Dental research using intraoral techniques with portable digital radiography adapted for fieldwork in Qubbet el-Hawa (Egypt)

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Introduction

"Paleoradiology," a term proposed by the American radiologist Derek Notman in 1987 to define "the study of bioarcheological materials using modern imaging methods" (Notman et al. 1987), has been developed in parallel with the progress of both radiology and medical imaging technology (Chhem 2008). It was only 3 months after X-rays were discovered in 1895 when a radiographic image of the mummified remains from Ancient Egypt was obtained (Cosmacini and Piacentini 2008). Due to their proven value in offering information on diet, stress, or habits (Greeff 2013), teeth and jaws have also been a successful focus of radiological research on Egyptian mummies (Gerloni et al. 2009; Melcher et al. 1997; Pausch et al. 2015; Thekkaniyil et al. 2000). However, much of the success of these evaluations has been carried out in relatively controlled contexts, a situation very different from that experienced under field conditions. The methods to record images of teeth or jaws depend not only on the integrity of these specimens but also on the workspaces and logistics for taking those shots (Saab et al. 2008). In 1968, a team led by RG Harrison had to adapt an old portable X-ray machine and perform many pre-calibrations in order to obtain a set of acceptable test films, because the permission to carry Tutankhamun's mummy from the tomb to Luxor Hospital was not granted (Chhem 2008).

On the island of Elephantine was settled the capital of the southernmost province of Upper Egypt since the later fourth millennium to the Byzantine period. The highest officials who controlled the border with Lower Nubia as well as the trade and people from the Central Nile were buried from the 6th Dynasty until the end of 12th Dynasty (2250–1800 BC) in a hill known today as Qubbet el-Hawa. In addition, non-elite burials re-occupied the noble funerary complexes during the New Kingdom (especially during the 18th Dynasty) and the Late Period (26th–27th Dynasties). Although this site has been excavated since 1880s, it has been just from 2008 when a systematic multidisciplinary project began to study the archeological remains (Al-Khafif and El-Banna 2015; Universidad de Jaén 2020). Unfortunately, the current particular conditions imposed by the Egyptian authorities for heritage protection make it very difficult to evaluate samples outside the site (Medina and Prado 2016). Similarly, it is unknown whether or not an analysis of dental structures has been carried out with specialized techniques in these specimens. The goal of this communication is to present the technical approach of making radiographic records using a portable X-ray device, intraoral digital receptors, and biosecurity equipment, all adapted for field use in Qubbet el-Hawa (Egypt).

Devices, equipment, and radiation protection

Between May and October 2019, a protocol for the radiographic approach of the specimens was developed at the Centro de Investigación en Odontología Legal y Forense (CIO) at the Universidad de La Frontera (Temuco, Chile). Calibrations were performed using simulations to optimize the operating time given the working conditions established by the Egyptian authorities for heritage protection with regard to effective working time limits, unavailability of moving specimens outside the necropolis, and intrinsic difficulties, such as weather, sand in suspension, and electrical availability (Medina and Prado 2016). Taking into consideration the conclusions formulated by Schillaci et al. (2001) regarding perceived difficulties in transporting and operating X-ray equipment, their recommendations were followed in adopting a methodology that prefers highly portable and user-friendly devices in the field, with commercially available biosafety equipment and accessories.

The device used was a Portable X-ray System DIOX-602 (DigiMed, Seoul, Korea). This device is approved by the Food and Drug Administration (FDA), stating that it is intended to be used by trained dentists and dental technicians as an extraoral X-ray source for producing X-ray images using intraoral receptors. According to the FDA (2008), “the result of bench testing and clinical evaluation indicates that the subject device is as safe and effective as the predicate devices.” Taking into consideration the recognized advantages of less radiation exposure and no need to use developer emulsions, it was preferred to carry a digital intraoral receptor. The device chosen for this protocol was the new IDA digital intraoral sensor (Dabi Atlante, Brazil), size 1 (active area: 20 × 30 mm). This system uses a sensor that employs the associated technologies of protective optical fiber and scintillator from the complementary metal-oxide-semiconductor (CMOS). According to the manufacturer’s recommendations, the sensor must be positioned behind the structure to be radiographed and then exposed to an X-ray dose using the external source. Once exposed, “the sensor performs a conversion of the X-ray photons into a digital sign and transfers it to a computer through USB 2.0 connection” (Dabi Atlante 2019). The software provided by the manufacturer (.Net Framework 4.5.1) manages that dental image allowing its visualization, improvement, storage, sending, and printing. This system uses a solid-state detector (DR), which was selected and for its reported advantage of allowing increased productivity of images in contrast to computed radiography (CR) with phosphor plates systems (Beckett and Conlogue 2020). We preferred to use a corded sensor as it was better adapted to the field work strategy and to avoid its potential loss (Clinicians Report 2011). The computer used was the HP 240 G6 I3-7020U laptop (Hewlett Packard, USA), which was conditioned to avoid contamination by sand in suspension, a pervasive problem that also determined all physical protection strategies in the field. The advantages of using this digital image receptor are obvious. Digital images are obtained immediately and with quality comparable to X-ray films, copies are easy to obtain and always of the same quality, and fundamentally, the need for chemicals is eliminated (Saab et al. 2008), a process obviously contraindicated if you consider your transfer or fieldwork. In November 2019, all protective equipment and implements belong to the CIO and were transported from Chile to Egypt by the authors, and arranged for use in the field in Qubbet el-Hawa.

Although the usefulness of radiography for dental evaluations is well-known, as well as the necessary protective barriers during radiographic recordings, few studies have been conducted regarding the management and protection of operators from exposure using portable X-ray units for dental use. Putting this point in our focus, the study proposed by Iwawaki et al. (2018) was followed. The portable equipment has an overlapped internal radiation shield designed to protect the operator when working from the posterior; the three operators (S.L.L., V.C.Y., and G.M.F.) worked one by one, taking into consideration the value resulting from the relationship of the number of the image and specimen proposed by Iwawaki et al. (2018) to limit occupational exposure and the passage of surrounding workers at the anterior was avoided. Personal protection measures included the use of a 60 × 85 cm lead aprons with thyroid protector (N. Martins e Teixeira Ltda., Colombo, Brazil), heavy level protection lead gloves (Infab Corporation, Camarillo, CA, USA), and mounted lead glasses, side-protective 0.5mmPb (Hangzhou Sailray Imp & Exp Co. Ltd., China). The three operators also had the corresponding accreditations for the use of this type of equipment by the Regional Secretariat of the Ministry of Health of Chile.

Radiographic technique

The possibility of occupational exposure in dentists or assistants when using portable dental X-ray units and the little attention they pay to radiation protection has already been the subject of study and caution (Cho and Han 2012). Given the characteristics of the specimens to be radiographed, and in order to avoid unnecessary exposure of the hands of both the operator and an eventual assistant, an extension of 50 mm was placed on the cone of the radiographic device (with a resulting length of cone of 150 mm), with fixing of a positioner holder for the digital intraoral sensor. This managed to maintain a fixed perpendicular position between the cone and the intraoral device (parallel technique) (Fig. 1a), also allowing for parallelism between the intraoral device and the long axis of the teeth. In all cases, periapical radiography was performed, a dental technique made of both posterior and anterior teeth, which captures the crown, root, and surrounding bone entirely. When performing periapical radiography, it has been recommended to implement the parallel technique whenever possible to minimize distortion. Considering that this technique requires the film (the digital intraoral device in this case) be situated further from the teeth, the palate does not allow this parallelization in some circumstances (Saab et al. 2008). As a result, we opted to modify the technique by inverting the cone entry point, thus maintaining the parallelism (Fig. 1b). This adaptation of the technique has already been proposed by Viner and Robson (2017). The resulting image only needs to be inverted again for its correct visualization, not only avoiding the use of the bisecting angle technique usually recommended for these cases but also generating unequal magnifications or distortions (Saab et al. 2008). The portable X-ray unit operates at fixed 60 kVp, 2 mA, and the setting for exposure was 0.2 to 0.55 s, depending on the source-to-object distance, to obtain the best image quality, as suggested by Pittayapat et al. (2010). Agreeing with what was suggested by Seiler et al. (2018) and given the logical absence of soft tissues, a full set of radiographs was not required. Radiographs were performed more restrictively, being indicated only for diagnosis of hidden lesions or confirming intraosseous bone alterations of pulpal origin. A total of 112 radiographs were taken in a period of 5 days, with an equitable daily distribution among the three operators and a maximum of 15 shots per operator per day (Fig. 1c and d). This meant a total of 14 (± 6.53) seconds/week of actual beam "on-time" at 60 kVp per operator, an operating parameter well below the limits established by international standards to ensure the minimum protection from scatter radiation (California Dental Association 2014). Shots with the portable X-ray device and digital intraoral sensor, as well as operational measures to ensure X-ray protection on-site (lead apron, lead gloves, and individual operator work). a Periapical intraoral radiograph with conventional parallel technique to the upper molar area. b Technique modified by inverting the cone entry point to avoid sensor malposition, thus maintaining the parallelism. c Lower left first molar, with evidence of significant occlusal wear and periodontal bone loss at the level of the mesial root (asterisk). d First and second upper left premolars, with significant occlusal wear. Note the infectious process of pulp origin at the apex of the first premolar (asterisk)

Discussion

Fieldwork has been argued to be probably the most neglected aspect of the process of obtaining X-rays in archeology and anthropology. Brothwell (2008) stresses that the reason for this is probably that most situations require laboratory actions but not on-site, so it remains a challenge to address. The same author states that, although the portability of X-ray devices is a clear advantage to work in field conditions, special attention should be given to protection maneuvers and equipment, as well as preference should be given to the use of digital receptors. Beckett and Viner (2020) highlight the large number of variables that must be taken into account during field paleoimaging fieldwork: physical hazards, equipment safety, knowing the current culture and local rituals, climatic conditions and environment, and biological hazards. We agree with these authors that each of these items poses important challenges that only a systematic and prudent preparation can control at the time the expedition is designed. In particular, carrying out field paleoimaging in remote locations and in adverse climatic and environmental conditions (as experienced in this report), the equipment selection, supplies, permits and customs papers, even food, lodging, and security are overwhelming logistical considerations (Beckett and Viner 2020). Very interesting are the contributions offered by researchers from the Bioanthropology Research Institute, Quinnipiac University in the USA, and the Cranfield forensic Institute, Defense Academy of the United Kingdom in the UK (Beckett 2014; Beckett and Conlogue 2020; Beckett and Viner 2020; Viner and Robson 2017) to solve these challenges not only technical but also logistical. In our case, although the equipment used was shown to have good performance compared to other similar ones (this is further enhanced by complementing it with digital intraoral receptors) (Lee et al. 2013), the application of strict protection measures and appropriate technical manipulation has made it possible to obtain optimal results given difficult field situations. In particular, and due to its ubiquity under field conditions, the radiological technique we used has already been proposed as an excellent method for examining the skulls and teeth of ancient Egyptian specimens (Seiler et al. 2018). Handheld X-ray devices have proven to be a useful tool in bioarchaeological setting due to their easy transport to tombs, caves, niches, and remote environments avoiding unnecessary damage to the object by moving it to an imaging center. Probably one of its greatest advantages is also being able to modify the instrumentation in order to increase its portability and flexibility to meet field requirements (Beckett 2014; Beckett and Conlogue 2020).

With regard to intraoral digital sensors, there are currently two systems: a direct one, known as digital radiography (DR), and an indirect one, known as computed radiography (CR), which uses a photostimulate phosphor plate. Both systems have reported advantages and disadvantages; in our case, we opted for DR because this system allows to increase the productivity of shots by not needing the waiting periods that the CR plate needs to “read and cleared” (Beckett and Conlogue 2020), in our case an advantage of great importance due to the time limitations established by the Egyptian authorities for work inside the tombs. Conlogue et al. (2020) highlight that other disadvantages of CE are the possible generation of “ghost images,” the risks of mechanical failure of its moving parts and the impossibility of capturing a rapid succession of images, particularly useful in forensics. Undoubtedly, having a wireless sensor would further enhance the portability of the system, also avoiding the deterioration caused by handling the wires (Seilern-Moy et al. 2017). However, given the designed field work strategy, we prefer to use the DR with corded sensor system, taking into account that both wireless sensors and corded sensors provide adequate images in a similar way, while the costs of wireless technology are higher, and there is increased potential for loss of wireless sensors (Clinicians Report 2011).

In particular and in relation to the modification that we propose to the parallel radiographic technique, we must emphasize that, even when it is impossible to implement in the dental clinic, it can be a significant contribution in bioarcheological or forensic contexts due to its feasibility given the nature of the sample. Our adaptation of use of both the portable equipment and intraoral device adheres to the considerations already made by the literature to obtain the best spatial resolution, reducing unnecessary radiation exposure and speeding up imaging (White and Pharoah 2008). We must highlight that, although X-ray devices and protection barriers have evolved as technological progress has advanced, there are always logistical limitations determined by their transportation (Schillaci et al. 2001), even their customs revenues. Equipment fragility, theft risks, airport security controls, obtaining permits, etc. are all sometimes very frustrating conditioning factors if they have not been foreseen in advance. The 2016 UK "Guidance on the safe use of handheld dental X-ray equipment" is emphatic when it mentions that this type of device "should be used in exceptional circumstances", since its use may involve potential exposure of the operator's hands, which should be avoided if possible (Gulson and Holroyd 2016). However, the report by Berkhout et al. (2015) (on which the 2016 UK Guidance is mostly based as indicated) mentions that this type of devices "are a non-standard form of dental X-ray equipment" and "are designed to be used handheld". According to the authors, this property makes them particularly useful for field work and mobile environments; but taking this procedural decision, a good practice recommendation for operators in expositions is to be adequately protected from that radiation (Berkhout et al. 2015; Gulson and Holroyd 2016). In our case, we opted for its use "handheld" without remote control and with the use of protections to maximize the number of shots (given the aforementioned time limitations imposed by the Egyptian authorities for work inside the tombs) and to allow placing the device in any angle and take X-rays in all possible positions (Aribex 2013). This alternative also made it easier to maintain a minimum weight of the equipment, which was particularly beneficial in our expedition; Seilern-Moy et al. (2017) reported in their field work that the use of a tripod was unnecessary in most cases and its exclusion greatly facilitated the handling and transfer of the equipment. The Egyptian Law No. 59/1960 regulates the licensing and use of radiation sources. Both Chile and Egypt adhere to and regulate their standards and recommendations according to those of the International Atomic Energy Agency (IAEA). In particular, Chile has demonstrated its commitment to radiological safety and compliance with the IAEA regulations, as well as the regulations made by the Chilean Ministry of Health on the subject (International Atomic Energy Agency 2018). In our case, presenting to the Egyptian authorities our accreditations for the use of the X-ray equipment adheres to the recommendations that dental practice staff in general, and paleoimagers in particular, must have current knowledge and sufficient training for the use of handheld X-ray devices, as well as local legislation (Beckett 2014; Gulson and Holroyd 2016). Berkhout et al. (2015) state that handheld X-ray devices "should only be operated by licensed/registered dentists or appropriately educated dental staff".

The evaluation of dental health in historical Nubian and Egyptian populations needs to consider the multifactorial nature of the conditions to contribute to conclusions about diet or health (Buzon and Bombak 2010). It has been suggested that the reevaluation of concepts from both the anthropological and dental point of view allows for a more holistic integration of the information to deconstruct and understand the complexities surrounding dentomaxillary morphofunction (Kaidonis et al. 2014). We agree with Medina and Prado (2016) who reported that the size and complexity of the site requires experts from different disciplines to expand the spectrum of possible approaches, a need not only conceptual but also technical given the particular conditions of the excavation, local regulations, and difficulty of accessing specific products and tools. We believe that this technical note offers genuine solutions to current field situations in this type of archeological context.

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