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# Smile photograph analysis and its connection with focal length as one of identification methods in forensic anthropology and odontology☆

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SUMMARY

To positively identify a highly decomposed body forensic experts often use information obtained from the dentition. In this study authors try to employ a method of comparing incisal borders of the anterior teeth from antemortem (AM) and postmortem (PM) photographs within an experimental scenario with living individuals. The second purpose was to determine how focal length of the lens affects compared smile lines. The research was divided into two stages. In procedure 1, the participants (28 individuals) were asked to provide a photo (for the purpose of the research considered as "antemortem") in which the anterior teeth were visible. A series of experimental photographs (considered as "postmortem") were then taken trying to reproduce the position of the person's head in relation to "AM" picture as faithfully as possible. The procedure 2 (10 individuals) consisted of taking "AM" photos under controlled conditions using an accidental focal length, then taking "PM" photos using a priori established focal lengths: 18 mm, 55 mm and 80 mm. In both procedures, the final stage involved marking and comparing the incisal borders from "AM" and "PM" photographs. Procedure 1 showed that in 82% of cases the compared smile lines are fully compatible. 11% was marked as "tolerable", and only 2% as "insufficient". Procedure 2 proved that the choice of focal length when taking a PM photograph is significant and that the medium focal lengths (range of 55–85 mm) are suggested in case of unknown focal length in AM photo. The results indicate that this method can be reliably applied in forensic cases when AM photographs of deceased are available.



## 1. Introduction

The identification of poorly preserved human remains may constitute a significant problem for forensic experts. Each feature that distinguishes one person from another can be a key element in determining positive identification. The more such identifiers, the better and more reliable the result of identification. Prior to advanced decomposition of a body, the pathologist/medical examiner may yet rely on many indicators regarding the deceased's physical appearance and comparison of fingerprints. In the case of a skeletonized, charred, decomposed, mutilated, macerated, or partially destructed corpse the procedures differ, as bones and teeth are the only source of information about the deceased. Many authors emphasize the importance of a multidisciplinary approach - a joint effort of experts in molecular biology, anthropologists and forensic odontologists [1–5].

According to Avon [6] forensic odontology "involves the management, examination, evaluation and presentation of dental evidence in criminal or civil proceedings, all in the interest of justice". Teeth, along with surrounding tissues, are found even in cases of burnt remains, or highly decomposed human bodies, which makes them an extremely useful material for identification purposes [7]. Tooth enamel is the most durable element of the skeleton, resistant even to very high temperatures. Another important feature is the uniqueness of teeth for any individual. Similar to fingerprints, the variation of shape, size and position of the dentition in dental arch creates an individual, unique pattern and provides enough data for a comparison process [8]. Hence, it is important to develop new, less conventional methods that allow positive identification of the largest possible number of cases, e.g. when there is lack of antemortem medical data as it happens in poorer, developing countries with a large number of residents (for example some regions of South

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America and Asia) but also in Europe where the increasing number of illegal immigrants without the desire to assimilate in the country of arrival causes an increasing problem with access to medical history, especially the one regarding teeth [9]. Sometimes the dentist of the deceased is not known to the family, or all the relatives have died. This leads investigators to search for alternative sources of reference data, such as facial photographs, video recordings and smile photographs received from the family, or downloaded directly from social network websites that show the characteristic features of the victim's teeth.

The use of smile images is burdened with several disadvantages which forensic experts needs to pay attention to. Photographs from personal belongings of the deceased may be characterized by insufficient quality. Sometimes the number of teeth visible in the picture, and thus the number of available dental characteristics, does not allow for an unambiguous opinion. Therefore, the family should be asked to provide a picture of the widest smile where all necessary dental traits are visible. That is also why it is so important for the forensic anthropologist to use as many methods as possible to ensure the most reliable verdict [5]. Another important factor is the period which passes from the moment of taking a picture to the time of death. This period should not be too long in order to avoid possible alterations, both environmental (loss, discoloration, attrition) and medical which are likely to significantly change a person's smile. Pictures of open mouths can provide evidence for the use of dental restorations and prosthetic appliances presenting key data that may be helpful in finding medical or dental records at the initial stage of identification when law enforcement agencies do not have too much information about the victim or, for various reasons, are not able to reach the family [7]. It is necessary that the proportions of the images which are being compared remain unchanged to minimize the risk of masking potential discrepancies by freely manipulating the height/width in the graphic program. The graphic processing of AM data allows some image enhancement to improve visibility of the dentition features [10].

There are three main methods related to the analysis of the smile photography for identification purposes that appear in the literature: direct comparison of dental traits, dental superimposition and analysis of the incisal outline of the anterior teeth. The first attempts of scientific validation concerned the dental superimposition [9,14], however, each of these methods is successfully used in the odontological examination (mainly in Brazil) and is based entirely on the morphological similarity of the ante- to postmortem data. In the case described by Silva et al. [2] a positive identification was detected with the application of all three techniques indicated above. In turn, in another case report from the same year, the author emphasizes the usefulness of the multidisciplinary approach [10]. A biological profile was created to reduce the police list of missing persons which allowed to indicate a potential victim. Then the application of the analysis of the smile photograph permitted to achieve a positive identification. Thus, the combination of forensic anthropology along with forensic odontology decided about the success of this case.

DNA analysis that is used for uncontested identity confirmation requires significant resources, specialized laboratory, an expert, and a comparative material - which is not always available. In this context forensic odontology stands out over other methods. The advantages of using smile photos for identification purposes are the speed of analysis, low cost and high reliability of the results. Dental remains constitute a very good comparative material which was used after many of recent mass disasters like the Christchurch earthquake in 2011 [11], attacks on the World Trade Center in 2001 [12] or tsunami that hit Thailand in 2004 when of 2269 victims, 1055 were identified only through forensic odontology analysis [13].

For these reasons, developing, validating and improving methodologies that use dental data for identification purposes is crucial. Case reports describing the use of smile photographs appear regularly in specialized literature [1,2,8,10]. Nevertheless, methodological research that would confirm the validity and reliability of such procedures are rather scarce. With this in mind, we propose an innovative, experimental study that, on the one hand would focus on the verification of smile photography analysis for identification purposes, and on the other hand would investigate the impact of focal length on the results of such analysis, an approach that has not yet been studied but represents an important factor of photographic analysis. Therefore, we believe that our research brings a valuable contribution to methodological aspects of forensic odontology and anthropology and can serve as a reference for further studies.

## 2. Photography

In the analysis of portraits potentially serving as comparative material for positive identification in a forensic context, image distortion appears to be a critical optic disadvantage that have the most significant impact on the photograph. Distortion can be defined as an optical aberration that deforms and bends physically straight lines and makes them appear curved in images [15]. This anomaly most often affects wide-angle lenses with focal lengths shorter than 35 mm. It is worth noting that currently most portraits or self-portraits (so-called "selfies") are created using mobile phones that have built-in permanent wide-angle lenses. They seem more universal for the needs of everyday photography because they enable a wide field of view, but on the other hand, when the photo is taken from a close distance to the person being photographed, his or her face becomes unnaturally distorted, which results in changed proportions and, in the case of smile analysis, dislocation of reference (anthropometric) points when it comes to comparing AM and PM data. A similar situation takes place during the use of 18 mm focal length in lenses attached to popular, amateur DSLR cameras, which are used by less experienced users. Typical portrait lenses are those with focal lengths of between 70 and 135 mm [16]. Thanks to their application, the face looks natural and is not distorted by optical defects.

When taking photos for comparative dental analysis, the main problem an expert is faced with is the head orientation in space (along the x, y, z axes). Photographs are two-dimensional projections of a three-dimensional object, so if objects in the picture are not positioned in an almost identical setting, such a comparison will be flawed. De Angelis et al. [9] in their research sought to establish a scientifically validated method allowing for an almost perfect reproduction of spatial orientation using cast models. It was found that only the lateral bending of the cervical spine (the ear to the shoulder) will not cause deformation in the 2D image. Flexion (forward bending), extension (backward bending), and torsion (left-right rotation) of the head affect the result of the comparison; therefore, the range of motion of the head can vary only by 2° to both sides without distorting the comparative process.

In case of a smile line comparison, all available case reports in which positive identification was obtained using incisal alignment analysis as one of the odontological methods [8] or as a supplementary method [10], did not use such rigorous forms of position control as the above-mentioned research by De Angelis et al. and probably have not followed any scientifically validated methodology. Mehrotra et al. [14] indicate that the comparative photo was taken multiple times, until an image enabling an accurate superimposition was taken. However, despite the lack of perfect positioning, it has been proven that dental characteristics in and of themselves are sufficient to identify an unknown person in each of the cases described in the literature [1,8,17].

However, considering the general lack of validating research for these methods, it becomes justified to investigate this topic more carefully in order to produce the most scientifically rigorous, and, in

consequence, reliable methodologies that could be successfully applied in forensic context.

Even though many studies have used smile photography for identification purposes, none of the authors paid attention to the limitations and features of the optics that may affect the results of the comparison between postmortem data and antemortem photographs. Therefore, as the aim of this study we propose to verify:

1. The usefulness of smile photographs of an individual to make a positive identification from the method of comparing the incisal contours of anterior teeth, using an image editing software.
2. Whether the focal length of a lens can affect the reliability of the analysis due to possible distortion of the image.
3. If knowing the focal length of the AM photo and using a similar focal length for taking the PM photograph makes the comparison process more accurate.

Different nomenclature can be found in the literature regarding the marked line, e.g. smile line, incisal contours of anterior teeth, incisal borders of anterior teeth, incisal outline of anterior teeth, incisal alignment, alignment of the incisal borders of anterior teeth. They all means the same and will be used in this article interchangeably.

## 3. Research sample and methodology

The experimental part of this research was divided into two stages: collection of data (smile photographs) and a comparative analysis of the smile lines retrived from the photographs. To check both – the utility of smile photography for identification purposes and the relationship between the distortion of the smile line and the focal length that had been used, two separate procedures: 1 and 2 were designed.

### *3.1. Equipment*

The following refers to both stages of the research.

All photographs were taken with a DSLR (Digital Single Lens Reflex Camera) Canon EOS 70D, 20.2 megapixels with 8.0 megapixels of resolution. In order to obtain the greatest possible diversity of comparative material (hereinafter referred to as "postmortem" material), three constant focal lengths were assumed - 18 mm, 55 mm and 80 mm.

Photographs with a focal length of 18 mm and 55 mm were taken with the Canon EF-S 18–55 mm f/3.5–5.6 IS lens. This lens is additionally characterized by a very large barrel distortion at 18 mm focal length which gradually decreases; at 55 mm focal length there is a slight pincushion distortion [18].

Photographs with 80 mm focal length were produced with Canon EF 28–80 mm f/3.5–5.6 II. Phenomenon of distortion no longer occurs, and the images are devoid of distortion that may interfere with the natural proportions of the face.

Alignments of the teeth from all the photographs were marked using the Huion New 1060 Plus+ graphic tablet which provides much more accurate mapping of details in the designated lines compared to the ordinary computer mouse.

### *3.2. Procedure 1 – Convergence of the smile lines from the "AM" and "PM" photographs*

Adult students and employees of the Jan III Sobieski High School in Olawa, Poland were invited to participate in the study. The purpose of the research, the manner of its conduction and the conditions for subsequent manipulation of the data were explained at an earlier meeting with the participants. The signed forms of informed consent for participation in the study were collected from all those interested. Each participant committed to providing a picture of himself/herself in a full smile, which was used at a later stage as material for the comparative analysis ("AM" data). Specific guidelines on the selection of photos had not been given, although it had been pointed out that previously existing photographs were preferable to imitate circumstances of a real forensic investigation. Inclusion and exclusion criteria of participants and photos for the study are as listed below:

- Upper teeth and their incisal contour (at occlusal surface) visible on the supplied photo, from at least left to right upper canine;
- No bridges and dentures of the upper teeth;
- Acceptable: orthodontic appliances, crowns, fillings.

Thirty individuals took part in this variant of the study, but in the post-processing stage, two of the "AM" photos were discovered to have been distorted, thus rendering the comparison impossible to conduct. In consequence, the final sample consisted of 28 persons (23 women, 5 men), in the age range of 18–55.

All photos were taken on the same day in one of the High School offices, using the same exposure settings (exposure time 1/40, aperture f/5.6 and ISO 500). Depending on the position of the individual in the "antemortem" photo, participants were photographed in either a standing or sitting position with the aim of reproducing the original distance of the camera from the person, and the position of the head in three planes (according to X, Y, Z axes). Several pictures of each participant were taken so as to have the option of choosing the best shot afterwards. These images were considered as images produced "postmortem".

### *3.3. Procedure 2 – Connection between smile lines and focal length*

After having been acquainted with the principles of the experiment and signing consent forms, ten individuals aged 14–50 (7 women and 3 men) were asked to participate in the second variant of this study. The criterion of participation was the possession of full, permanent anterior dentition. The anterior permanent tooth eruption ends at around the age of 12, therefore a 14-year-old is expected to have all permanent anterior teeth visible [19]. Since the overall shape of permanent teeth do not change with age, it is not a variable that can disrupt the reliability of comparison results [20].

In order to consider how focal length affects the appearance of the dental arch in photographs, a set consisting of four full face photographs was taken for all individuals. It was more appropriate to take the new set of photos in which the only variable parameter was the focal length as in the „AM" photos provided by participants in the procedure 1 the head was tilted in different directions according x, y, z axes and it would not be possible to perfectly repeat the same head orientation during the three consecutive photos with different focal lengths (and during the lens change). All participants were photographed in a standing position in frontal aspect, showing their teeth in a wide grimace so that the incisal edges of the anterior teeth could be seen. The position remained unchanged for all photos in the series, as well as lighting conditions and exposure (exposure time 1/50, aperture f/5.6 and ISO 320). A tripod and external flash lamp were used. The first shot (considered as the "AM" data) was made at random focal length using one of the two lenses (Canon 18–55 mm or Canon 28–80 mm). Then a constant, previously determined focal length value (18 mm, 55 mm and 80 mm) was used to take three "PM" photographs.

### *3.4. Processing of the "AM" and "PM" data*

In order to demonstrate the use of smile images for human identification, the alignment of the incisal borders of the anterior upper teeth was marked and then compiled in the Adobe Photoshop

**Fig. 1.** Smile line juxtaposed with corresponding "AM" photo

CS 6® graphic design software (Adobe Systems Inc.®, San Jose, USA) from both photographs – "AM" received from participants and "PM" taken during the experiment.

The following is the entire procedure designed by the authors to determine the smile line in the image editing software [Figs. 2–6]. Identical steps were then taken for the "antemortem" and "post-mortem" photograph, and consequently applied in the next 27 sets of photos. This was also applied in procedure 2 concerning the analysis of the influence of focal length on changing proportions of smile lines. Fig. 1 shows the smile line placed over an "antemortem" photo according to which it was created. Whether or not the determined contour corresponds sufficiently to the shape of the incisal edge of the teeth is therefore allowed to be verified.

Using the Crop Tool, the "AM" picture was cropped at 2 × 3 aspect ratio. The cropped area was located between the corners of the mouth; the center was determined by the incisal borders of the upper teeth [Fig. 2]. The incisal outline of each tooth was highlighted with the Pen tool, starting from the distal margin of one of the canines. The Pen tool allows for the marking of a great number of points that are connected to form a fully editable line. It is essential to use many points to ensure the highest level of accuracy of the

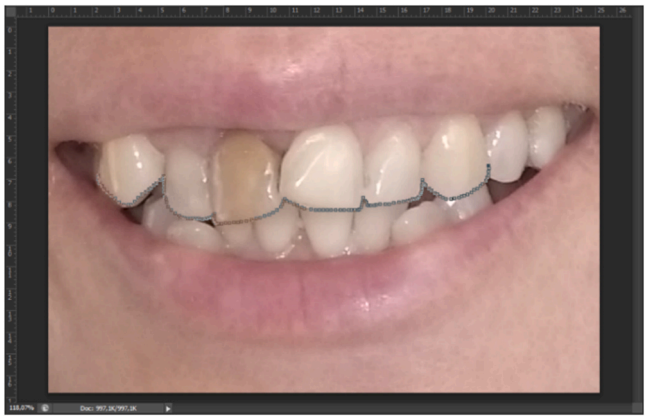

**Fig. 3.** Marking points to form an alignment of the anterior teeth

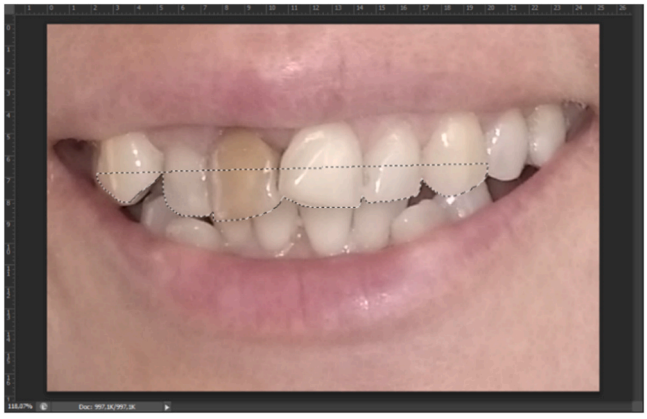

**Fig. 4.** The use of "Make selection" tool

selection. Each point can be removed and its location edited, which enables the correction of any shortcomings [Fig. 3]. With the Make Selection option (Feather Radius: 0 pixels), a closed selection was made [Fig. 4]. The selection was then copied into a new layer. In the

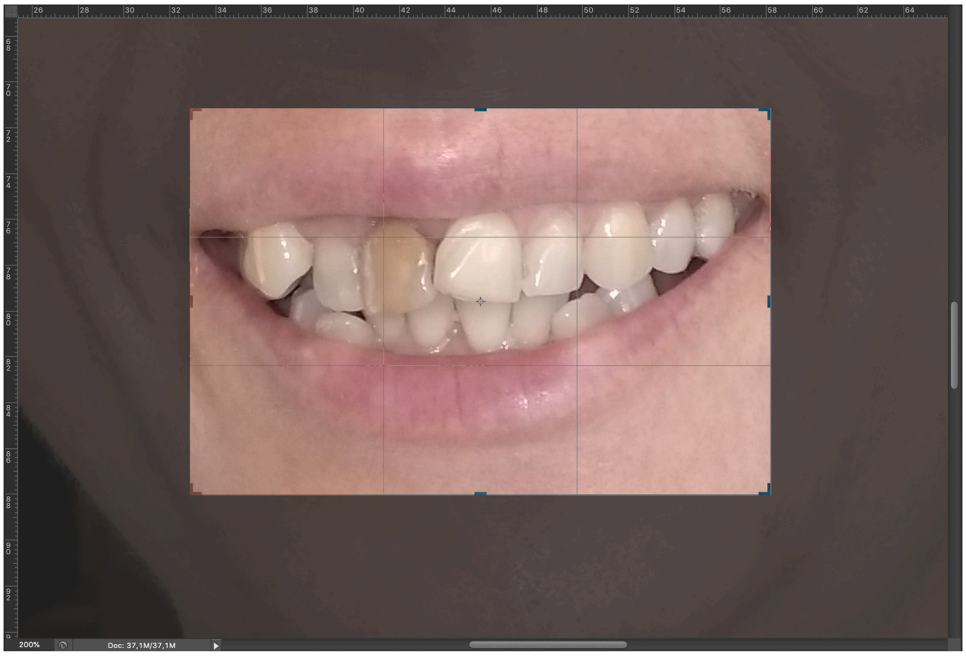

**Fig. 2.** Cropped area located between the corners of the mouth

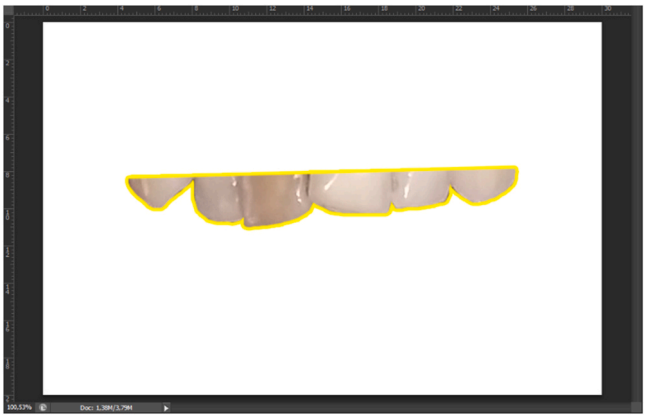

**Fig. 5.** Creation of colored contour of the teeth

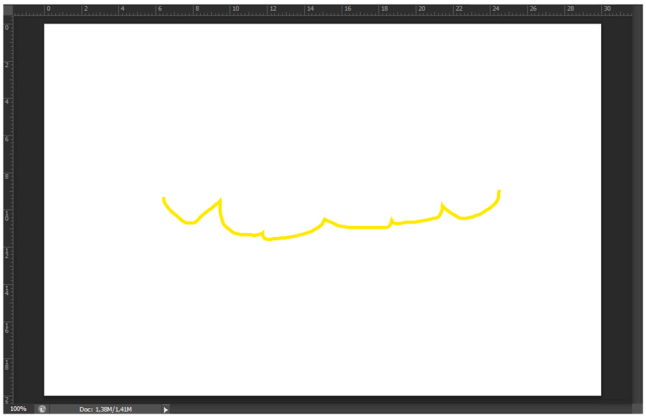

**Fig. 6.** Elimination of filling and upper border from the contour

Blending Options tab, the Stroke option (size: 5px) had been selected - this allows for the creation of a filled contour. The colors corresponding to Interpol forms were used [28] – the smile line determined from the photo “AM” was marked in yellow. Pink was used for marking the “PM” data [Fig. 5]. The fill had been removed from the contour by reducing the value from 100% to 0% using the Fill Level option. Then the Rasterize Layer Style had been chosen, and the unnecessary upper border of the contour was removed [Fig. 6]. After completing the above steps, it is possible to move, rotate, copy, and enlarge or reduce the smile line using the Free Transfer option.

### 3.5. Comparison and analysis

At this point, smile lines from the “AM” and “PM” photos were compiled together to explore the similarities between them [Fig. 7]. After pasting the line marked from the “AM” photo into a separate file, the “PM” line was then copied and adjusted by size and angle to match the “AM” line as best as possible. To obtain the best match, in procedure 1 the lines were adjusted according to the first incisors. In procedure 2 the effect of the phenomenon of distortion (which affects the image most strongly in the center of the frame) was considered, therefore at low focal lengths the lines were adjusted according to the distal teeth (canines and furthermore the second incisors). When the initial compatibility had been accomplished, the “PM” line was modified so that the remaining borders also overlap well. It is extremely important not to change the line ratio during this procedure. It can be rotated, reduced, or increased, but always within its own proportions to avoid manipulating the image and, consequently, distorting the final results.

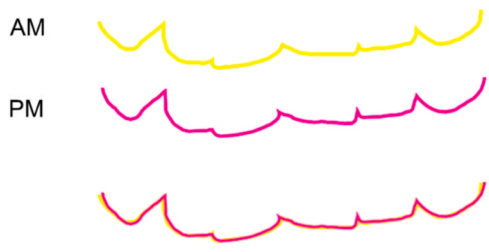


**Fig. 7.** “AM” and “PM” smile lines compared next to each other and then superimposed

## 4. Results

### 4.1. Procedure 1 – Convergence of the smile lines from the “AM” and “PM” photographs

In order to confirm the usefulness of this method as a tool helpful in human identification, grading was introduced to determine the accuracy of mapping the lower contour of the upper teeth from the “postmortem” photo in relation to the original image (“antemortem”, delivered by the family; in this case provided by the participants).

Accuracy of the compared smile lines has been assigned according to the scheme designed by the authors:

- Exact match – all the teeth almost perfectly overlap in both arches. Inequalities are so insignificant that they do not affect the result of the comparison and result from an error during the process of marking the lines.
- Satisfactory – one or two teeth do not match perfectly. It is caused by a slight skewing of the head in the “PM” photo in relation to the original position from the “AM” photo in one or more planes. Such a comparison is still considered acceptable because the shape of the teeth, although not equated with the original pattern, still allows for a strong resemblance.
- Tolerable - when only the shape of the first upper incisors overlaps and the contours of the remaining teeth are lower or higher than the “AM” contour; inaccuracy involving more than two teeth.
- Insufficient – contours of the teeth have significantly different shapes. This is due to the poor head position of the individual relative to the original position in the “AM” picture.

The comparison of smile lines from 28 pairs of photos was analysed. The majority of smile line sets (17 pairs, 61%) align almost perfectly, and were classified as "exact match". Six pairs (21%) showed some minor shortcomings due to slight differences in the position of the head in the compared photos, and they were described as "satisfactory". Three pairs (11%) were defined as "tolerable" wherein the inaccuracies concerned more than two teeth, and finally two pairs (7%) were classified as "insufficient". In total, 82% of cases can be considered positive (from the categories exact match and satisfactory), thus allowing confident identification based on a comparison of the incisal contours of the anterior upper teeth.

Fig. 8 shows selected sets of “AM” and “PM” smile lines from all the categories. Examples A1 and A2 are unquestionably similar, therefore resulting in the determination that the contours belong to one and the same individual; these were assigned to the category “exact match”. In the C1-C2 set (“tolerable”), it can be observed that the lines began to diverge at the level of the second incisors, which is in contrast to B1-B2 (“satisfactory”) where the defect mainly concerned the canines, indicating a slight change in position that does not largely disturb the image of the dental arch. The difference is dependent upon the axis (one or more) along which the head has changed its position. In picture C1 there was rotation to the right and


**Fig. 8.** Selected comparison of the smile lines from "AM" and "PM" pictures classified as exact match [A1,A2], satisfactory [B1,B2], tolerable [C1,C2] and insufficient [D1,D2] – procedure 1 of the study

**Table 1**
Focal lengths of "AM" photos next to the most suitable focal lengths for taking a "PM" photo

| Category | no | AM [mm] | PM 18 mm | PM 55 mm | PM 80 mm |
|---|---|---|---|---|---|
| Low focal lenght | 1 | 28 | ✓ | ✓ | |
| | 2 | 28 | | ✓ | |
| | 3 | 32 | ✓ | ✓ | |
| | 4 | 36 | | ✓ | |
| | 5 | 40 | | ✓ | ✓ |
| Medium focal lenght | 6 | 40 | | ✓ | ✓ |
| | 7 | 45 | | ✓ | ✓ |
| | 8 | 62 | | ✓ | ✓ |
| Higher focal lenght | 9 | 63 | | ✓ | ✓ |
| | 10 | 67 | | ✓ | ✓ |

flexion forward toward the position in the AM picture, while in C2 there was rotation to the left and the head was also bent forward. The D1-D2 pair shows smile lines classified as "insufficient". These are cases where the shape of the borders of some teeth from a "PM" photo is not sufficiently similar to those of the "AM" line. The reason for this was a significant mistake in the head position in several axes in the "postmortem" photographs taken during the experiment. This is a characteristic mistake in this type of research as a by-product of working with a living person, and it is not possible to repeat this part of examination on later stage of a research. Although some of the teeth in the two lines overlap, the dentition cannot be unequivocally qualified as the teeth of the same individual, because there is not enough agreement between those lines.

### 4.2. Procedure 2 – Connection between smile lines and focal length

Ten pairs of "AM" and "PM" photos were analysed. The focal length of "AM" photos was chosen by chance, and eventually oscillated between 28 and 67 mm. To facilitate the presentation of later findings, focal lengths of "AM" photos were divided into three groups and included:

- low focal lengths: 28 mm (twice), 32 mm and 36 mm;
- medium focal lengths: 40 mm (twice) and 45 mm;
- higher focal lengths: 62 mm, 63 mm and 67 mm.

Table 1 shows what focal length is most useful for taking a "postmortem" photo with reference to the focal length of the source

image (“antemortem”). In some cases, two focal lengths were appropriate. It is worth noting that the smile line from the “PM” photo taken with 55 mm focal length was suitable for all “AM” photos. However, analysing the results within groups, some patterns can be observed: the best focal length for taking the “PM” photographs was a focal length of similar value, as used for taking “AM” photo. This is particularly noticeable when comparing “AM” and “PM” photos taken with the most distal focal lengths. In most cases, it coincided with the expectations arising from the optical properties of the equipment, which have been mentioned earlier.

For "lower focal length" photographs, the result turned out to be ambiguous. With the use of 18 mm focal length for the “PM” image, in half of the cases (2) the contour of the teeth was perfectly reproduced, while in the other two there was too much distortion typical for this construction. The 80 mm was a focal length clearly too distal, as smile lines from “AM” (28, 32, 36 mm) pictures showed visible distortion in the center of the contour as compared to “PM” arches taken with 80 mm focal length. The 55 mm focal length was suitable for every focal length of “AM” photograph.

The medium focal lengths are characterized by a much lower potential for distortion, therefore “PM” smile lines from photos taken at 18 mm focal length are certainly different from “AM” smile lines. The distortion is too visible and causes the enlargement of the first molars and the bulge in the center of the frame, lowering the contour down. Both 55 mm and 80 mm focal lengths, free from optical defects, perfectly reproduce the contour of teeth from “AM” images.

In the “AM” photos from the group of the highest focal lengths, the same relationships as in the previous category can be observed, but in this case, the difference between the focal length of 18 mm and “AM” smile lines can be seen even more clearly. Fig. 9 presents examples of combinations from each of the focal groups.

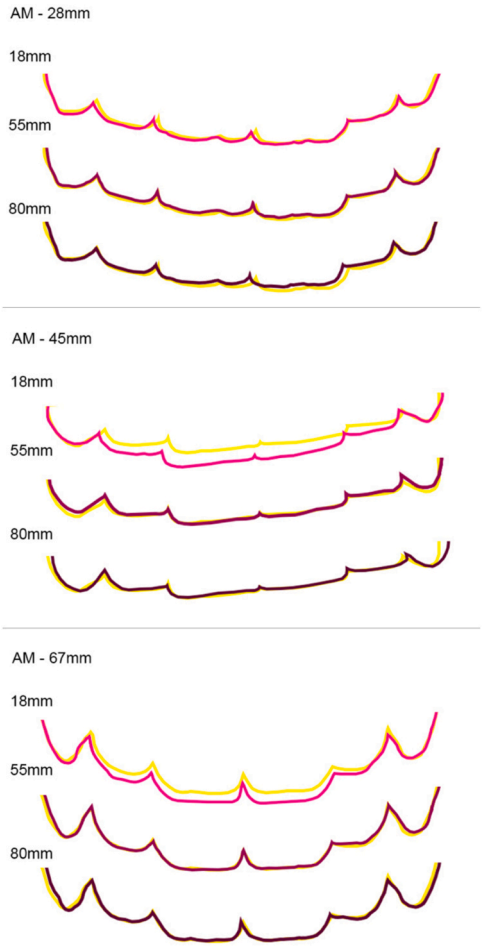


**Fig. 9.** Examples of smile line sets from all the focal length categories – procedure 2 of the study

## 5. Discussion

The results show that the method of comparing the incisal contours of the upper teeth, although burdened with possible errors, can be successfully applied in human identification. Teeth, similar to fingerprints, are an individual signature assigned to each person [8], therefore new methods of analysing and interpreting the available data are still sought. The analysis of almost 40 pairs of dentitions underscores not only the differences between the photographs of the dentition, but also between marked smile lines.

This experiment was carried out according to a predetermined pattern, focusing only on a comparison of the incisal contours of the anterior maxillary teeth. However, in a real investigation, a forensic expert decides whether the teeth from the AM picture sufficiently correspond to those in the PM photo observing shape of the whole crown of teeth, their position in relation to one another, possible fillings or cavities, etc. The morphological appearance of the teeth is of great assistance – the less standard, the easier to classify. It is therefore crucial to use more than one method of analysing the available data, especially when one of the methods (as was in this case) is not yet widely used and validated.

Our research was biased with one fundamental disadvantage, which was working with living subjects. Previous studies on this matter [9,14] were based on tooth casts taken from participants. The cast replaced the participant, and it was photographed as a “PM” object. This enabled the free manipulation of the model for an indefinite period, along with the repetition of unsuccessful shots if any shortcomings have been identified during the digital analysis of the recreated “AM” position. Unfortunately, it was impossible to repeat the “postmortem” photographs taken at school, hence the need of division into several matching categories shown in the results - it was not always possible to perfectly reproduce the position of the individual from the AM photo as it would be when working in a laboratory with human remains.

With the increase in interest in photography among non-professional users, most of the photographs that will be delivered to the police in the case of a missing member of the family will be probably taken either with mobile phone cameras or with cheaper, more amateur devices, comparable with the one used in our study. Hence, the focal length of the photographs will very likely coincide within the range from 18 to 55 mm – and quite often with those marginal values as the zoom lens most often added to amateur DSLRs cameras is 18–55 mm.

A greater part of the photographs received from the participants were selfies. It shows how current trends are alive in everyday life, and in the lives of the youth in particular, as the majority of the participants from procedure 1 attends high school. Perhaps the large number of selfies resulted from convenience, providing that nowadays taking a picture requires less time than searching for the best shot in photo albums. However, far-reaching conclusions about the form of comparative data received from the families of the missing persons should not be drawn on the basis of that consideration. In the event of a missing relative, the family makes an effort to ensure that the pictures meet the requirements of the law enforcement agencies to the greatest possible extent. A selfie, usually taken with a phone positioned close to the face, can be burdened with some facial distortions, because the lenses in mobile phones have a wide viewing angle. It is worth taking this into account when selecting the lens for taking PM photos. The focal length information is stored in the original file, which has not been subjected to major graphic

processing. It can be found in graphic software as EXIF information. For unknown reasons, almost all “AM” photographs gathered from the participants were devoid of EXIF data, a situation that can be highly comparable to real-life case, therefore, in this part of the research the authors did not focus on selecting the lens with the appropriate focal length.

Selfie pictures are often taken either with a front camera, in the mirror, or in various types of mobile applications, meaning the orientation of the picture must be taken into significant consideration so as to ensure it is not flipped. When such an occurrence takes place, the face as well as the teeth are a symmetrical reflection (turned by 180°) of their real image. Due to such an oversight, 2 of the 30 participants who initially took part in procedure 1, had to be excluded during the graphic analysis. When the head of a person in the AM picture is in an upright position, it is possible to flip the picture horizontally to the correct side without major consequences for the comparison results. However, when the head is tilted to one side after changing the position, the dental arches will not overlap.

The issue of subjectivism in the assessment also needs to be considered - how does one determine when the match is already sufficient for a positive identification, and when it is not? The division proposed in this study seems to provide a certain solution to this issue.

The second part of the study (procedure 2) focused on the focal length of the photographs that were analysed. Participants were photographed under fixed laboratory conditions, i.e., with a front-facing camera. In order to investigate how the phenomenon of lens distortion affects the symmetry of the dental arches in the pictures, the faces of the photographed persons were positioned in the center of the frame, as the defect is most visible in this area. The analysis of the results from this part of the study showed that it is worth considering mainly whether the AM photo was taken with a wide-angle lens. If a low value focal length has not been used to take a picture (up to approx. 40 mm), it seems that there are no significant differences between the AM and PM smile lines that would require the choice of an identical or highly similar focal length for the comparative picture (PM). Overall, to create good quality PM photos it seems reasonable to focus mainly on choosing a lens of advanced optical properties and brightness in order to get a picture of high sharpness, thus capturing all details. A fixed focal length lens certainly meets these standards. The most favorable focal length would be within the range of standard lenses, from 50 mm (viewing angle similar to the human eye angle) up to approximately 85 mm, such as for typical portrait lenses, as the possibility of distortions in these cases is the lowest. If it is known that the AM photo was taken with a wide-angle lens, or a mobile phone, it is better to choose a lens with a wider viewing angle.

Despite the aforementioned drawbacks, the analysis of the borders of anterior teeth is a method that has a number of advantages:

- low cost – it does not require the use of expensive equipment and complicated computer software (the ability to analyse even in PowerPoint [10]);
- photographing is now so popular that there is a very high probability of finding an appropriate antemortem picture presenting smile, or otherwise the incisal border of the maxillary teeth, of the missing person;
- ability to observe cavities, fillings, gold implants, and other individualizing characteristics;
- the usefulness of the method in the absence of medical or dental data;
- it can serve as a supplement to previously used and validated methods;
- individuality and uniqueness of the tooth pattern.

Forensic anthropologists, odontologists and medical examiners must face the challenges of the modern world. In the era of ever-growing transport and technological advancements, traveling has become a part of everyday life. Migration of peoples, especially pertaining to illegal immigration, terrorist attacks or natural disasters, often leave forensic experts without any possibility of finding missing individuals or assigning identities to unidentified remains. These limitations are solely due to the lack of clues that could lead the investigators to the victim's personal data. Therefore, there is a great need for an international information exchange and the creation of databases, which would make the data currently used by law enforcement agencies widely available.

It is also critical to raise awareness among dentists to create and store archives containing the medical data of their patients. In each country there are legal regulations regarding the minimum time of data storage, for example two years in England, Wales and Scotland, and six years in Northern Ireland [21]. In some specific occurrences this time increases, and each such case is specified in the relevant regulations [21,22]. However, it is recommended that medical data should be stored for longer than the minimum time allowed.

This study was created to visualize the application of the method on human remains during the real investigation, check the repeatability of the results on a larger group (available case reports were carried out only on one person, the deceased), and also to check for the first time whether the focal length used by the expert to take a postmortem photo affects the effect of comparison and consistency of results. The objectives established for this research have been achieved. The results show that the comparison of alignment of the teeth is a tool that allows to obtain a positive identification. In addition, the choice of the focal length of the lens to take a PM picture is important as shown in procedure 2. That is why it is worth paying attention to the focal length of the photos provided by relatives. Such information should be sought in file’s EXIF data. If it is not available, the information about the camera should be obtained from the family or ultimately, one should observe the elements in the photo which may lead to the proof of potential distortions (for example: fences, wires, other vertical or horizontal lines). When the information about AM photo focal length cannot be got it is safer to use 50 mm focal length or more, because it minimizes the risk of distortion.

## 6. Conclusions

The results obtained in the first part of the study (procedure 1) are optimistic. A great majority (93%) of the determined “PM” lines in the experiment coincided with the “AM” line retrieved from a photograph delivered by each participant of the study. The observed minor errors resulted mainly from:

1. In case of the "exact match" category - pen tool inaccuracies. Sometimes the selected area was slightly higher or lower from the exact border of the teeth, but it did not impinge on the comparison of the two lines.
2. In case of the other categories - smaller or larger differences in the position of the participant's head in the “PM” picture in relation to its position in the “AM” picture along the Y, X, Z axes, or different distance of the camera from a subject. Depending on the size of the error, the mismatch between the lines differed, but as long as the position of the person in the two pictures did not differ significantly, the shape of the teeth remained very similar.

The results of procedure 2 indicate that the choice of focal length when taking a PM photograph of a smile line is highly relevant. This is especially noticeable when comparing AM and PM smile lines marked from pictures taken with more distant focal length values. Low-value focal lengths are exposed to the phenomenon called

optical distortion, which causes the alteration of the image, especially in the center of the frame and when the object is close to the lens. In the analysis of smile photographs, it translates to changed proportions of the face and teeth, as well as the changed shape of the smile alignment. The use of similar focal lengths while collecting PM data allows for the most accurate comparative analysis, thus helping to improve the reliability of the results, ultimately resulting in a positive identification.

Further research under more rigid test conditions is needed to analyse smile photographs on a larger research sample in order to establish criteria for positive identification, improve and validate the already existing techniques, and to work on the development of new identification methods using non-standard tools.

## CRediT authorship contribution statement

**Melania Mazur**: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft preparation, Writing – review & editing, Visualization, **Katarzyna Górka**: Conceptualization, Writing – review & editing, Visualization, Supervision, **Inmaculada Alemán Aguilera**: Writing – review & editing, Supervision.

## Declarations of Competing Interest

None.

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