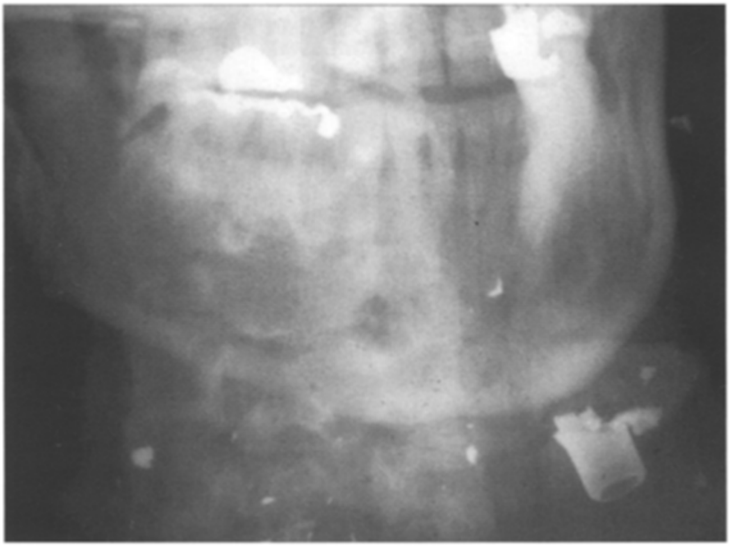


Fig. 1. Fragmented bullet within the head and neck areas of a gunshot wound victim. The attending physician at the hospital was puzzled by the presence of one entrance and one exit wound while the projectile appeared retained on radiographic examination, which during autopsy was discovered to be a metallic dental jacket on the second left maxillary molar.

The presence of “souvenirs” within the body can be revealed through radiographic examination of the body before autopsy. The precise location of a foreign body is better visualized in multiple radiographic planes, including antero-posterior and lateral ones.

In victims of bombings, the examination of radiographic plates before handling the body is imperative; one of the threats posed by the centrifugally expanding wave of the blast is the presence of undetonated components of the device, which can remain embedded within the body cavities of the victims (Fig. 2), placing the unsuspecting forensic pathologist in danger of detonating these parts by manipulating them during body handling and examination. Location and documentation of the shrapnel within the body is a key step in this type of criminal investigation because the identification of the terrorist cell involved in the act can be expedited since the kind of shrapnel added by the perpetrators acts as a signature to specific terrorist groups (Fig. 3A,B *[6]*). Occasionally, in victims of nautical sporting accidents, the injuring agent, for example, a propeller blade fragment, can be evinced on radiography, and thus retrieved for physical matching with a suspected boat.

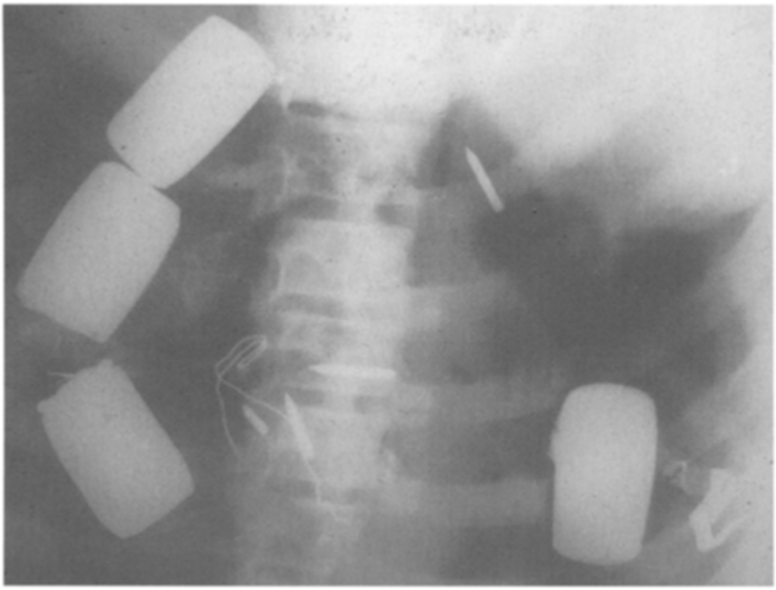
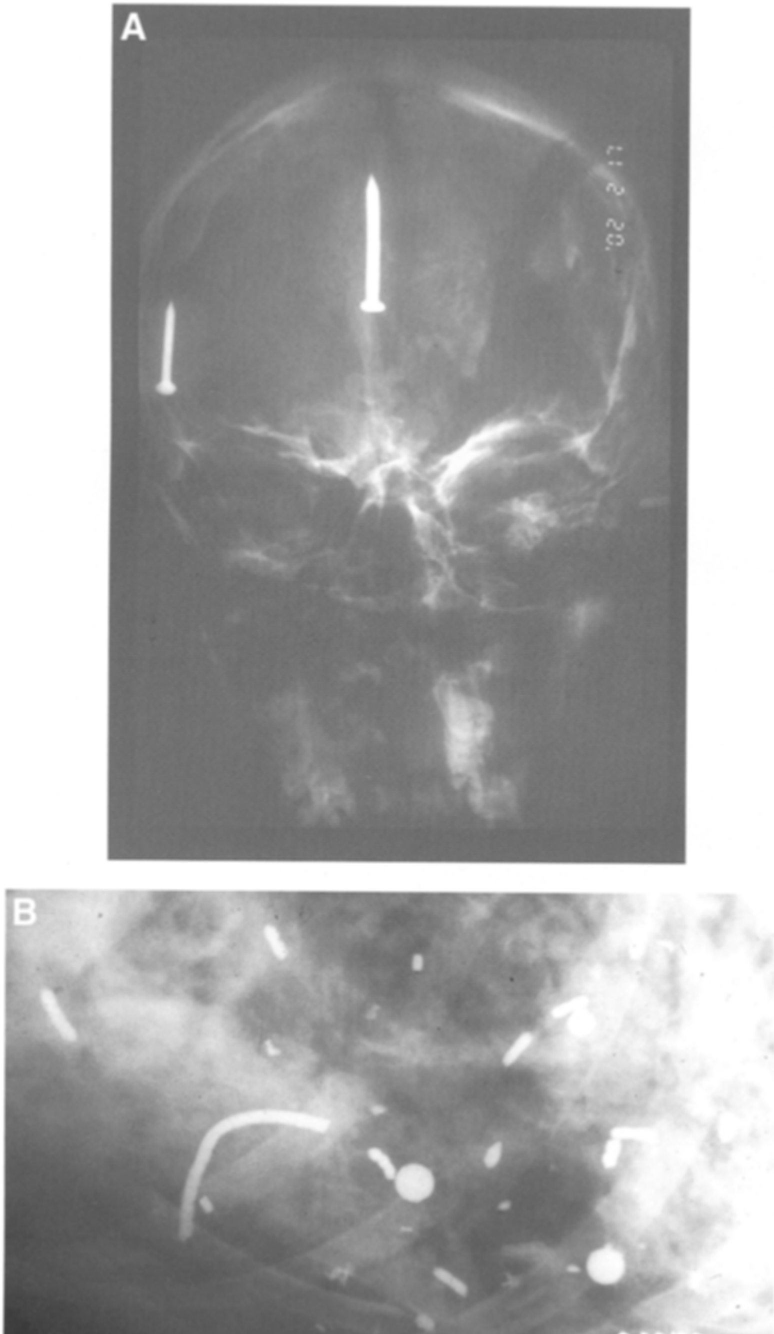


Fig. 2. Unexploded detonators embedded within the thoracic cavity of a victim of a suicidal bombing.

The estimation of age at death of unidentified victims also can be achieved through radiographic evaluation of epiphyseal closure when, for different reasons, an autopsy is not feasible. The poor visualization on x-ray of certain articular phases like the pubic symphysis makes radiographic age determination of the adult nonadvisable.

For certain cultures and religions conventional autopsy is stigmatized or even forbidden; various imaging techniques, like ultrasound, CT, and magnetic resonance imaging (MRI) allow conducting medicolegal investigations, sparing the feelings of the victim's next of kin.

During the 1990s, a variety of alternative noninvasive procedures were proposed as substitute for conventional autopsy. The concept of "virtopsy" (virtual autopsy) was born of the desire to overcome the obstacles posed by relatives of the deceased and to provide objective and indestructible documentation of postmortem evidence. The technique combines whole-body examination by CT and MRI to obtain two-dimensional and three-dimensional documentation. The advantages of virtopsy lie in the ability to "freeze" the findings at the moment of the investigation without causing damage and allowing the investigator to recapitulate the results later on, either for presentation in court, teaching, consultation through telemedicine, and/or quality con-


A
B
8 20 98

trol *(7,8)*. Additional advantages of radiologic necropsy include safe and easy examination of infected cadavers minimizing the hazards to the practitioner. The importance of a full radiological examination of victims of suspected physical abuse is discussed later in Section 5.

3. *Identification of Human Remains*

The identification of human remains is one of the most essential aspects of forensic pathology. Unidentified human remains constitute approx 10% of the caseload of most forensic practitioners. This fraction includes skeletonized, decomposed, and burnt victims along with cases of extensive mechanical trauma to the face. During the 1990s, the socioeconomic changes in the European eastern block and the opening of frontiers in most European and American countries brought large waves of illegal foreign immigrants, some of whom became homeless and, when they died, often left unidentified bodies. Currently, there are no comprehensive statistics dealing with the number of unidentified cadavers and human remains within the European community and Middle East, but the numbers seem to be increasing.

There may be variations in the state of preservation of human remains caused by factors such as normal thanatological processes affecting the cadaver, the mechanism of death, or animal scavenging. The skeleton, or at least some of its components, usually offers resistance towards environmental, mechanical, and physical processes and hence nearly always can be examined radiographically. Furthermore, because radiography is a common diagnostic tool for a great variety of dental and medical conditions, it frequently is possible to obtain antemortem radiographs for positive identification *(9)*.

Personal identification of human remains is achieved when specific features detected on the cadaver match data recorded during the life of the individual. Radiographic identification can be accomplished when there is a lead as to the possible identity of the victim; usually, this is the result of comparing an anthropological profile (gender, age, stature, and ethnic affinity) with police or military "missing persons" reports. The correct radiographic identification of the deceased greatly depends on the similarity of the conditions in which the antemortem and postmortem radiographs were taken, that is, position and intensity *(10)*.

Fig. 3. (A) Nails used as additional shrapnel by homicidal bombers to increase the lethality of the explosive device. **(B)** Metallic spheres in the thoracic cavity encountered in explosive devices prepared by a different terrorist group.

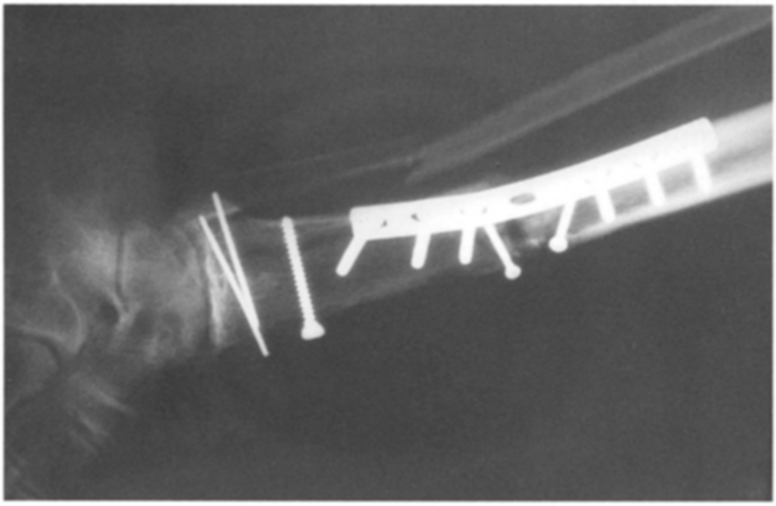


Fig. 4. Radiography of the right leg of an unidentified victim of a light plane crash. The presence of surgical scars and the consecutive radiographic study showing extensive orthopedic surgery were instrumental in the positive identification of the body.

Positive radiographic identification is accomplished by meticulous comparison of the details present on the film; however, unlike fingerprints there is no established minimum number of points of comparison that must be concordant to determine identity. The features depicted on radiographs must comply with two requirements in order to be of forensic identification value; on the one hand the feature has to be unique to each individual, and on the other hand it has to remain stable over time despite ongoing life processes and aging. Usually, one to four unique analogous features and no discrepancies are considered enough for a positive identification *(11)*.

Radiographic positive identification of unknown human remains is often attained by comparison of some markers present on the antemortem and postmortem plates, for example, signs of previous medical intervention such as old surgical or orthopedic procedures (Fig. 4) as well as prosthetic devices, evidence of healed trauma, normal anatomical variation like the variation and configuration of the frontal and paranasal sinuses *(12)*, osseous and vascular degenerative changes, congenital malformations, and certain slow growing neoplasms that might be evident within the remains *(13)*.

Bearing in mind that teeth are composed of the most resilient structures of human tissues, for example, enamel, and that the materials used in dental restorations are extremely resistant to destruction by chemical and physical

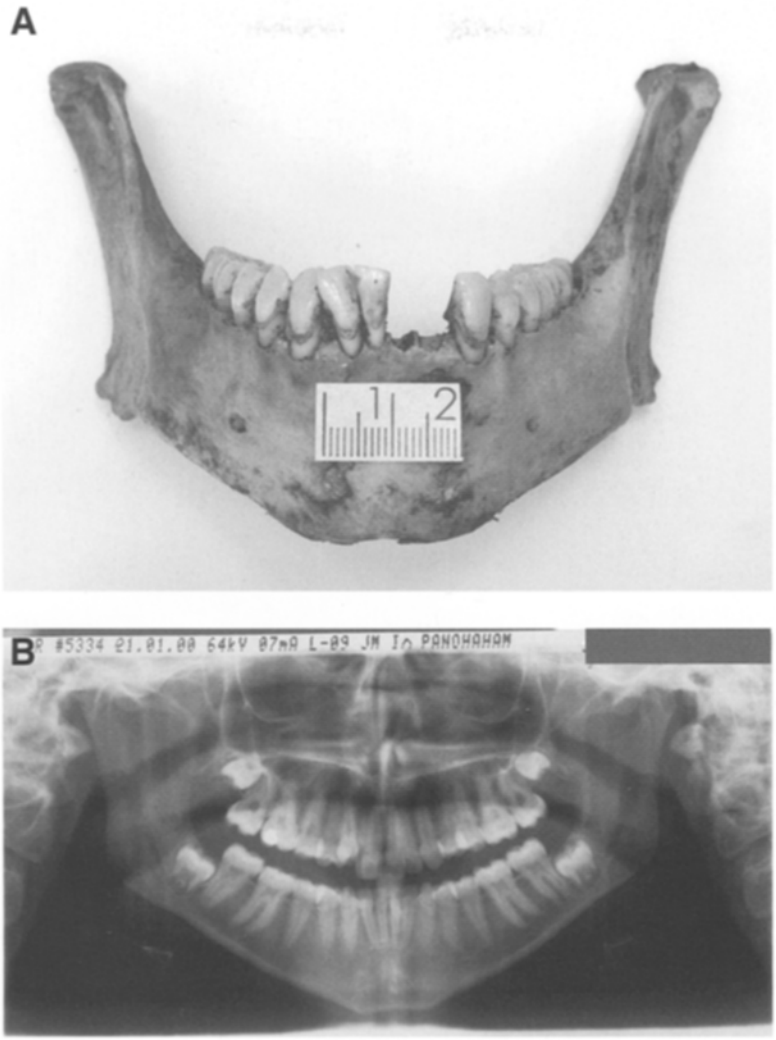


Fig. 5. (A) Human mandible encountered in the woods near the area where a 19-year-old woman had disappeared 2 years before. **(B)** Orthopantogram of the missing woman taken when she was 16 years old. Note the unerupted mandibular third molars. **(C)** Periapical radiograph of the left mandibular third molar. Note the position of the impacted tooth, which rules out the possibility of this being the mandible of the missing woman because during the time elapsed between the antemortem radiograph and her being missing, the tooth could have not rotated to the present position underneath the bulge of the second molar.

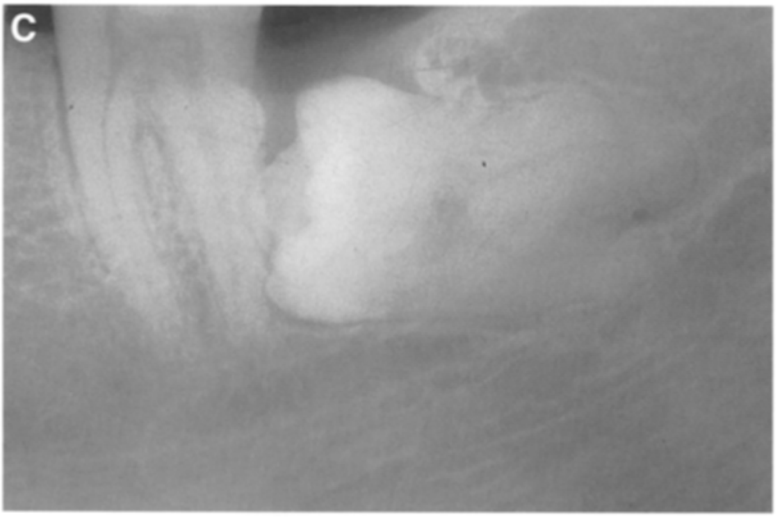


Fig. 5. *(Continued)*

agents, the innumerable combinations of missing teeth, carious lesions, restorations, and prostheses involving the surfaces of deciduous and permanent dentition, together with the normal morphological variation of crowns and roots, render dental identification the most useful and powerful tool. Most often, radiographic identification techniques are implemented in daily casework (Fig. 5A–C), as well as in mass disaster situations *(14)*. Panoramic radiographs, which enable the visualization of most structures of the jaws and related areas on a single film, have been advocated for mass screening, such as of military personnel *(15)*.

Manipulation of the radiographs is very common in modern roentgenography. With digitalization of all kinds of radiographic equipment and image-processing software becoming more easily available, it is not an unusual practice to enhance and correct the image, especially for clinical purposes. In the forensic setting, digital image processing is very useful. Contrast enhancement, brightness correction, and segmentation of images are all acceptable procedures to facilitate radiographic identification. However, any manipulations that distort radiologically visible structures by changing their angular relationship are inadmissible; the use of drawing tools which can retouch, accentuate, or fade out contours should be avoided *(16,17)*.

The potential value of comparison between antemortem and postmortem radiographs in forensic pathology is nowadays fully appreciated. Similar comparisons between antemortem and postmortem CT images can yield successful personal identification *(18)*. This type of comparison is becoming more feasible as CT equipment is growing to be more available to forensic facilities worldwide.

4. Age Estimation of the Living

Age determination of living individuals is crucial in many legal issues. In developing countries, where many a birth takes place in rural venues with deficient record keeping, when the suspicion of fraudulent registration arises—especially in light of the recent increasing illegal emigration from third-world countries and the lack of proper official documentation of these individuals—the forensic practitioner's expert opinion plays a key role in legal rulings.

In general, every country has an official age limit underneath which an individual will be considered a minor and will be granted certain leniency, for example, will be judged in juvenile court in cases of criminal charges, will not be enrolled into military service, or will be excluded from certain labors on the one hand, however, the individual who has not reached this official age limit will be denied certain financial and legal rights, such as the right to legal binding contracts, marry, the right to have sexual intercourse with an adult, and so on.

When the chronological age of an individual is questioned, the investigator must resort to the evaluation of the individual's biological age, that is the growth and developmental stage the individual has reached. The estimation of the biological age is obtained from combining clinical and radiological data on dental and osseous development.

The development of the deciduous and permanent dentition spans the infant and juvenile years. Dental age is estimated from the combined observation of the degree of mineralization of dental buds, the presence of individual teeth erupted, and the extent of root formation.

Skeletal age can be evaluated by the sequence of development and fusion of epiphyses of long bones and development of centers of ossification in small bones. The point in time of each epiphysis' fusion varies greatly according to their anatomy and physiology. The pace of growth and development differs between the sexes and between various ethnical groups, and the onset of the diverse age indicators is affected by genetic and environmental factors; thus, they should be taken into consideration. Atlases of the various stages have been developed for hands and knees *(19)*. Other radiological developmental techniques include the careful estimation of bone-by-bone development of the hand *(20)*.

The most accurate source of information for age estimation during the juvenile phase is the sequence of fusion of epiphyses and the unification of the three bones of the os coxa *(21)*. The standard deviation of the estimate in this stage is greater than the assessment based on the appearance of the centers of ossification during childhood and oscillates between 2 and 4 years, depending on the gender and ancestry of the individual. The correlation between chronological and dental age is stronger than that of chronological and skeletal age because dental development is less affected by adverse environmental conditions. For individuals in good health, skeletal age can be more than 1 year older or younger than chronological age.

The stage of fusion of the basilar synchondrosis (spheno-occipital fissure) has been regarded as a trustworthy indicator of biological age. A number of authors proffer that the synchondrosis remains open throughout childhood and adolescence and coalesces as the individual reaches adulthood, whereas others propose that fusion commences during the adolescent stage, concomitant with the eruption of the second permanent molars *(22)*. The stage of fusion of the basilar synchondrosis (spheno-occipital fissure) has been regarded as a trustworthy indicator of biological age. Albeit the assertions regarding the basilar synchondrosis as a good age indicator for the adolescence period, forensic investigators should be aware of the great variability in the time of closure of this trait in male individuals. Various ages of fusion of the spheno-occipital fissure have been reported by different researchers, from as early as 10 years old to as late as 25 years *(23,24)*. Age estimation of the living adult is extremely inaccurate; the correlation between degenerative processes of the various osseous elements, such as those evinced in radiographs of the vertebral column is low and can be affected by extraneous factors such as physical activity, nutrition, and pathological conditions. Furthermore, reliable osseous markers, such as pubic symphysis or sternal rib articulation, cannot be visualized in conventional radiographs. A CT scan of the clavicle has been suggested as a reliable age indicator for individuals younger than 21 to 25 years of age *(25)*.

5. Nonaccidental Injury

Radiological technology plays an important role in diagnosing nonaccidental injury (physical abuse) in children. In fact, more than 80% of all identified child abuse-related injuries in the United States are detected through medical imaging.

Although radiographs for the detection of fractures are normally not a requisite during autopsy because the bones themselves can be inspected and

Fig. 6. Humeri of a 3-month-old baby who died of severe head injuries. Note the callus on the right humerus resulting from a spiral fracture sustained while he was 4 weeks old.

the fractures—new and healed ones—be well documented (Fig. 6), in cases of suspected nonaccidental injuries, a complete radiographic study is mandatory. This radiographic skeletal survey should include the entire axial and appendicular skeleton and not a single radiograph of the entire child (i.e., "babygram"), which is considered diagnostically inadequate *(26)*.

Some techniques such as skeletal scintigraphy are highly sensitive in the detection of rib, spinal, and diaphyseal fractures and have a low sensitivity for cranial fractures. This procedure should be considered as a supplemental examination in suspected cases of nonaccidental injuries *(27)*.

The mechanisms of trauma associated with the various types of fractures have been discussed in the relevant literature *(11,28,29)*; in this section, the authors emphasize only the most prominent radiological findings.

The most common fractures associated with inflicted injuries of children are diaphyseal, spiral-oblique, or transverse fractures (Fig. 7). Metaphyseal–epiphyseal fractures are less common. All these are considered diagnostic of nonaccidental injury because the forces necessary to produce such fractures cannot be generated from simple falls or other accidents. Caffey (1946) coined the term "bucket-handle" fracture to describe metaphyseal fractures of long bones, which are typical of abused children *(30)*.

Fig. 7. Lateral view of an oblique fracture of the left humerus of a 20-month-old baby. This type of fracture is mostly consistent with twisting of the limb.

Another pathognomonic sign of abuse is the presence of multiple rib fractures (seen in 5–27% of physically abused children). These fractures are rarely seen in motor-vehicle accidents or after resuscitation attempts. Multiple rib fractures may be difficult to diagnose on radiographs in the acute setting and might be best detected with bone scanning *(31)*.

Accidental cranial fractures in infants usually are simple, linear, and unilateral, affecting the parietal bone, and do not branch or cross sutures. In general, falls from beds, sofas, diaper-changing tables, or stairs (commonly referred to as "short falls") produce relatively minor trauma *(32)*. Abusive fractures are often complex, wide at presentation, multiple or depressed, and bilateral *(33)*. There are some descriptions in the literature of fatal "short falls," but the majority of experts concur that these are unlikely *(34)*.

Subdural hemorrhages are a common sequel to violent shaking of an infant. The relatively large, heavy, and poorly supported head predisposes an infant to violent acceleration and deceleration forces in the "whiplash shaken syndrome," causing disruption and bleeding of the bridging veins into the subdural space. The contemporary literature on the subject contends that these forces often are insufficient to cause permanent damage and that the mechanism includes some type of blunt injury to the head *(35)*. Diagnosis of the syndrome is made by CT scan *(26,30)* and MRI *(26,34,36)*. There is no universal consensus as to the best imaging procedure for detection of nonaccidental cranial injuries. Forensic radiologists suggest different techniques for specific head injuries. CT is recommended for detection of subarachnoid hemorrhages, whereas MRI is superior in revealing subdural hematomas, concussive injuries, and shear injuries. CT and MRI are equally efficient for demonstrating epidural hematomata, and for detection of fractures, CT is advocated *(32)*.

Age assessment of cranial injuries is rather imprecise. As a rule, cranial CT is considered both sensitive and specific in defining acute (recent up to several days old) extracerebral blood collections because fresh subdural blood collections are of high density on CT. The density gradually diminishes over the first week after the injury, and at that time, MRI is superior to CT in depicting subacute (a few weeks old) and chronic (more than 3 months old) extracerebral bleedings and deep cerebral injuries. Subacute, early chronic subdural blood produces a distinct, high signal intensity with T_1-weighted images (short echo time [TE] and short relaxation time [TR]). As subdural blood evolves, it manifests increasing signal intensity with T_2-weighted images (long TE and long TR *[37,38]*). It has been postulated that posttraumatic brain swelling can be detected on head CT as early as 1 hour and 17 minutes after the injury *(39)*.

6. Conclusions

Imaging techniques are a powerful tool in forensic sciences. Medical examiners and forensic anthropologists are less versed in the finer points of roentgenology than are radiologists; nevertheless, they are required to interpret findings from imaging studies to further medicolegal investigations. Often, the forensic investigator calls on the radiologist whose expertise might prove invaluable in forensic consultations.

Radiological investigation during autopsy is priceless not only in gunshot wound cases, but in all instances when the practitioner might be required to locate foreign bodies within the cadaver, like in suicidal bombing victims.

The implementation of other imaging techniques, such as MRI and CT, are strongly advocated for cases of suspected air embolisms and for abuse victims. In the last decade of the 20th century, investigators have suggested the use of "virtopsy" (virtual autopsy) as the best tool to be used in conjunction with conventional postmortem examination to reveal the greatest amount of details pertinent to the case at hand *(7,8)*.

The importance of complete radiological examination of postmortem as well as clinical cases of suspected abuse cannot be overestimated. Radiological evidence of skeletal trauma commonly is found in abused children aged 18 months and younger; the location, nature, and multifocal aspect of these injuries are considered specific for nonaccidental injuries. Radiological imaging plays a crucial role in evaluating craniospinal injury, and the implementation of CT and MRI is advised in all cases of suspected nonaccidental cranial injuries *(40,41)*.

In forensic anthropology and odontology, radiographic examination plays a key role in positive identification of unknown human remains. This often is attained by comparison of antemortem and postmortem radiographs. Some of the markers frequently collated in the plates are signs of medical intervention, normal anatomical variation, and evidence of healed trauma. There are numerous accounts of cranial, dental, and postcranial radiographic features useful for identification. The correct radiographic identification of the deceased depends greatly on the similarity between the antemortem and postmortem films. Positioning of the questioned anatomical specimens prior to radiograph is of paramount importance for comparison since the investigator strives to duplicate as closely as possible the antemortem object-film angulation.

Biological age estimation of living individuals, an undertaking that is becoming more common worldwide in most forensic anthropology practices, is mostly supported by radiographic evaluation of dental and skeletal maturation.

The importance of careful record keeping in medical facilities and private practices for as long as feasible cannot be overemphasized. In most countries, radiographs pertaining to inactive patient's files are stored at least for 5 years *(42)*. The radiographic information can be stored on a magnetic media when facing space constrains, thus allowing one to save data for 20 years *(43)*.

References

1. Knight B (1996) Forensic Pathology, 2nd ed. Arnold, London.
2. Hiss J, Kahana T (2002) Confusing exit gunshot wound. Two for the price of one. Int J Legal Med 116, 47–49.
3. Bajanowski T, Karger B, Brinkmann B (2001) Scratched pustule or gunshot wound? A medical odyssey. Int J Legal Med 114, 267–268.
4. DiMaio VJM (1999) Gunshot Wounds. Practical Aspects of Firearms, Ballistics, and Forensic Techniques, 2nd ed. CRC Press, Boca Raton.
5. Thali MJ, Schweitzer W, Yen K, et al. (2003) New horizons in forensic radiology. The 60-second "digital autopsy": Full body examination of a gunshot victim by multi-slice computed tomography. Am J Forensic Med Pathol 24, 22–27.
6. Hiss J, Kahana T (2000) Trauma and identification of victims of suicidal terrorism in Israel. Mil Med 165, 889–893.
7. Thali MJ, Vock P (2003) Role and techniques in forensic imaging. In Payne-James J, Busuttil A, Smock W, eds., Forensic Medicine: Clinical and Pathological Aspects. Greenwich Medical Media, London, pp. 731–746.
8. Thali MJ, Yen K, Vock P, et al. (2003) Image-guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography and magnetic resonance imaging and subsequent correlation between radiology and autopsy findings. Forensic Sci Int, 138, 8–16.
9. Kahana T, Hiss J (1999) Forensic radiology. Br J Radiol 72, 129–133.
10. Kahana T, Hiss J (1997) Identification of human remains: Forensic radiology. J Clin Forensic Med 4, 7–15.
11. Di Maio DJ, Di Maio V J (1989) Forensic Pathology. Elsevier, New York.
12. Ribeiro F de A (2000) Standardized measurements of radiographic films of the frontal sinuses: an aid to identifying unknown persons. Ear Nose Throat J 26, 32–33.
13. Kahana T, Goldin L, Hiss J (2002) Personal identification based on radiographic vertebral features. Am J Forensic Med Pathol 23, 36–41.
14. Hiss J, Freund M, Motro U, Kahana T (2002) The medicolegal investigation of the El Aqsah Intifada. Isr Med Assoc J 4, 549–553.
15. Kahana T, Hiss J (2002) Forensic odontology in Israel. Alpha Omegan 95, 47–48.
16. Du Chesne A, Benthaus S, Brinkmann B (1999) Manipulated radiographic material—capability and risk for the forensic consultant? Int J Legal Med 112, 329–332.
17. Richardson ML, Frank MS, Stern EJ (1999) Digital image manipulation: what constitutes acceptable alteration of a radiologic image? Am J Roentgenol 164, 228–229.
18. Kahana T, Goldstein S, Kugel C, Hiss J (2002) Identification of human remains through comparison of computerized tomography and radiographic plates. J Forensic Ident 52, 151–158.
19. Greulich WE, Pyle SI (1966) Radiographic atlas of skeletal development of the hand and wrist. Stanford University Press, Stanford.
20. Tanner JM, Whitehouse RH, Cameron N, Marshal WA, Healy NJR, Goldshetein H (1991) Assessment of skeletal maturity and prediction of adult height (TW2 Method), 2nd edition, Academic Press, London.
21. Stewart TD (1979) Essentials in Forensic Anthropology. Charles C Thomas, Springfield, IL.

22. Kahana T, Birkby WH, Goldin L, Hiss J (2003) Estimation of age in adolescents—the basilar synchondrosis. J Forensic Sci 48, 504–508.
23. Okamoto K, Ito J, Tokiguchi S, Furusawa T (1996) High-resolution CT findings in the development of the sphenooccipital synchondrosis. Am J Neuroradiol 17, 117–120.
24. Schmeling A, Olze A, Reisinger W, Rosing FW, Geserick G (2003) Forensic age diagnostics of living individuals in criminal proceedings. Homo 54, 162–169.
25. Brown T (1995) Radiography's role in detecting child abuse. Radiol Technol 66, 389–390.
26. Merten DF, Carpenter BLM (1990) Radiologic imaging of inflicted injury in the child abuse syndrome. Orthop Clin North Am 37, 815–837.
27. Mandelstam SA, Cook D, Fitzgerald M, Ditchfield MR (2003) Complementary use of radiological skeletal survey and bone scintigraphy in detection of bony injuries in suspected child abuse. Arch Dis Child 88, 387–390.
28. Lonergan GB, Baker AM, Morey MK, Boos SC (2003) From the archives of the AFIP. Child abuse: radiologic-pathologic correlation. Radiographics 23, 811–845.
29. Carty H (1997) Non-accidental injury: a review of the radiology. Eur Radiol 7, 1365–1376.
30. Hobbs CJ, Hanks HGI, Wynne JM (1993) Child Abuse and Neglect. A Clinical Handbook. Churchill Livingston, Edinburgh.
31. Cramer EC (1996) Orthopedic aspects of child abuse. Orthop Clin North Am 43, 1035–1051.
32. Brogdon BG (1998) Forensic Radiology. CRC Press, Boca Raton, FL.
33. Hiss J, Kahana T (1995) The medicolegal implications of bilateral cranial fractures in infants. J Trauma 38, 1–5.
34. Reiber GD (1993) Fatal falls in childhood. How far must children fall to sustain fatal head injury? Report of cases and review of the literature. Am J Forensic Med Pathol 14, 201–207.
35. Blumenthal I (2002) Shaken baby syndrome. Postgrad Med J 78, 732–735.
36. Rubin DM, Christian CW, Bilaniuk LT, Zazyczny KA, Durbin DR (2003) Occult head injury in high-risk abused children. Pediatrics 211, 1382–1386.
37. Sato Y, Yuh WT, Smith WL, Alexander RC, Kao SC, Ellerbroek CJ (1989) Head injury in child abuse: Evaluation with MR imaging. Radiology 73, 653–657.
38. Mimkin K, Kleinman PK (1997) Imaging of child abuse. Pediatr Clin North Am 44, 615–635.
39. Willman KY, Bank DE, Senac M, Chadwick DL (1997) Restricting the time of injury in fatal inflicted head injuries. Child Abuse Neg 21, 929–940.
40. Jaspan T, Griffiths PD, McConachie NS, Punt JA (2003) Neuroimaging for non-accidental head injury in childhood: a proposed protocol. Clin Radiol 58, 44–53.
41. Demaerel P, Casteels I, Wilms G (2002) Cranial imaging in child abuse. Eur Radiol 12, 849–857.
42. Berlin L (1997) Malpractice issues in radiology. Storage and release of radiographs. Am J Radiol 168, 895–897.
43. Mason J K (1983) Forensic Medicine for Lawyers, 2nd ed. Butterworths, London.

XIV. DISCUSIÓN

XIV. DISCUSIÓN

La tecnología radiográfica es una herramienta eficaz en casi todas las fases de investigación medicolegal. Desde la determinación de la causa y mecanismo de la muerte, pasando por la necroidentificación en casos individuales y en desastres masivos, sin dejar de lado la estimación de la edad de individuos vivos y la documentación de traumatismos no accidentales.

14.1. El aporte de la radiografía a la necroscopia

El examen radiológico post mortem es común en la mayoría de las entidades forenses. Las técnicas radiográficas se utilizan en diversas fases de la investigación dependiendo de las circunstancias del caso que se investiga. Por lo general, las radiografías del cadáver se toman una vez finalizado el examen externo y antes de empezar la disección del cuerpo (Benbow y Roberts, 2003).

En casos de muerte natural, así como en investigaciones de posible mala praxis médica, el uso de varias técnicas radiográficas es la forma más adecuada de detectar fenómenos patológicos como embolias de aire o hemorragias (Knight, 1996). En casos en que el cadáver esta en avanzado estado de descomposición, o en casos de explosiones, se recomienda realizar un estudio radiográfico para visualizar mejor traumatismos y patologías (Knight, 1996).

En general, en todos los casos de traumatismo de bala se recomienda tomar radiografías, tanto cuando los proyectiles se encuentran dentro del cadáver como cuando se sospecha que han salido. El tipo del proyectil (de alta o baja velocidad) se puede deducir por las heridas detectadas en las radiografías, aunque no se debe tratar de determinar el calibre de la bala por su tamaño en la placa, pues el ángulo y distancia pueden distorsionar la imagen (Mason, 1983).

La presencia de "souvenirs" dentro del cadáver puede ser revelada por medio de la radiografía antes de la autopsia. La posición correcta de objetos dentro del cuerpo se puede visualizar mejor si se toman múltiples placas antero – posteriores y laterales (Davies et al., 2004).

El uso de radiografías es particularmente valioso en las autopsias de casos en los que se sospecha posible abuso infantil, puesto que las típicas fracturas de estos casos pueden no detectarse durante el examen visual (Thomsen, Elle y Thomsen, 1997). El examen radiográfico se suplementa con TAC y RMN, que resultan muy útiles para detectar hemorragias subdurales y hematomas epidurales (Merten y Carpenter, 1990).

14.2. Técnicas alternativas a la autopsia convencional

Durante la segunda mitad del siglo XX el número de autopsias practicadas en el mundo occidental declinó drásticamente, principalmente porque en algunas culturas y religiones, la práctica de la autopsia o toda actividad que comprometa la integridad del cadáver se considera tabú (Geller, 1984; Benbow y Roberts, 2003).

Tradicionalmente los médicos forenses rechazan autopsias parciales, aunque en algunos casos acceden a realizar limitar las incisiones para satisfacer las exigencias de los familiares del difunto y obtener al mismo tiempo evidencia medicolegal (Dorsey, 1984).

En la literatura científica se han sugerido diversas técnicas tanatológicas no invasivas. En los años 50s del siglo pasado, Terry (1955) propuso la toma de muestras cadavéricas por medio de técnicas citológicas. A esta propuesta le siguieron otras como la ultrasonografía (Pacheco Cuadros, Sendino Revuelta y Hernández Albújar, 2000) y las endoscopias post mortem (Avrahami et al., 1995).

A pesar de que la propuesta de la endoscopia como sustituto total o parcial a la autopsia no fue bien recibida por la comunidad científica (Taff y

Boglioli, 1996), algunos investigadores continúan defendiendo esta práctica por considerarla altamente fiable en la detección de patologías y traumatismos (Damore et al., 2000; Cacchione et al., 2001).

La sugerencia de los exámenes endoscópicos dio paso a la "virtopsia" o autopsia virtual, que consiste en un escaneo tomográfico de la totalidad del cadáver (Donchin et al., 1994; O'Donnell, et al., 2007; Rutty, 2007). Posteriormente, los exámenes de resonancia magnética (RMN) pasaron a ser parte integral de la virtopsia (Thali et al., 2003 a; Yen et al., 2007; O'Donnell y Woodford, 2008).

El uso de técnicas de imagen avanzadas como TAC y RMN no necesariamente sustituye a la autopsia, aunque son excelentes tecnicas auxiliares. Los estudios que comparan la fiabilidad de la evidencia obtenida por medio del estudio de imágenes con la derivada de la autopsia convencional, arrojan resultados positivos en cuanto al TAC (Roberts et al., 2003; Thali et al., 2003; Yen et al., 2007; Yamazaki et al., 2006). Los resultados de la RMN, que es superior a la hora de definir estructuras viscerales y delinear patologías, pueden verse afectados por la presencia de gases y metales en el cadáver (O'Donell et al., 2007; O'Donell y Woodford, 2008). A pesar de los avances en la tecnología de la RMN, que permiten realizar el examen de la totalidad del cadáver en menos de una hora, suele restringirse al análisis del tórax o del abdomen como complemento de la virtopsia (Hart, Dudley y Zumwalt, 1996; Bisset et al., 2003; Jackowski et al., 2006).

14.3. Necroidentificación radiográfica

Durante las primeras décadas del siglo XX, el uso de placas radiográficas dentro del campo de la necroidentificación se arraigó definitivamente. En la actualidad, esta técnica forma parte esencial del examen médico-legal de restos humanos en todos los aspectos de la investigación, pero sin duda ocupa un lugar cardinal en el campo de la identificación.

La necroidentificación forma parte de toda práctica medicolegal, en la que cadáveres y restos no identificados suelen conformar un promedio del 10% de todos los casos (Ranson, 2003). Actualmente no existen estadísticas concretas respecto al número de cadáveres no identificados dentro de la Unión Europea (Cattaneo et al, 2000). En Estados Unidos, diversos institutos de Medicina Legal reciben entre 70 y 100 cadáveres no identificados cada año (Anderson y Parks, 2008; Hinkes, 2008).

El estado de conservación de los restos a identificar varía de acuerdo a diversos factores tanatológicos, por la causa y mecanismo de la muerte o por actividad animal. El esqueleto, o algunos de sus componentes suelen resistir factores ambientales, mecánicos y físicos, por lo cual casi siempre puede realizarse algún tipo de comparación radiográfica. Puesto que la radiografía es una herramienta diagnostica común para una gran variedad de condiciones medicas y dentales, con frecuencia es posible obtener placas ante mortem para la identificación positiva (Fischman, 1985).

La pericia de identificación en Antropología y Odontología Forense suele realizarse por medio de la comparación de radiografías ante mortem, o sea, placas del individuo cuya identidad se sospecha, con radiografías post mortem, o sea, radiografías del cadáver (Murphy y Gantner, 1982). La identificación radiográfica es posible cuando existen indicios de la posible identidad de la victima; por lo general como resultado de la comparación del perfil antropológico (sexo, edad, estatura, y población) con informes policiales o militares de personas desaparecidas. La identificación positiva se obtiene cuando caracteres específicos detectados en el cadáver concuerdan con datos registrados durante la vida del individuo (Fischman, 1985).

El concepto de individualidad es único a las Ciencias Forenses, mientras que otras ciencias estudian exclusivamente las relaciones entre categorías, las Ciencias Forenses estudian lo que ocurre más allá de las características clasificatorias y se concentran en esas categorías. La principal hipótesis de las Ciencias Forenses es que los objetos o individuos poseen suficientes diferencias entre si de tal manera que, si se analizan adecuadamente, un objeto no puede confundirse uno con otro.

A diferencia de otras técnicas de identificación, en la comparación radiográfica no existe un número mínimo de rasgos concordantes para establecer la identidad. Algunos radiólogos sugieren que cuanto mayor sea el número de concordancias, mayor será el grado de certidumbre de la identificación (Mulligan et al., 1988). Los rasgos empleados en la identificación deben cumplir con dos requisitos (Taroni, Mangin y Perrior, 2000):

1. La expresión del rasgo debe ser única a cada individuo.
2. Debe permanecer invariable a lo largo del tiempo.

El aspecto fundamental en la investigación en este terreno radica más que todo en la calidad de los rasgos útiles para la identificación; es la experiencia del investigador la que determinará si existe evidencia suficiente que permita establecer la identidad (Acharya y Taylor, 2003).

Las radiografías del cráneo son una fuente importante de información ante mortem (Bass, 1989). En ellas quedan fielmente grabadas sus estructuras anatómicas, así como la evidencia de condiciones patológicas, traumas previos e intervenciones quirúrgicas. Las estructuras craneales y faciales visibles en los diferentes tipos de radiografías extraorales comúnmente utilizadas hoy en día, proporcionan numerosos detalles que pueden ser comparados con radiografías post mortem que muestren estas mismas estructuras. Los marcadores óseos más frecuentes son estructuras anatómicas como los senos maxilares y frontales, variaciones normales y la arquitectura trabecular (Mesmer y Fierro, 1986).

Los dientes contienen los tejidos humanos más duraderos y los materiales utilizados en restauraciones dentales son extremadamente resistentes a la destrucción de los elementos químicos y físicos. La base de la identificación dental son las innumerables combinaciones posibles de piezas dentales extraídas o ausentes congénitamente, caries, restauraciones y prótesis que cubren las superficies de la dentadura decidua y adulta, junto con la variación anatómica de las piezas dentales y de las estructuras óseas (Petju et al., 2007). En análisis de muchos individuos, como los que se realizan en los centros de alistamiento militar, se recomiendan radiografías panorámicas que permiten la visualización, con un alto grado de fiabilidad, de la mayoría de las estructuras y áreas anexas en una sola placa (Buchner, 1985).

Las principales características postcraneales útiles en la necroidentificación incluyen la variación anatómica normal de varias estructuras: la forma de los cuerpos vertebrales, la configuración de las apófisis espinosas y transversas de las vértebras, el tamaño y forma de las costillas y su mutua relación, la forma y tamaño de la apófisis xifoides o el dibujo trabecular y vascular en los coxales, manos y pies (Valenzuela, 1997; Van der Kraan y Van der Berg, 2007).

Igualmente, los cambios degenerativos resultan buenos indicadores para abordar la identificación, como pueden ser los osteofitos, picos de loro y aplastamientos de los cuerpos vertebrales, calcificación de los cartílagos costales, hernias discales, puentes óseos entre las vértebras, espículas óseas en los huesos pélvicos, presencia de cálculos y flebolitos. Asimismo, son útiles las evidencias de traumatismos curados, patología congénita (espina bífida) e intervenciones médicas que pueden dejar restos de materiales radiopacos empleados en exámenes clínicos (Kahana, Goldin y Hiss, 2002).

Numerosos estudios enfocados a examinar la validez forense de radiografias postcraneales, o sea su especificidad y estabilidad a lo largo del tiempo, concluyen que los rasgos individualizadores en radiografias postcraneales son fiables incluso cuando han transcurrido más de dos décadas entre radiografias ante y post mortem (Sauer, Brantley y Barondess, 1988).

La admisibilidad del testimonio de tipo científico en el ámbito judicial ha sido tema de discusión en la literatura forense. Con el fin de guiar jueces y miembros del jurado, los diversos países han creado doctrinas jurídicas a la hora de considerar asuntos relacionados con la ciencia. En 1993, a raíz de la sentencia de Daubert v Merrell Dow Pharmaceuticals Inc. en Estados Unidos, cambió radicalmente la perspectiva científica de la investigación en las Ciencias Forenses (Cecil, 2005).

En la época precedente al dictamen de Daubert, las guías de Frye solían ser el punto de referencia en cuanto a la admisibilidad de la evidencia científica. Estas guías indican que la técnica en la que se basa la evidencia debe estar fundada en principios o descubrimientos bien reconocidos. El método debe estar suficientemente establecido y tener aceptación general en el campo científico al que se refiere (Frye, 1923). Más tarde estos requisitos se ampliaron para incluir exigencias respecto a los conocimientos, habilidades, entrenamiento y educación del experto.

A raíz de la sentencia de Daubert, los científicos forenses han comenzado a poner un mayor hincapié en la validez científica de los métodos empleados en diversos aspectos de la identificación. Los requisitos de Daubert incluyen:

- El contenido de la pericia debe ser comprobado mediante el método científico.
- La técnica debe haber sido comprobada mediante la revisión de otros peritos en la materia, sobre todo a través de publicaciones científicas.
- Ajustarse a los estándares profesionales en cuanto a consistencia y fiabilidad del método, definiendo las posibles tasas de error del sistema.
- Aceptación del método por la comunidad científica relevante.

Investigadores en el campo de las Ciencias Forenses, principalmente de la Odontología, han intentado crear escalas de identificación basadas en a la calidad y cantidad de puntos concordantes en las radiografías (McKena, 1986; Borman y Grondahl, 1990; Zahrani, 2005).

Estudios de validación respecto al uso de la radiografía dental como herramienta de identificación, proponen investigar el efecto de algunas variables en la fiabilidad de la identificación. Los tratamientos terapéuticos realizados posteriormente a las radiografías ante mortem o periodos muy largos transcurridos entre las radiografías a comparar, pueden afectar la fiabilidad de la identificación (Kogon, McKay y MacLean, 1995), especialmente durante la fase de crecimiento y desarrollo dental (Borman y Grondhal, 1990).

Diversos estudios epidemiológicos analizan la frecuencia y distribución de tratamientos y patología dental en diversas poblaciones con el fin de cuantificar las posibles tasas de error al identificar al individuo por medio de caracteres dentales (Friedman, Cornwell y Lorton, 1989; Adams, 2003; Martínez Chicón, Luna del Castillo y Valenzuela, 2008).

La cuantificación de los métodos de identificación permite que se ajusten a los requisitos impuestos por la comunidad forense en base a las guías de Daubert (Daubert vs Merrell Dow Pharmaceuticals, INC.- 509 US 579, 1993).

La identificación del individuo depende de la similitud entre los caracteres comparados en las radiografías ante y post mortem. La influencia de las diferencias en la proyección geométrica del origen de los rayos X en las radiografías ante y post mortem afecta la visualización de los rasgos. Alteraciones en la dirección del haz de radiación o cambios en la posición del sujeto, cambian los valores de intensidad y por lo tanto la información radiográfica (McKenna, 1999), y afectan la toma de decisión en cuanto a la identificación del individuo (Fishman, 1985).

En un estudio piloto, realizado en La Universidad Hebrea de Jerusalén, sobre la fiabilidad de la identificación positiva basada en la arquitectura trabecular, se observó que existe una alta correlación en el patrón trabecular de radiografías del mismo individuo, independientemente de las condiciones radiográficas y del ángulo de proyección, siempre y cuando estas diferencias no sobrepasen estándares aceptables (Kahana, 1993).

La validez de la comparación entre radiografías ante y post mortem está claramente establecida en la práctica forense; comparaciones similares se pueden realizar entre placas radiográficas e imágenes de TAC con resultados igualmente fiables (Haglund y Fligner, 1993; Smith, Limbird, y Hoffman, 2002; Pfaeffli et al., 2007).

Dentro del campo de la Antropología Forense, se han empleado las imágenes aportadas por TAC y RMN tanto para la creación del perfil antropológico del individuo no identificado (Uysal, et al., 2005; Abdel Moneim et al., 2008; Akansel et al., 2008; Dedouit et al., 2008; Robinson et al., 2008; Veyre-Goulet et al., 2008; DiGangi et al., 2009) como para la comparación de caracteres (Pfaeffli et al., 2007).

La introducción de técnicas digitales dentro del campo de la Radiología facilita la manipulación de las imágenes. Aumentar el contraste, corregir el brillo, y segmentar la imagen son prácticas aceptables dentro del ámbito forense. Sin embargo, son inadmisibles manipulaciones que distorsionan las estructuras visibles en la radiografía que cambien sus relaciones angulares; así mismo debe evitarse el uso de utensilios de dibujo para retocar, acentuar y difuminar contornos (Du Chesne, Benthaus y Brinkmann, 1999; Richardson, Frank y Stern, 1999).

14.4. Técnicas radiológicas en Antropología y Patología Forense Clínica

Las técnicas radiográficas en el campo de la medicina forense clínica son especialmente útiles en la investigación del abuso del menor y en la estimación de la edad biológica.

En casos de abuso infantil, también denominado traumatismo no accidental, la radiografía juega un importante papel. Se calcula que cerca del 80% de los diagnósticos de abuso infantil se basan en técnicas radiograficas (Brown, 1995) en las que se detectan las fracturas típicas del abuso infantil: diafisarias, espirales-oblicuas, transversales y metafisarias (Hobbs, Hanks y Wynne, 1993). La presencia de múltiples fracturas de costillas en diversas fases de curación es otro indicio patológico del abuso infantil, detectable por medio de radiografías y TAC (Cramer, 1996), así como fracturas craneales múltiples, bilaterales o hundidas (Rubin et al., 2003).

Se recomienda el uso de TAC y RMN para detectar hemorragias intracraneales, típicas del síndrome del niño agitado (shaken baby syndrome)

(Merten y Carpenter, 1990). Sin embargo, no existe un consenso general en cuanto a la mejor técnica radiográfica para revelar traumatismos craneales asociados al abuso infantil. El TAC parece ser más apropiado para detectar hemorragias subaracnoideas mientras que la RMN es superior a la hora de demostrar conmociones, hemorragias extracerebrales subagudas y crónicas, al igual que heridas cerebrales profundas (Sato et al., 1989).

Otro de los campos forenses en los que las técnicas radiograficas juegan un papel primordial es el de la estimación de la edad de individuos vivos.

El desarrollo esquelético de los centros de osificación primarios y secundarios observados en radiografías de diversas zonas del cuerpo: mano, codo, tórax o rodilla es un excelente indicador del estadio de crecimiento del individuo (Greulich, 1960 a-b). La correlación entre la madurez esquelética y la edad cronológica ha sido estudiada extensivamente (Boechat y Lee, 2007; Schulz et al., 2008).

La estimación de la edad biológica se realiza bien por comparación del grado de desarrollo óseo en su totalidad con placas radiograficas determinadas como típicas de cierta edad, sistema conocido como "atlas" (Schmidt et al., 2008 a), o por asignación de un valor numérico a cada uno de los elementos óseos; cuya suma se compara con tablas preestablecidas de correlación entre puntuación y edad biológica (Schmidt et al., 2008 b).

La radiografía dental es fundamental en la estimación de la edad de individuos en crecimiento y adultos; su fiabilidad ha sido demostrada por un gran número de autores (Demirjian et al., 1973; Liversidge et al., 1999; Nyström et al., 2000; Mesotten et al., 2002; Gunst et al., 2003; Cameriere et al., 2006; Scmelling et al., 2008).

El estudio del desarrollo dental se basa en la observación del grado de calcificación de cada pieza dental (Teivens y Mörnstad, 2001; Knell et al., 2009) o en medidas tomadas sobre radiografías, ya sea de la longitud del diente en su totalidad, de la corona o de la raíz (Lilliequist y Lundberg, 1971; Mörnstad et al., 1995; Cameriere et al., 2006).

La estimación de la edad biológica en individuos que se encuentran en las ultimas fases de desarrollo se basa en el estudio de la epífisis medial de la clavicula ya sea por medio de su visualización en placas radiograficas (Schmeling et al., 2008), TAC (Schulz et al., 2008a), o por RMN (Schulz et al., 2008b).

14.5. Aplicación de la Radiología Forense a la investigación forense de desastres masivos

Una de las principales herramientas en la investigación forense de desastres masivos es la radiografía (Moody y Busuttil, 1994; Prieto et al., 2007), que resulta útil no solo para la identificación de las victimas sino en la evaluación inicial de los restos, el examen patológico y antropológico (Rutty et al., 2007; Blau, Robertson y Johnstone, 2008).

Con el fin de evitar errores, es recomendable utilizar mas de una técnica de identificación para cada cadáver en la identificación de victimas en grandes catástrofes, tales como accidentes de transporte público, explosiones, hundimiento de estructuras arquitectónicas o desastres naturales (Clark, 1986). Igualmente, no se recomienda la identificación de las victimas basada en el reconocimiento visual de familiares o amigos (Hiss y Kahana, 2000).

El examen rutinario y sistemático de la dentición como herramienta de identificación de víctimas de desastres masivos forma parte intrínseca de casi todos los protocolos de identificación (Byard, Cooke y Leditsche, 2006; Keiser, Laing y Herbison, 2006). La importancia del examen detallado de la dentición, incluyendo el registro radiográfico quedó claramente comprobado en el desastre natural el tsunami en el Océano Indico en el año 2004, en el cual el 46.2% de las 3750 víctimas en Tailandia fueron identificadas por medio de la comparación dental. En este caso, para aumentar la eficacia y seguridad del personal, se diseñó un aparato de radiografía portátil de fácil manejo y muy poca dispersión (James et al., 2005; Keiser et al., 2005; Petju et al., 2007).

Se han recomendado otras técnicas radiográficas como TAC y RMN para la fase de la evaluación inicial de restos humanos en grandes catástrofes (Blau, Robertson y Johnstone, 2008), y para la identificación de víctimas (Dedouit et al., 2007). Cabe resaltar que actualmente son pocas las unidades forenses que cuentan con este tipo de tecnologías.

XV. CONCLUSIONES

XV. CONCLUSIONES

Los avances de las diversas técnicas radiograficas a lo largo de los siglos XX y XXI han ejercido una gran influencia en la evolución del campo de la necroidentificación.

La investigación radiológica como parte del examen tanatológico es instrumental en una gran variedad de casos: accidentes de tráfico, traumatismos de bala e identificación del cadáver.

En Antropología y Odontología Forense el examen radiográfico juega un papel crucial en la identificación positiva de restos humanos. Algunas de las características que se comparan para la identificación incluyen huellas de intervención médica y variación anatómica.

La efectividad y utilidad de cualquier técnica de identificación depende de la rapidez con la que se puede obtener data ante mortem. En Israel, Estados Unidos y Reino Unido; países en los que no existen registros de huellas digitales de toda la población, un promedio del 10% de todos los casos medicolegales son individuos o restos cuya identidad se desconoce. De estos, durante la década de los 90, el 80% fueron identificados por medio de comparaciones radiográficas.

La identificación radiográfica depende de la similitud entre las placas ante y post mortem; por lo que es necesario replicar la posición del espécimen observado en la placa ante mortem, cuidando que el ángulo entre el objeto y la placa se asemeje lo más posible en la radiografía post mortem.

Uno de los rasgos radiográficos utilizados en la necroidentificación es el dibujo de las trabéculas en diversas unidades óseas.

A pesar de que estudios realizados en pacientes que sufren de osteoporosis demuestran que existen diferencias morfológicas en el patrón trabecular maxilar y mandibular, la arquitectura trabecular puede ser utilizada como indicador de identidad radiográfica en el esqueleto apendicular. No se debe emplear en la red trabecular de los cuerpos vertebrales, ya que está directamente influida por los procesos degenerativos.

No obstante, algunos de los cambios degenerativos de la columna vertebral son excelentes rasgos radiológicos, útiles para la identificación de cadáveres y restos humanos. En general, las radiografías de la columna vertebral contienen un gran número de características individualizadoras.

Las características vertebrales útiles para la necroidentificación incluyen condiciones tales como evidencia de traumatismos curados, procesos degenerativos e infecciosos, malformaciones congénitas y variaciones anatómicas normales de las estructuras vertebrales.

Los flebolitos pélvicos y suprapélvicos, reconocidos como procesos degenerativos normales, son también caracteres útiles para la necroidentificación. Los flebolitos suprapélvicos suelen producirse en ~2% de la población adulta, de aquí su utilidad forense.

Dada la alta frecuencia de los flebolitos pélvicos, no se recomienda basar la identificación exclusivamente en ellos, sino utilizarlos como rasgo adjunto a la evidencia.

La necroidentificación radiográfica realizada por medio de la comparación entre placas radiograficas post mortem e imágenes de TAC ante mortem, es un procedimiento valido dentro del ámbito forense. Estudios similares entre imágenes de TAC ante y post mortem son igualmente validos aunque menos factibles, puesto que no es fácil realizar estudios de TAC cadavéricos.

El uso de técnicas radiograficas como TAC y RMN es altamente ventajoso para detectar embolismos y traumatismos en casos de abuso de menores en los que se recomienda realizar un estudio radiológico de la totalidad del cuerpo.

Las ventajas de la endoscopia como técnica no invasiva que no altera la integridad del cadáver, hacen de la autopsia endoscópica, una alternativa eficaz a la autopsia convencional en casos en los que la familia del difunto, por razones religiosas o culturales, se niega a la realización de la necropsía.

El procedimiento endoscópico es extremadamente útil para obtener muestras de fluidos corporales y de tejidos.

La endoscopia post mortem es altamente eficaz para la determinación de hemorragias intracavitales, traumatismos viscerales, heridas de instrumento corto-punzantes en el tórax, cavidad peritoneal e intestino delgado.

A diferencia de la autopsia convencional, la evidencia obtenida por medio de la endoscopia no es suficiente para establecer la causa de la muerte, aunque si lo es para detectar lesiones abdominales, torácicas y sobre todo para descartarlas.

La autopsia endoscópica es menos útil a la hora de detectar traumatismos retroperitoneales y del mediastino posterior.

La identificación positiva es un asunto crucial en la gestión tanatológica de desastres masivos. El trabajo realizado durante la identificación de las victimas del ataque terrorista en AMIA, Buenos Aires, una serie de recomendaciones a seguir para garantizar un diagnostico veraz de la data y para obtener la identificación de las victimas.

Estas recomendaciones incluyen la creación inmediata de registros informáticos de la data antemortem que deben contener información antropológica, características fisonómicas, información médica, archivos radiográficos, datos dentales y números de diversos documentos de identidad.

En el campo de la identificación, resulta fundamental realizar un examen radiográfico de todos los restos humanos. Este examen no solo provee documentación del material recuperado, sino que es útil en la localización de traumatismos esqueléticos y en la localización de piezas dentales ocultas en los tejidos.

La aplicación de estas pautas aplicadas a la identificación radiográfica de restos humanos fragmentados es cardinal en la comparación de características vertebrales, como calcificación de ligamentos y de discos intervertebrales, así como de formaciones osteofíticas.

La íntima relación entre la Radiología y la Antropología Forense y su evolución conjunta, han dado lugar a la creación de un nuevo campo dentro de las disciplinas forenses: la Radiología Forense, que paulatinamente se ha llegado a se reconocer en la actualidad como disciplina independiente en el ámbito medicolegal.

XVI. CONCLUSIONS

XVI. CONCLUSIONS

The advances in various radiographic techniques throughout the 20th and 21st centuries have exercised a great influence in the evolution of necroidentification.

Radiological investigation as part of the thanatological examination is instrumental in a variety of cases: motor vehicular accidents, gun shot wounds and identification of the victims.

In Forensic Anthropology and Odontology, the radiographic exam plays a key role in the identification of human remains. Some of the characteristics compared for identification include signs of medical intervention and anatomic variation.

The effectiveness and usefulness value of any identification technique depends on the swiftness in which the ante mortem data can be obtained. In Israel, the United States and Great Britain; countries that have no fingerprints data banks for the whole population, ~10% of all medicolegal cases involve individuals of remains of unknown identity. During the decade of the 1990s, some 80% of these cases were identified by means of radiographic comparisons.

The radiographic comparison depends on the similarity between ante and post mortem plates thus, it is imperative to replicate the specimen's position as seen on the ante mortem radiograph, taking care of the correct angulation between the object and the plate while taking the post mortem radiograph.

One of the radiographic characters used in necroidentification is the trabecular pattern of various osseous elements.

Even though studies conducted on patients suffering from osteoporosis, show that there are morphological differences in the trabecular pattern of the maxilla and mandible, the trabecular architecture can be used as an indicator of radiographic identity in the appendicular skeleton. The trabecular mesh of vertebral bodies can't be used in this fashion, since it is directly affected by the degenerative processes.

Nonetheless, some of the degenerative changes of the vertebral column are excellent radiological characters, useful for identification of cadavers and human remains. In general, radiographs of the vertebral column contain a great number of individualizing characteristics.

The vertebral characteristics useful for necroidentification include signs of healed trauma, degenerative processes, congenital malformations, and normal anatomic variations of the vertebral structures.

Pelvic and suprapelvic phlebolithes, known as normal degenerative processes, are also useful characters for identification. Suprapelvic phlebolites tend to occur in ~2% of the adult population, hence their high forensic value.

Given the high frequency of pelvic phlebolites, it is not recommended to base the identifications exclusively on their presence, but to use them as an indicator that requires more evidence.

Radiographic identification based on the comparison between post mortem radiographic plates and ante mortem CT images is a valid forensic procedure. Similar comparisons between ante and post mortem CT images are equally valid, although less feasible due to the difficulties of performing post mortem CT.

The use of radiographic techniques like CT and MRI is highly advantageous in detecting air embolisms as well as in child abuse injuries. In these instances a total body radiographic study is recommended.

The advantages of endoscopies as a non invasive technique that preserves the integrity of the cadaver make the endoscopic autopsy an efficient alternative to conventional autopsy. In cases in which the next of kin of the deceased refuse to give their permission to perform an autopsy, because of cultural and religious reasons, this technique can be useful.

The post mortem endoscopic procedure is very useful in sampling body fluids and tissues.

Endoscopic autopsy was found to be highly sensitive in the detection of intracavity hemorrhages, visceral injury, penetrating wounds to the thorax and peritoneal cavity, as well as tears in the small bowel.

As opposed to conventional autopsy, the evidence obtained by endoscopy is not enough to establish the cause of death, although it is possible to detect abdominal and thoracic lesions, and especially to discard their presence.

The endoscopic autopsy is less useful in detecting retroperitoneal and posterior mediastinum injuries.

The positive identification is a key issue in the thanatological investigation of mass disasters. The measures taken during the identification of the victims of the terrorist attack in AMIA, Buenos Aires, resulted in a series of recommendations to guaranty the efficient collection of data and the correct identification of the victims.

These recommendations include the creation of a computerized ante mortem databank which should include information on anthropological characteristics, physiognomy, medical information, radiographic archives, dental data, and all identity numbers.

In the area of forensic identification, it is essential to conduct a radiographic examination on all human remains. This examination provides not only documentation of the collected remains, but it is useful in localizing fragments of the dentition embedded in the soft tissues.

The implementation of these recommendations to the radiographic identification of fragmentary human remains is vital in the comparison of vertebral characteristics, like ligament and intervertebral disks calcifications, as well as osteophites.

The close relationship between Radiology and Forensic Anthropology and their joined evolution have set in motion the creation of a new discipline within Forensic Sciences: Forensic Radiology, which gradually is being recognized as an independent field within the medicolegal realm.

XVII. RESUMEN

XVII. RESUMEN

La radiografía es una de las herramientas principales en la investigación medicolegal, tanto en la Tanatología como en la Medicina Forense Clínica y en la Antropología Forense.

En esta tesis se recopilan una serie de artículos que representan los cambios en la perspectiva científica de la Medicina y la Antropología Forense en relación a las técnicas radiograficas, ajustándose a nuevos requerimientos jurídicos, a la magnitud de las grandes catástrofes de los siglos XX y XXI y a los avances tecnológicos del mundo moderno.

Dentro del contexto de la Medicina Legal, la radiografía necroscópica juega un papel primordial en casi todos los tipos de casos: muerte natural, traumatismos, abuso infantil, explosiones y cadáveres en avanzado estado de descomposición. Los usos de las diversas técnicas radiograficas se presentan en una serie de reseñas publicadas en la literatura forense y radiográfica.

El uso de la laparoscopia como técnica alternativa a la autopsia convencional se propone en un artículo publicado en 1995 por el equipo de investigación del Centro Nacional de Medicina Legal de Israel.

La contribución de la radiografía a la Medicina y a la Antropología Forenses en los campos de la estimación de la edad de individuos indocumentados y de la investigación de casos de abuso infantil se resume en un artículo publicado en 2005.

En el campo de la necroidentificación, el aporte de la radiografía es fundamental. El uso de radiografías craneales y postcraneales, así como de diversas técnicas radiograficas, se discute en artículos que presentan varios caracteres radiográficos, como el patrón trabecular, huellas de intervención médica y cambios degenerativos del esqueleto axial.

La inclusión de técnicas radiográficas en los protocolos de identificación de grandes catástrofes, se recapitula en un artículo que refleja la experiencia de patólogos, antropólogos y radiólogos forenses en una explosión terrorista. El uso de radiografías de restos humanos fragmentados para la identificación positiva de víctimas se describe en detalle dentro de la secuencia de operaciones necesarias para la recogida eficiente de información antemortem.

XVIII. SUMMARY

XVIII. SUMMARY

Radiography is one of the most important tools in the medicolegal investigation, not only in thanatologic cases, but in Clinical Forensic Medicine and Forensic Anthropology.

This thesis compiles a series of articles that represent the changes in the scientific perspective of Forensic Medicine and Anthropology as it relates to radiographic techniques, in its adjustment to the new legal requirements, to the magnitude of the big catastrophes of the 20th and 21st centuries, and to the technological advances of the modern world.

Within the context of Legal Medicine, necroscopic radiography plays a key role in almost all types of cases: natural death, blunt injury, child abuse, explosions and decomposed bodies. The uses of the diverse radiographic techniques are presented in a series of reviews published in the forensic and radiological literature.

The use of laparoscopy as an alternative technique to conventional autopsy is suggested in an article that was published in 1995 by the investigation team of the National Centre of Forensic Medicine of Israel.

The contribution of radiology to Forensic Medicine and Anthropology in the area of age estimation on undocumented persons and in the investigation of child abuse is summarized in an article published in 2005.

In the area of necroidentification, the contribution of Radiology is fundamental. The use of cranial and post cranial radiographs, as well as various radiographic techniques is discussed in articles that present various roentgenographic characteristics, like the trabecular pattern, signs of medical intervention and degenerative changes of the axial skeleton.

The inclusion of radiographic techniques in the identification protocols of great catastrophes is recounted in an article that reflects the experience of forensic pathologists, anthropologists and radiologists in a terrorist explosion. The use of radiography of human remains for the positive identification of victims is described in detail within the sequence of operations necessary for efficiently collecting antemortem information.

XIX. BIBLIOGRAFÍA

XIX. BIBLIOGRAFÍA

Abdel Moneim, W.M., Abdel Hady, R.H., Abdel Maaboud, R.M. et al. (2008). Identification of sex depending on radiological examination of foot and patella. *Am J Forensic Med Pathol.* 29:136-140.

Acharya, A.B. y Taylor, J.A. (2003). Are a minimum number of concordant matches needed to establish identity in forensic odontology? *J Forensic Odontostomatol.* 21:6-13.

Adams, B.J. (2003). Establishing personal identification based on specific patterns of missing, filled, and unrestored teeth. *J Forensic Sci.* 48:487-496.

Akansel, G., Nagihan, I., Kurtas, O. et al. (2008). Gender and the lateral angle of the internal acoustic canal meatus as measured on computerized tomography of the temporal bone. *Forensic Sci Int.* 178:93-95.

Almog, J. y Springer, E. (1995). Proceedings of the International Symposium on fingerprint detection and identification. June 26-30, 1995. Oxford University Press.

Amoëdeo, O. (1898). L'Art dentaire en médicine légale. Paris. Editeurs libraries de l'académie de médecine.

Anderson, B. y Parks, B.O. (2008). Symposium on border crossing deaths: Introduction. *J Forensic Sci*. 53:6-7.

Arensburg, B. (1989). Methods for age identification of living individuals of uncertain age. *Can Soc Forensic Sci J.* 22:147-157.

Atkins, L. y Potsaid, M.S. (1978). Roentgenographic identification of human remains. *J Am Med Asso*. 240:2307-2308.

Aufderheide, A.C. y Rodriguez-Martín, C. (2005). Degenerative disease of the spine. En: *The Cambridge encyclopedia of human paleopathology*. Cambridge, Cambridge University Press. Pp 96-97.

Avrahami, R., Watember, G. Daniels-Philips, E. et al. (1995). Endoscopic Autopsy. *Am J Forensic Med Pathol.* 16:147-150.

Bass, W. (1989). A review of studies on certain forensic aspects of skull identification and individualization. *J Forensic Sci.* 34:360-361.

Beale, D.R. (1991). The importance of dental records for identification. *NZ Dent J.* 87:84-87.

Benbow, E.W. y Roberts, I.S.D. (2003). The autopsy: Complete or not complete? *Histopathology*. 42:417-423.

Bisset, R.A., Thomas, N.B., Turnbull, I.W., et al. (2003). Postmortem examinations using magnetic resonance imaging: four year review of a working service. *BMJ*. 324:1423-1424.

Blanshan, S. (1977). Disaster body handling. *Mass Emerg*. 2:249-258.

Blanshan, S. y Quarentelli, E.L. (1981). From dead body to person: The handling of fatal mass casualties in disaster. *Victimology*. 6:275-287.

Blau, S., Robertson, S y Johnstone, M. (2008). Disaster victim identification: new applications for postmortem computed tomography. *J Forensic Sci.* 53:956-961.

Boechat, M.I. y Lee, D.C. (2007). Graphic representation of skeletal maturity representations. *Am J Roentgenol*. 189:873-874.

Bordas, T. (1896). Medico-legal uses of the roentgen rays. *J Am Med Assoc (JAMA).* 26:1084.

Borman, H. Y Grondhal, H.G. (1990). Accuracy in establishing identity by means of intra-oral radiographs. *J Forensic Odontostomatol.* 8:31-36.

Bosmans N., Medhat. A.P.A y Willems, G. (2005). The application of Kvaal's dental age calculation technique on panoramic dental radiographs. *Forensic Sci Int*. 153:208-212.

Borman L., Solheim, T., Magnuson, B. et al. (1995). Inter-examiner variation in the assessment of age related factors in teeth. *Int J Legal Med*. 107:183-186.

Buchner, A. (1985). The identification of human remains. *Int Dent J*. 35:307-311.

Brogdon, B.G. (1998). Radiological identification of individual remains. En: Brogdon, B.G. *Forensic radiology*. Boca Raton, CRC Press. Pp 149- 187.

Brogdon, B.G. y Lichtenstein, (1998). Forensic radiology in historical perspective. En: Brogdon, B.G. *Forensic radiology*. Boca Raton, CRC Press. Pp 13-34.

Brown, T. (1995). Radiography's role in detecting child abuse. *Radiol Technol.* 66:389-390.

Bushberg, J.T., Seibert, J.A., Leidholdt, E. et al. (2003). Film processing. En: *The essential physics of medical imaging.* Philadelphia. Lippincott Williams. Pp. 175-186.

Byard, R.W., Cooke, C. y Leditsche, J. (2006). Practical issues involed in setting up temporay mortuaries. *For Sci Med Pathol.* 2:1-59.

Cacchione, R.N., Sayad, P. Pecoraro, Jr. A. M., et al. (2001). Laparoscopic Autopsies. *Surg Endosc.* 15:619-622.

Cameriere, R., Ferrante, L., Mirtella, D. et al. (2005). Frontal sinuses for identification: quality of classifications, possible error and potential corrections. *J Forensic Sci*. 50:770-773.

Cameriere, R., Brogi, G. Ferrante, L. et al. (2006). Reliability in age determination by pulp/ratio in upper canines in skeletal remains. *J Forensic Sci*. 51:861-864.

Cameriere, R. Ferrante, L. Liversidge, HM. et al. (2008a). Accuracy of age estimation in children using radiograph of developing teeth. *Forensic Sci Int*. 176:173-177.

Cameriere, R., Ferrante, L., Molleson, T. et al. (2008b). Frontal sinus accuracy in identification as meassured by false positives in kin groups. *J Forensic Sci.* 53:1289-1282.

Campobasso, C.P., Dell'erba, A.S., Belviso, et al. (2007). Craniofacial identification by comparison of antemortem and postmortem radiographs: two case reports dealing with burnt bodies. *Am J Forensic Med Pathol.* 27:182-186.

Cattaneo, C., Ritz-Timme, S., Schutz, H.W. et al. (2000). Unidentified cadavers and human remains in the EU: An unknown issue. *The Newsletter of the International Academy of Legal Medicine.* 113:N2-N3.

Cecil, J.S. (2005). Ten years of judicial gatekeeping under Daubert. *Am J Public Health*. 95 (suppl 1):74-80.

Chaillet, N., Willens, G. y Demirjian, A. (2004). Dental maturity in Belgian children using Demirjian's method and polynomial functions: new standard curves for forensic and clinical use. *J Forensic Odontostomatol*. 22:18-27.

Christensen, A.M. (2004). The impact of Daubert: Implications of testimony and research in forensic anthropology (and the use of frontal sinuses in personal identification). *J Forensic Sci*. 49:427-430.

Clark, D.H. (1986). Dental identification problems in the Abu Dhabi air accident. *Am J Forensic Med Pathol.* 7:317-321.

Cramer, E.C. (1996). Orthopedic aspects of child abuse. *Orthop Clin North Am.* 43:1035-1051.

Cox, J. y Kirkpatric, R.C. (1896). The new photography with report of a case in which a bullet was photographed in the leg. *Montreal Med J*. 24:661-665.

Culbert W.F. y Law F.M. (1927). Identification by comparison of roentgenograms of nasal accessory sinuses and mastoid processes. *J Am Med Assoc.* 4:1634-1636.

Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579 (1993).

Da Silva, R.F., Prado, F.B., Caputo, I.G. et al. (2009). The importance of frontal sinus radiographs. *J Forensic Leg Med*. 16:18-23.

Dailey, J.C. (1991). The identification of fragmented Vietnam War remains utilizing a healing extraction site. *J Forensic Sci.* 36:264-271.

Damore, L.J., Barth, R.F., Morrison C.D. et al. (2000). Laparoscopic postmortem examination: A minimally invasive approach to the autopsy. *Ann Diagn Pathol.* 4:95-98.

Davies, G.J. y Peterson, B.R. (1996). Dilemas and solutions for the pathologist and clinician encountering religious views of the autopsy. *South Med J.* 89:1041-1044.

Davis N.L., Kahana, T. y Hiss, J. (2004). Souvenir knife: A retained transcranial knife blade. *Am J Forensic Med Pathol*. 25:259-61.

Deduit, F., Bindel, S., Gainza, D. et al. (2008). Application of the Iscan method to two- and three-dimensional imaging of the sternal end of the right fourth rib. *J Forensic Sci*. 53:288-295.

Dedouit, F., Telmon, N., Costagliola, R. et al. (2007). New identification possibilities with postmortem multislice computer tomography. *Int J Legal Med.* 121:507-510.

Demirjan, A., Goldstein, H. y Tanner, J.M. (1973). A new system of dental assessment. *Hum Biol*. 45:211-227.

De Vore, D. (1977). Radiology and photography in forensic dentistry. *Dent Clin North Am*. 21:69-83.

DiGangi, E.A., Bethard, J.D., Kimmerle, E.H. et al. (2009). A new method for estimating age-at-death from the first rib. *Am J Phys Anthropol*. 138:164-176.

Donchin, Y., Rivkind, A., Bar Ziv, J. et al. (1994). Utility of post mortem computed tomography in trauma victims. *J Trauma*. 37:552-555.

Dorsey, D.B. (1984). Limited autopsies: defined benefits, limited costs. *Arch Pathol Lab Med.* 108:469-472.

Du Chesne, A., Benthaus, S. y Brinkmann, B. (1999). Manipulated radiographic material – capability and risk for the forensic consultant? *Int J Legal Med.* 112:329-332.

Dunn, S.M. y Kantor, M.L. (1993). Digital radiology, facts and fictions. *J Am Dent Assoc.* 124:39-47.

Dutra, F.R. (1944). Identification of a person and determination of cause of death from skeletal remains. *Arc Path.* 38:339-349.

Erzinclioglu, Z. (2000). True crime scene investigations. UK. Carlton Books. Pp 6-11.

Evans, K.T., Knight, B. y Whittaker, D.K. (1981). *Forensic Radiology*. Oxford. Blackwell Scientific Publications.

Fariña Gonzales, J. (1998). Ultrasonographic autopsy: A minimally invasive postmortem technique. *An R Acad Nac Med (Madr).* 115:703-716.

Fellingham, S.A., Kotze, T.J., Nash, J.M. (1984). Probabilities of dental characteristics. *J Forensic Odontostomatol*. 2:45-52.

Fishman, S.L. (1985). The use of medical and dental radiographs in identification. *Int Dent J.* 35:301-306.

Friedman, R.B., Cornwell, K.A. y Lorton, L. (1989). Dental characteristics of a large military population useful for identification. *J Forensic Sci*. 34:1357-1364.

Friedrich, R.E., Schulz, F. Y Scheuer, H.A. (2005). Pneumatic spaces of the zygomatic arch (zygomatic air cell defect) on pantograms – an aid for age determination and identification. *Arch Kriminol.* 215:151-157.

Frye v. United States. 54 App.D.C.46, 293 F 1013. 1923.

Geller, S.A. (1984). Religious attitudes and the autopsy. *Arch Path Lab Med.* 108:494-496.

Gill, J.R. (2006). 9/11 and the New York City office of chief medical examiner. *Forensic Sci Med Pathol*. 2:1-29.

Gleiser, I. y Hunt, E.E.J. (1955). The permanent mandibular first molar: its calcification, eruption and decay. *Am J Phys Anthropol*. 13:253-283.

Goodman, P.C. (1995). The new light: discovery and and introduction of the x-ray. *Am J Roentgenol*. 165:1041-1045.

Greulich, W.W. (1960a). Skeletal features featured visible on roentgenigrams of the hand and wrist which can be used for establishing individual identification. *Am J Roent*. 83:756-764.

Greulich, W.W. (1960b). Value of x-ray films of hand and wrist in human identification. *Science*. 131:155-156.

Graham, D.T. y Cloke, P. (2007). Princilples of radiologic physics. 5th ed. Edinburgh. UK. Churchil Livingston. Pp. 8-20.

Gunst, K., Mesotten, K., Carbonez, A. et al. (2003). Third molar root development in relation to chronological age: a large sample sized retrospective study. *Forensic Sci Int*. 136:52-57.

Haavikko, K. (1974). Tooth formation age estimated on a few selected teeth. A simple method for clinical use. *Proc Fin Dent Asoc*. 70:15-19.

Haglund, W.D. y Fligner, C.L. (1993). Confirmation of human identification using computerized tomography (CT). *J Forensic Sci*. 38:708-712.

Harris, A.M.P., Wood, R.E., Nortje, C.J. et al. (1987). The frontal sinus: Forensic fingerprint? – A pilot study. *J Forensic Odontostomatol*. 5:9-15.

Hart, B.L., Dudley, M.H. y Zunwalt, R.E. (1996). Postmortem cranial MRI and autopsy correlation in suspected child abuse. *Am J Forensic Med Pathol.* 17:217-224.

Happonen, R.P., Laaksonen, H., Wallin, A. et al. (1991). Use of orthopantographs in forensic identification. *Am J Forensic Med Pathol* 12:59-63.

Hill, I.R. (1989). Forensic Odontology – Are points of correspondence viable? *J Forensic Odontostomatol*. 7:17-18.

Hines, E., Rock, C. y Viner, M. (2006). Radiography. En: Thompson, T y Black, S. (eds). *Forensic human identification*. Boca Raton, CRC Press. Pp 221-228.

Hinkes, M. (2008). Migrant deaths along the California – Mexico border: An anthropologic perspective. *J Forensic Sci*. 53:16-20.

Hiss, J. y Kahana, T. (2000). Trauma and identification of victims of suicidal terrorism in Israel. *Military Med*. 165:889-893.

Hobbs, C.J., Hanks, H.G.I. y Wynne, J.M. (1993). Child abuse and neglect. A clinical handbook. Edinbrough, Churchil-Livingston. Pp 47-76.

Howerton, W.B. y Mora, M.A.M. (2008). Advancements in digital imaging. What is new and on the horizon? *J Am Med Assoc. (JADA).* 129: 205 – 245.

Hyma, B.A. y Rao, V.J. (1991). Evaluation and identification of dismembered human remains. *Am J Forensic Med Pathol*. 12:291-299.

INTERPOL (2009). Disaster victim identification guide. http://www.interpol.int/Public/DisasterVictim/guide/default.asp

Jackowski, C., Chrise, A., Sonnenschein, M., et al. (2006). Postmortem unenhanced magnetic resonance imaging of myocardial infarction in correlation to histological infarction age characterization. *Eur Heart J.* 27:2459-2467.

James, H.E., Keiser, J.A., Laing, W. et al. (2005). Thai Tsunami victim identification – overview to date. (June 2005) *J Forensic Odontostomatology*. 23: 1-18.

Jordan, F.B. (1999). The role of the medical examiner in mass casualty situations with special reference to the Alfred P. Murrah building bombing. *J Okla State Med Assoc*. 92:159-163.

Kade, H., Meyers, H., Wahlke, J.E. (1967). Identification of skeletonized remains by x-ray comparison. *J Criminal Law.* 58:261-264.

Kahana, T. (1993). The effect of radiographic conditions on the reliability of trabecular bone pattern as marker on radiographs for positive identification purposes. Presentado en la *American Academy of Forensic Sciences. Boston, USA.*

Kahana, T. y Hiss, J. (1994). Positive Identification by means of trabecular bone pattern comparison. *J Forensic Sci.* 39:1325-1330.

Kahana, T. y Hiss, J. (1997). Identification of human remains: Forensic radiology. *J Clin Forensic Med*. 4:7-15

Kahana, T., Freund, M. y Hiss, J. (1997). Suicidal terrorist bombings in Israel - Identification of human remains. *J Forensic Sci*. 42:259-263.

Kahana, T., Ravioli J.A., Urruz, C.L. et al. (1997). Radiographic identification of fragmentary human remains from mass disaster. *Am J Forensic Med Pathol.* 18:40-44.

Kahana, T., Hiss, J. y Smith, P. (1998). Quantitative assessment of trabecular bone pattern identification. *J Forensic Sci.* 43:1144-1147.

Kahana, T. y Hiss, J. (1999). Forensic radiology. *Br J Radiol.* 72:129-133.

Kahana, T., Goldin, L. y Hiss, J (2002). Personal identification based on radiographic vertebral features. *Am J Forensic Med Pathol.* 23:36-41.

Kahana, T. y Hiss, J. (2002a). Suprapelvic and pelvic phleboliths – a reliable radiographic marker for positive identification. *J Clin Forensic Med.* 9:119-122.

Kahana, T. y Hiss, J. (2002b). Forensic odontology in Israel. *Alpha Omegan*. 95:47-48.

Kahana, T., Goldstein, S., Kugel, C. et al. (2002). Identification of human remains through comparison of computerized tomography and radiographic plates. *J Forensic Identification.* 52:151-158.

Kassiker, J.P. y Cecil, J.S. (2002). Inconsistencies in evidentiary standards for medical testimony: Disorder in the Courts. *JAMA*. 288:1382-1383.

Keiser, J.A., Laing, W. y Herbison, P. (2005). Lessons learned from large-scale comparative dental analysis following the South Asian Tsunami of 2004. *J Forensic Sci*. 51:109-112.

Keiser-Nielsen, S. (1977). Dental identification: Certainty vs probability. *Forensic Sci*. 9:87-97.

Kirk, N.J., Wood, R.E. y Goldstein, M. (2002). Skeletal identification using the frontal sinus region: a retrospective study of 39 cases. *J Forensic Sci.* 47:318-323.

Kirchoff, S., Fischer, F., Lindemaier, G. et al. (2008). Is post-mortem CT of the dentition adequate for correct forensic identification? Comparison of dental computed tomography and visual dental record. *Int J Legal Med*. 122:471-479.

Knell, B., Ruhstaller, P., Prieels, F. et al. (2009). Dental age diagnostic by means of radiographical evaluation of the growth stages of lower wisdom teeth. *Int J Legal Med.* IN PRESS

Knight, B. (1996). Forensic pathology, 2da edición. London, Arnold. Pp 31-32.

Kogon, S.L., McKay, A.E., y MacLean, D.F. (1995). The validity of bite-wings radiographs for the dental identification of children. *J Forensic Sci*. 40:1055-1057.

Koç, A, Karaaslan, O. y Koç, T. (2004). Mastoid air cell system. *Otoscope*. 4:144-154.

Kolltveit, K.M., Solheim, T. y Kvaal, S.I. (1998). Methods of measuring morphological parameters in dental radiographs – comparison between image analysis and manual measurements. *Forensic Sci Int*. 94:87-95.

Koot, M.G., Sauer, N.J., y Fenton, T.W. (2005). Radiographic human identification using bones of the hand: a validation study. *J Forensic Sci.* 50:263-268.

Kuehn, C.M., Taylor, K.M., Mann, F.A. et al. (2002). Validation of chest x-ray comparison for unknown decedent identification. *J Forensic Sci.* 47:725-729.

Kullman, L., Eklund, B. y Grunding, R. (1990). The value of frontal sinus identification of unknown persons. *J. Forensic Odontostomatol*. 8:3-10.

Kvaal, S.I. (2006). Collection of post mortem data: DVI protocols and quality assurance. *Forensic Sci Int.* 159S:12-14.

Lee, S.S., Coi, J.H., Yoon, C.L. et al. (2004). The diversity of dental patterns in the orthopantomography and its significance in human identification. *J Forensic Sci.* 49:784-786.

Lichtenstein, J.E., Madewell, J.E., McMeekin, R.R. et al. (1980). Role of radiology in aviation accident investigation. *Aviat Space Environ Med*. 51:1004-1014.

Liliequist, B. y Lundberg, M. (1971). Skeletal and tooth development. A methodological investigation. *Acta Radiol*. 11:97-112.

Liversidge, H.M., Speechly, T. y Hector, M.P. (1999). Dental maturation in British children: are Dermijian's standards applicable? *Int J Paedriatr Dent*. 9:263-269.

Mann, R.W. (1998). Use of bone trabeculae to establish positive identification. *Forensic Sci Int.* 98:91-99.

Martin, D.C., Clark, M.A. y Standish, M. (1991). Identification of human remains by comparison of frontal sinus radiographs: a series of four cases. *J Forensic Sci.* 36:1765-1772.

Martínez Chicón, J., Luna del Castillo, J.D. y Valenzuela Garach, A. (2008). La variabilidad de los tratamientos dentales en una población militar española y su importancia para la estimación de la probabilidad de identificación dental. *Cuad Med Forense.* 14:223-233.

Martel, W., Wicks, J.D. y Hendrix, R.C. (1977). The accuracy of radiologic identification of humans using skeletal landmarks: A contribution to forensic pathology. *Radiol*. 124:681-684.

Mason, J.K. (1983). Radiology in forensic medicine. En: Forensic medicine for lawyers. (2nd ed). London, Butterworths. Pp 285-290.

McKenna, C. (1999). Radiography in forensic dental identification – a review. J Forensic Odontostomatol. 17:47-53.

McKenna, J.J.I. (1986). A qualitative and quantitative analysis of the anterior dentition visible in photographs and its application to forensic odontologists. Tesis submitida para el grado de Magisterio, Facultad de Medicina, Universidad de Hong Kong.

Merten, D.F. y Carpenter, B.L.M. (1990). Radiologic imaging of inflicted injury in the child abuse syndrome. *Orthoped Clin North Am.* 37:815-837.

Mertz, C.A. (1977). Dental identification. *Dent Clinics North Am*. 21:47 – 67.

Mesmer, J.M. y Fierro, M.F. (1986). Personal identification by radiographic comparison of vascular groove patterns in the calvarium. *Am J Forensic Med Pathol.* 7:159-162.

Mesotten, K., Gunst, K., Carbonez, A. et al. (2002). Dental age estimation and third molars: a preliminary study. *Forensic Sci Int*. 129:110-115.

Moody, G.H. y Busuttil, A. (1994). Identification of the Lockerbie air disaster. *Am J Forensic Med Pathol.* 15:63-69.

Mörnstad, H., Reventlid, M. Y Teivens, A. (1995). The validity of four methods for age determination by teeth in Swedish children: A multicentre study. *Swedish Dent J*. 19:121-130.

Moser, R.P y Wagner, G.N. (1990). Nutrient groove of the illium, a subtle but important forensic radiographic maker in the identification of victims of severe trauma. *Skeletal Radiol.* 19:15-19.

Mulligan, M.E., McCarthy, M.J., Wippold, F.J. et al. (1988). Radiologic evaluation of mass casualty victims: Lessons from the Gander, Newfoundland, accident. *Radiology*. 168:229-233.

Murphy, W.A y Gantner, G.E. (1982). Radiologic examination of anatomic parts and skeletonized remains. *J Forensic Sci*. 27:918.

Nambiar, P., Naidu, M.D. y Subramaniam, K. (1999). Anatomical variability of the frontal sinuses and their application in forensic identification. *Clin Anat*. 12:16-19.

Nortje, C.J. y Harris, A.M. (1986). Maxillo-facial radiology in Forensic Dentistry: A review. *J Forensic Odontostomatol*. 4:29-38.

Nyström, M., Aine, L., Peck, L. et al. (2000). Dental maturity in Danes and the problem of missing teeth. *Acta Odontol Scand*. 58:49-56.

O'Donnell, C., Rotman, A., Collet, S., et al. (2007). Current status of routine post-mortem CT in Melbourne, Australia. *Forensic Sci Med Pathol*. 3:226-232.

O'Donnell, C. y Woodford, N. (2008). Post-mortem radiology – a new sub-speciality? *Clin Radiol.* 63:1189-1194.

Ortner D.J. y Putschar, W.G.J. (1985). The biology of skeletal tissues. En: *Identification of pathological conditions in human skeletal remains.* Washington, Smithsonian Institution Press. Pp 8-26.

Owsley, D.W., Mann, R.W., Chapman, R.E. t al. (1993). Positive identification in a case of intentional extreme fragmentation. *J Forensic Sci.* 38:985-996.

Pacheco Cuadros, R., Sendina Revuelta, A y Hernández Albújar, S. (2000). Autopsia ultrasónica o ecoscopia. *An Med Interna.* 17: 457-459.

Petju, M., Suteerayongpraset, A., Thongpud, R. et al. (2007). Importance of dental records for victim identification following the Indian Ocean tsunami disaster in Thailand. *Public Health*. 121:251-257.

Pfaeffli, M., Vock, P., Dirnhofer, R. et al. (2007). Post-mortem radiological CT identification based on classical ante-mortem X-ray examinations. *Forensic Sci Int.* 171:111-117.

Phillips, V.M. y Scheepers,C.F. (1990). A comparison between fingerprint and dental concordant characteristics. *J Forensic Odontostomatol*. 8:17-19.

Prieto, J.L., Tortosa, C., Bedate, A. Et al. (2007). The 11 March 2004 Madrid terrorist attacks: the importance of the mortuary organization for identification of victims. A critical review. *Int J Legal Med*. 121:517-522.

Quatrehomme, G., Fronty, P., Sapanet, M. et al. (1996). Identification by frontal sinus pattern in forensic anthropology. *Forensic Sci Int*. 83:147-153.

Raino, L., Lalu K., Ranta H. et al. (2001). Radiology in forensic expert team operations. *Leg Med (Tokyo).* 3:34-43.

Ranson, D. (2003). Death investigation. En: Payne-James, J., Busutil, A. Y Smock, W. *Forensic medicine*. London. Greenwich Medical. Pp 13-26.

Rhine, S. y Sperry, K. (1991). Radiographic comparison of mastoid sinus and arterial pattern. *J Forensic Sci*. 36:272-279.

Richardson, M.L., Frank, M.S. y Stern, E.J. (1999). Digital image manipulation: what constitutes acceptable alteration of a radiologic image? *Am J Roentgenol.* 164:228-229.

Ritz-Timme. S., Cattaneo, C., Collins, M.J. et al. (2000). Age estimation: The state of the art in relation to the specific demands of forensic practice. *Int J Legal Med.* 112:129-136.

Roberts, I.S., Benbow, E.W., Bisset, R., et al. (2003). Accuracy of magnetic resonance imaging in determining cause of death in adults: comparison with conventional autopsy. *Histopathology*. 42:424-430.

Robinson, C., Eisma, R., Morgan, B. et al. (2008). Anthropological measurement of lower limb and foot bones using multi-detector computed tomography. *J Forensic Sci*. 53:1289-1295.

Röentgen, W.C. (1895). On a new kind of rays – preliminary presentation. *Ann Würzburg Phys Med Soc.* Traducido a Ingles en *Nature.* 1896;53:274-276.

Rouge, D., Telmon, N., Arrue, P. et al. (1993). Radiographic identification of human remains through deformities and anomalies of post-cranial bones: A report of two cases. *J Forensic Sci*. 38:997-1007.

Rubin, D.M., Christian C.W, Bilaniuk L.T. et al. (2003). Occult head injury in high-risk abused children. *Pediatrics*. 211:1382-1386.

Rutty, G.N. (2007). The role of computed tomography as a possible alternative to invasive autopsies. *Rechtsmedizin*. 17:21-28.

Rutty, G.N., Robinson, C., Jeffery, A. et al. (2007). Mobile computed tomography for mass fatality investigations. *Forensic Sci Med Pathol.* 3:138-145.

Ruprecht, A. (2008). Oral and maxillofacial radiology. *J Am Dent Assoc. (JADA)*. 139: 55-65.

Saint Martin, P., Rogers, C., Muto, J., et al. (2008). Pacemaker/defibrillator evaluation at Los Angeles County Department of Coroner. *J Forensic Sci*. 53:1160-1165.

Saferstein, R. (1982). *Forensic Science Handbook*. Englewood Cliffs. Prentice Hill. Pp. 342-345.

Sanders, I., Woesner, M.E., Ferguson, R.A. et al. (1972). A new application of forensic radiology: Identification of deceased from a single clavicle. *Am J Roentg Radium Ther Nuclear Med*. 115:619-622.

Santoro V., Lozito, P., Mastrorocco, N. et al. (2008). Morphometric analysis of third molar root development by experimental method using digital orthopantographs. *J Forensic Sci.* 53:904-909.

Sato, Y. Yuh, W.L. Smith, R.C. et al. (1989). Head injury in child abuse: evaluation with MR imaging. *Radiology.* 173:653-657.

Sauer, N., Brantley, R.E. y Barondess, D.A. (1988). The effect of aging on the comparability of antemortem and postmortem radiographs. *J Forensic Sci.* 33:1223-1230.

Schulz, R., Mühler, M., Reisinger W. et al. (2008a). Radiographic staging of ossification of the medial clavicular epiphysis. *Int J Legal Med*. 122:55-58.

Schmeling, A., Schultz, R, Reisinger, W. et al. (2004): Studies on the time frame for the ossification of medial clavicular epiphyseal cartilage in conventional radiography. *Int J Legal Med*. 118:5-8.

Schmeling, A., Grundmann, C., Fuhrmann, A. et al. (2008): Criteria for age estimation in living individuals. *Int J Legal Med*. 122:457-460.

Schmidt, S., Koch, B., Schulz, R. et al. (2008 a). Studies in the use of Greulich-Pyle skeletal age method to assess criminal liability. *Leg Med.* 10:190-195.

Schmidt, S., Nitz, I., Schulz, R. et al. (2008 b). Applicability of skeletal age determination method of Tanner and Whitehouse for forensic age diagnostics. *Int J Leg Med.* 122:309-314.

Schmörl, G. y Junghanns, H. (1971). *The human spine in health and disease*. New York, Grune and Stratton. Pp. 188-189.

Schüller, A. (1921). Das Röentgenogram der stirnhöhle: ein hilfsmittel für die identitatsbestimmung von schadeln. *Monatschrift Ohrenheikunde*. 5:1617-1620.

Schüller, A. (1943). A note on the identification of skulls by X-ray pictures of the frontal sinuses. *Med J Asustralia.* 1:554-556.

Schollmeyer, W. (1965). Sutura frontalis (metopica) as hereditary and identification mark. *Tsch Z Gesarite Gerichtl Med*. 56:245-249.

Schwartz, S., y Woolridge, E.D. (1976). The use of panoramic radiographs for comparison in cases of identification. *J Forensic Sci*. 31:145-146.

Scott, C.C. (1946). X-ray pictures as evidence. *Mich Law Rev.* 44:773-779.

Sebire, N.J. (2006). Towards the minimally invasive autopsy? *Ultrasound Obstet Gynecol.* 28:865-867.

Sekharan, F.C. (1985). Identification of skull from its suture pattern. *Forensic Sci Int.* 27:205-214.

Silverstein, H.A. (1995). Dental identification: Comparison of antemortem and postmortem findings. En: Bowers, C.M. y Bell, G.L. (eds). *Manual of forensic Odontology*. Vermont, Printing Specialists. Pp 31-34.

Simpson E.K., James, R.A., Eiten, D.A. et al. (2007). Role of orthopedic implants and bone morphology in the identification of human remains. *J Forensic Sci.* 52:442-448.

Simpson, E.K. y Byard, R.W. (2008). Unique characteristics at autopsy that may be useful in identifying human remains. In: Tsokos, M. (ed). *Forensic pathology reviews*. 5:176-196.

Singleton, A.C. (1951). Roentgenological identification of victims of "Noronic" disaster. *Am J Roentgenol* . 66:375-384.

Slabbert, H., Ackermann, G.L. y Altini, M. (1991). Amalgam tattoo as means for personal identification. *J Forensic Odontostomatol*. 9:17-23.

Smith, B.H. (1991). Standards of human tooth formation and dental age assessment. En: Kelley, M.A. y Larsen, C.S. eds.. *Advances in dental anthropology*. New York, Wiley-Liss. Pp 143-168.

Smith, D.R., Limbird, K.G. y Hoffman, J.M. (2002). Identification of human remains by comparison of bony details of the cranium using computerized tomography (CT) scans. *J Forensic Sci*. 47:937-939.

Sopher, I. Forensic Odontology. In: Spitz, W.U. (editor) *Spitz and Fisher's medicolegal investigation of death*. 3rd ed. Springfield, Charles C. Thomas. Pp. 118-136.

Southart, K.A. y Southart, K.A. (1994). Detection of simulated osteoporosis in dog alveolar bone with use of digital substraction. *Oral Surg Oral Med Oral Pathol*. 77:412-632.

Stehr, S. y Simpson, D. (2002). Victim identification and management following the collapse of the World Trade Center. *Natural hazards research and applications information center*. *University of Colorado. Report* No. 148:1-7.

Stein, K.M. y Grünberg, K. (2009). Forensic radiology. *Radiologe*. 49:73-86.

Taff, M.L. y Boglioli, L.R. (1996). Endoscopy is no autopsy. *Am J Forensic Med Pathol.* 17:86-88.

Tai, C.C.E., Blenkinsop, B.R. y Wood, R.E. (1993). Dental radiographic identification utilizing computerized digital slice interposition: A case report. *J Forensic Odontostomatol*. 11:22-30.

Taniguchi, M., Sakoda, S., Kano, T. et al. (2003). Possible use of nasal septum and frontal sinus patterns to radiographic identification of unknown human remains. *Osaka City Med J.* 49:31-38.

Taroni, F., Mangin, P. y Perrior, M. (2000). Identification concept and he use of probabilities in forensic odontology – an approach by philosophical discussion. *J Forensic Odontostomatol*. 18:15-18.

Tatlisumak, E., Yilmaz, O.G., Asian, A., et al. (2007). Identification of unknown bodies by using CT images of frontal sinus. *Forensic Sci Int*. 166:42-48.

Terry, R. (1955). Needle necropsy. *J Clin Pathol.* 8:31-48.

Teivens, A. y Mörnstad, H. (2001). A modification of the Demirjian method for age estimation in children. *J Forensic Odontostomatol*. 19:26-30.

Thali, M.J., Yen, K., Schweitzer, W., et al. (2003). Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by post-mortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) – a feasibility study. *J Forensic Sci*. 48:386-403.

Thali, M.J., Yen, K., Vock, P., et al. (2003). Image-guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI) and subsequent correlation between radiology and autopsy findings. *Forensic Sci Int*. 138:8-16.

Tohnak, S., Mehnert, A.J., Mahoney, M. et al. (2007). Synthesizing dental radiographs for human identification. *J Dent Res*. 86:1057-1062.

Thomsen, T.K., Elle, B. y Thomsen, J.L. (1997). Postmortem radiological examination in infants: evidence of child abuse? *For Sci Int.* 90:223-230.

Ubelaker DH. (1984). Positive identification from the radiographic comparison of frontal sinus patterns. In: Rathbun TA, Buikstra. J, (editors). Human Identification: Case studies in Forensic Anthropology. Pp. 399-411.

Ubelaker, D.H. (1990). Positive identification of American Indian skeletal remains from radiographic comparison. *J Forensic Sci*. 35:466-472.

Uysal, S., Gokharman, D., Kacar, M. et al. (2005). Estimation of sex by 3D CT measurements of the foramen magnum. *J Forensic Sci*. 50:1310-1314.

Valenzuela, A. (1997). Radiographic comparison of the lumbar spine for positive identification of human remains. A case report. *Am J Forensic Med Pathol*. 18:215-217.

Varga, M. y Takacs, P. (1991). Radiographic personal identification with characteristic features in the hip joint. *Am J Forensic Med Pathol*. 12:328-331.

Van der Kraan, P.M. y Van den Berg, W.B. (2007). Osteophytes: relevance and biology. *Osteoarthritis Cartilage*. 15:237-244.

Van der Kuiji, B. y Van der Pols, L.C. (1995). Forensic odontological identification of disaster victims. Experience with the disaster of the Martinair DC-10 in Faro, Portugal. *Ned Tijdschr Tandheelkd*. 102:236-242.

Van der Stelt. P., Webber, R.L. y Ruttiman, U.E. (1986). Forensic identification of trabecular patterns from dental radiographs. *J Dent Res*. 65:176.

Veyre-Goulet, S.A., Mercier, C., Robins, O. et al. (2008). Recent human sexual dimorphism study using cephalometric plots on lateral teleradiography and discriminant function analysis. *J Forensic Sci*. 53:786-789.

Villiers, C.J. y Phillips, V.M. (1998). Person identification by means of a single unique dental feature. *J Forensic Odontostomatol* . 16: 17-21.

Viner, M.D. (2009). Director de la Asociación de radiógrafos forenses, Reino Unido. Comunicación personal.

Voluter, G. (1959). The "V" test. *Radiol Clin*. 28:1-32.

Wenzel, A. (2002). Two decades of computerized information technologies in dental radiography. *J Dent Res.* 81: 590 – 593.

White, S.C. y Rudolph, D.J. (1999). Alterations on the trabecular pattern of the jaws in patients with osteoporosis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 88:628-635.

Wilcher, G. (2008). The use of multiple exostoses in the identification of incinerated human remains: a case report. *Med Sci Law.* 48:82-86.

Wilcher G.W. y Hulewicz, B. (2005). Positive identification of a decomposed body using a trilogy of identification criteria: a case report. *Med Sci Law*. 45:267-272.

Yamazaki, K., Shiotani, S., Ohasi N., et al. (2006). Comparison between computer tomography (CT) and autopsy findings in cases of abdominal injury and disease. *Forensic Sci Int*. 162:163-166.

Yen, K., Thali, M., Aghayev, E. et al. (2005). Strangulation signs: initial correlation of MRI, MSCT and forensic neck findings. *J Magn Reson Imaging*. 22:501-510.

Yen, K., Lovblad, K.O., Scheurer, E., et al. (2007). Post-mortem forensic neuroimaging: correlation of MSCT and MRI findings with autopsy results. *Forensic Sci Int*. 173:21-35.

Yoshino, M., Miyasaca, S, Hajime, S. et al. (1987). Classification system of frontal sinus patterns by radiography. Its applicability to identification of unknown human remains. *Forensic Sci Int*. 34:289-299.

Zahrani, A. (2005). Identification of unidentified human remains – validity of records. *Pakistan Oral Dent J.* 25:3-6.