

# DOES THE QUALITY OF DENTAL IMAGES DEPEND UPON PATIENT'S AGE AND SEX? – EXPLANATIONS FROM THE FORENSIC SCIENCES

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## ABSTRACT

The objective of this analysis was to investigate the dependency of image quality of dental panoramic radiographs on patient's age and sex, and to demonstrate that forensic science can explain these relationships. The image qualities of 100 dental panoramic radiographs obtained from 50 patients with two devices were assessed by ten independent observers of different specialisations. Image quality decreased with increasing age of the patients ( $P=0.003$ ). One of the devices turned out to be superior to the other; however, this difference between the devices was present only in older patients but not in young ones ( $P=0.03$ ). Image quality was higher in women than in men ( $P=0.01$ ). The observed influences of age and sex are explained by results of forensic investigations concerning age-related changes of the dental pulp and sex differences of the skull geometry. Thus forensic science can elucidate effects relevant for everyday clinical practice. Studies on dental image quality must consider age and sex of the patients.

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**Keywords:** forensic odontostomatology, age estimation, sex differences, dental panoramic radiography, image quality

## INTRODUCTION

X-ray imaging became generally available to dental practitioners in the past few decades and is widely used. Numerous investigations on image quality in dental radiography have been carried out in order to compare, for example, several devices, different operational modes of devices, the effects caused by varying radiation doses, and various techniques of image processing. The possibility that dental image quality as a matter of principle might be related to age and sex of the patients

was mentioned years ago.<sup>1</sup> However, a data based examination of this issue has never been presented so far.

The data we deal with were originally collected for a comparison of two imaging devices. However, the scope of the analysis presented herein is to demonstrate that the image quality of panoramic radiographs depends on age and sex of the patients by using empirical data. Results of forensic investigations concerning the estimation of age and sex provide plausible explanations for these phenomena. The consequences for forensic and radiological practice and investigations will be discussed.

According to the intention of this paper, a review of the image quality literature will not be presented here. The reader who is not familiar with the matter may refer, for example, to Dannewitz et al<sup>2</sup> in order to see a typical study on image quality and to get a link to further references.

## MATERIALS AND METHODS

### Radiography devices

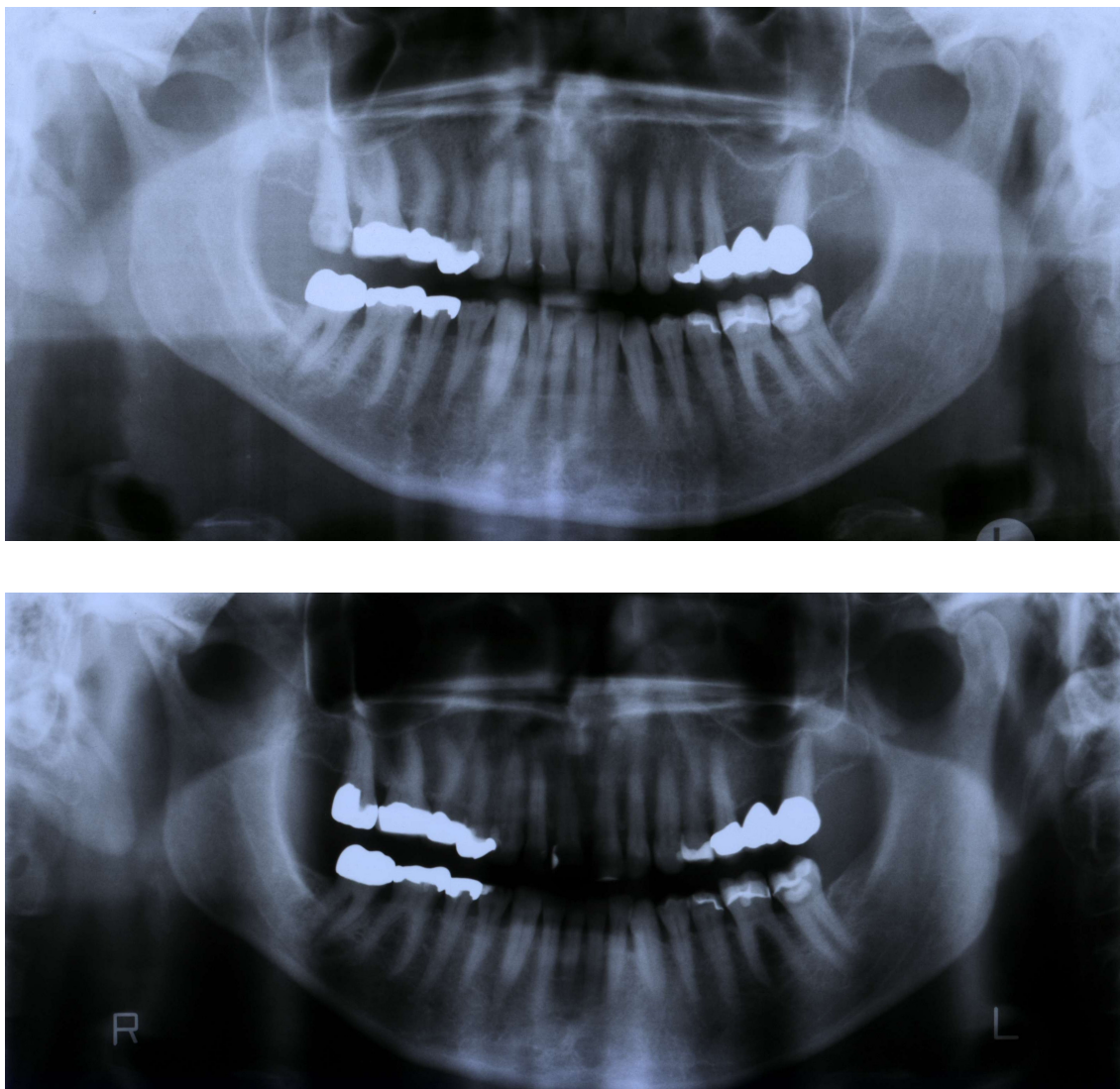
Radiographic images were obtained by using Orthophos Plus Ceph<sup>®\*</sup>, programme P1, with Lanex Regular Screens<sup>†</sup> for image output, and Veraviewepocs<sup>®‡</sup>, programme P1, with output on Grenex HR-12 Super HR-S 30 screens<sup>§</sup>. These two devices will

\* Sirona Dental Systems GmbH, Bensheim, Germany

† Kodak, Rochester, NY, USA

‡ J. Morita MFG Corp., Kyoto, Japan

§ Fuji, Kanagawa, Japan



**Fig.1:** Panoramic images of the same patient obtained with OPC (upper panel) and VVE (lower panel).

be referred to as OPC and VVE, respectively, in the following. VVE was working with lower exposure to radiation than OPC (time 8.2 vs. 14.1 seconds, respectively, at similar tube current and voltage). For all radiographs taken with both techniques the same developer solution and device was used. Figure 1 shows panoramic images of the same patient obtained by both devices.

### **Subjects**

Radiographs of 50 patients (27 male, 23 female) aged 17-75 years were included in the study by screening their files for the presence of two consecutive panoramic images, one obtained with OPC and one

with VVE. Exclusion criteria were any missing teeth that were subject to assessment in this study, or major treatment of such teeth in the time between the dates of the two radiographs, as well as concomitant diseases associated with significantly impaired bone mineral density (e.g. osteoporosis). As the study was retrospective, and no clinical or identity data of the patients were processed, a vote of the ethics committee was not necessary according to German legal requirements.

### **Assessment of images**

All 100 images were presented to ten observers of different specialisations (dental radiologists, oral and maxillofacial

**Table 1:** Landmarks included in the assessment of image quality and their grouping into anatomical regions.

Anatomical region	Items subject to assessment
Dentoalveolar region	Root canal Periodontal ligament space Periapical region Crown and Filling  each assessed for first incisors, first premolars and first molars
Maxilla	Anterior nasal spine Nasal septum Maxillary sinus Floor of maxillary sinus Maxillary tuberosity
Mandible	Condylar process Coronoid process Mandibular canal Mental foramen Inferior cortex

surgeons, orthodontists, dental practitioners, students of dental medicine) in random order. Information regarding the radiographic device used and patients' data, in particular age and sex, were blinded. The Planilux LJS 75x44 AP/HER screen\*\* was used for presentation. Each observer assessed the image quality by separate ratings of each of the anatomical details listed in Table 1. The possible ratings were the following five levels: 100 = excellent, 75 = good, 50 = moderate, 25 = poor but still usable, 0 = inadequate for clinical use.

### Statistical analysis

Total image quality was computed as the average of all particular ratings across the ten observers and the 42 items assessed on each image. This overall score was computed for each patient and both OPC and VVE images. Furthermore, regional image qualities were computed for each of the dentoalveolar, maxillary and mandibular regions by averaging only over

ratings concerning items of the respective region (see Table 1). Because image quality scores were averages of multiple particular ratings, they could be treated as continuous variables, so parametric methods were used. Normality was examined using the Shapiro-Wilk test. Agreement of observers was described by the intra-class correlation coefficient (ICC). Repeated measurement analysis of covariance was applied to assess the dependency of image quality on age (covariate), sex (between-subject factor) and device (OPC or VVE, within-subject factor). The particular relationships of age and sex to the image qualities in the three anatomical regions were investigated using Pearson's correlation coefficient. Parameter estimates are accompanied by 95% confidence intervals (CI) and P-values for the test of the null hypothesis that the respective parameter is zero. P-values less than 0.05 were considered significant. All

\*\* F. Schulte GmbH, Germany

statistical analyses were carried out using SPSS 14††.

## RESULTS

The overall image qualities on a scale from 0 to 100 were ranging from 47.9 to 70.7 (OPC, median 57.1, interquartile range 53.1 to 61.0) and from 41.6 to 67.3 (VVE, median 52.7, interquartile range 49.7 to 55.7). Normality of the image quality scores was accepted ( $P=0.60$  for OPC,  $P=0.89$  for VVE). Inter-observer agreement was high ( $ICC=0.92$ , 95% CI: 0.85 to 0.95, for OPC and  $ICC=0.85$ , 95% CI: 0.79 to 0.91, for VVE).

### Relationship between image quality and age and sex

The relationships between image quality, age and sex of the patients, and imaging device are displayed in Figure 2.

There are two kinds of relationship between age and image quality. First, image quality decreased with higher age of the patient, regardless of patient's sex and of the imaging device. This is illustrated by the negative slopes of all regression lines. For each ten years of age, average image quality was reduced by 1.0 point (95% CI: 0.6 to 1.7,  $P=0.003$ ). In terms of analysis of covariance, this is called the main effect of age.

Second, Figure 2 suggests that the scoring is better for OPC images than for VVE images, since the regression lines for OPC (dashed) are above the lines for VVE (solid) for both sexes. The magnitude of this superiority was depending on age, illustrated by the lines drifting apart from each other when seen from the left to the right. In statistical language, this is called the age-by-device interaction. The mean difference between the devices increased by 1.1 points per decade (95% CI: 0.1 to 2.1,  $P=0.03$ ). Consequently, the superiority of OPC over VVE should be expressed as a linear function of age rather than by a single quantity. For example, the estimates for difference between the devices was 1.8 points (95% CI: -1.6 to 4.9,  $P=0.22$ ) for patients aged 20 years, but 6.9 points (95% CI: 4.2 to 9.6,  $P<0.001$ ) for patients aged 65 years.

Another observation is that women had higher ratings than men. This is illustrated by the fact that for each of the devices the regression lines for women (Fig.2, right panel) lie above the corresponding lines for men (left panel). The mean difference between sexes was 2.8 points (95% CI: 0.6 to 5.0,  $P=0.01$ ). This influence of sex on image quality was present independently of age and device, as there was no significant interaction of sex with age ( $P=0.74$ ) or device ( $P=0.65$ ).

Age, sex and device explained 33% of the variance of overall image quality.

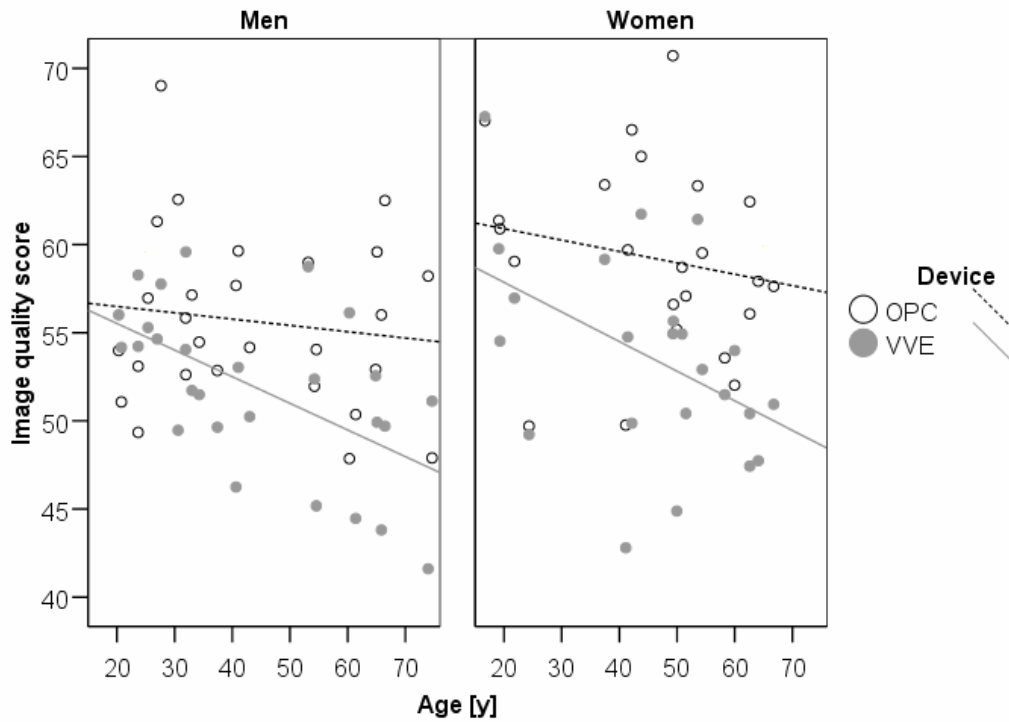
### Differences between the anatomical regions

The results of pairwise correlation analysis of age and sex with image quality in the three anatomical regions are summarised in Figure 3. For comparison, correlations with total image quality are included. Note that the P-values of the latter differ slightly from those of the analysis of covariance results mentioned above, since they were computed from pairwise correlation.

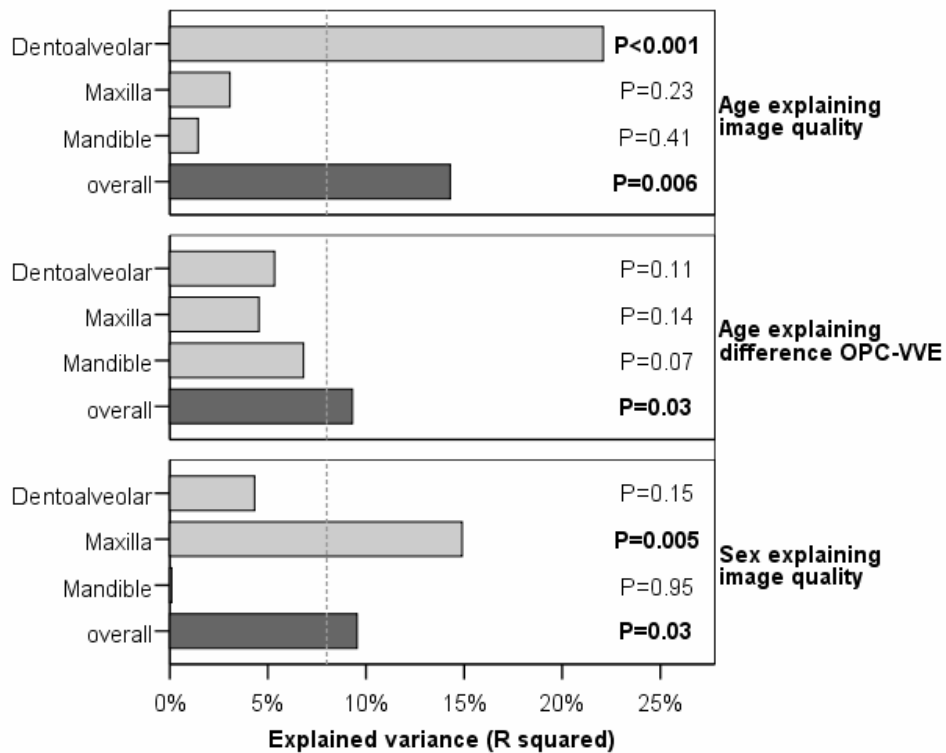
From the upper panel (Fig.3) it can be seen that the main effect of age as described above is attributable to the dentoalveolar region since only the quality score for this region was significantly correlated with age. The correlation of age with the overall score was lower than with the dentoalveolar score alone. Thus, in terms of statistics, averaging over all three regions somewhat obliterates the essential information on age hidden in the dentoalveolar region.

In contrast, the detailed analysis of the age-by-device interaction effect shows another pattern (Fig.3, middle panel). The correlation of age with the difference between the devices (OPC minus VVE image quality) was not significant in all three anatomic regions. However, the correlation coefficients were similar (0.23, 0.21 and 0.26, respectively), and averaging over the regions resulted in a significant correlation of age with the total score. This pattern is typical for the statistical scenario that each of several components (scoring of the three regions) contains a small piece of the same type of information. Averaging over all components accumulates this information, leading to stronger correlation

†† SPSS Inc., Chicago, IL, USA



**Fig.2:** Overall quality of the panoramic radiographic images depending on age, sex and device. Each circle corresponds to one image. Regression lines were computed separately for both images and both sexes.



**Fig.3:** Variances of image quality explained by age (upper panel), the age-by-device interaction (middle panel), and sex (lower panel) in the three anatomical regions and overall.

and thereby, higher explained variance and higher statistical significance.

The situation for the effect of sex is similar like for the main effect of age, with the difference that the essential information is now contained in the maxillary region (Fig.3, lower panel). While the relationship of sex to the quality scoring of maxillary items was considerable, no meaningful correlation was found for the dentoalveolar and mandibular regions. Again, averaging over all regions resulted in lower explained variance and weaker significance for the overall image quality, compared to the scoring for the maxillary region alone.

## DISCUSSION

We demonstrated that subjectively assessed image quality of dental panoramic radiographs depends upon age and sex of the patients. Such findings in empirical data are presented for the first time. We should therefore, first, exclude that findings were misled by significant bias in the data, and second, explain the results. According to the correlation pattern (Fig.3), these explanations should be based on facts solely related to dentoalveolar structures for the main age effect and to the maxilla for the effect of sex. On the other hand, the dependency of the difference between the devices upon age should be explained by arguments which are not associated with a specific region.

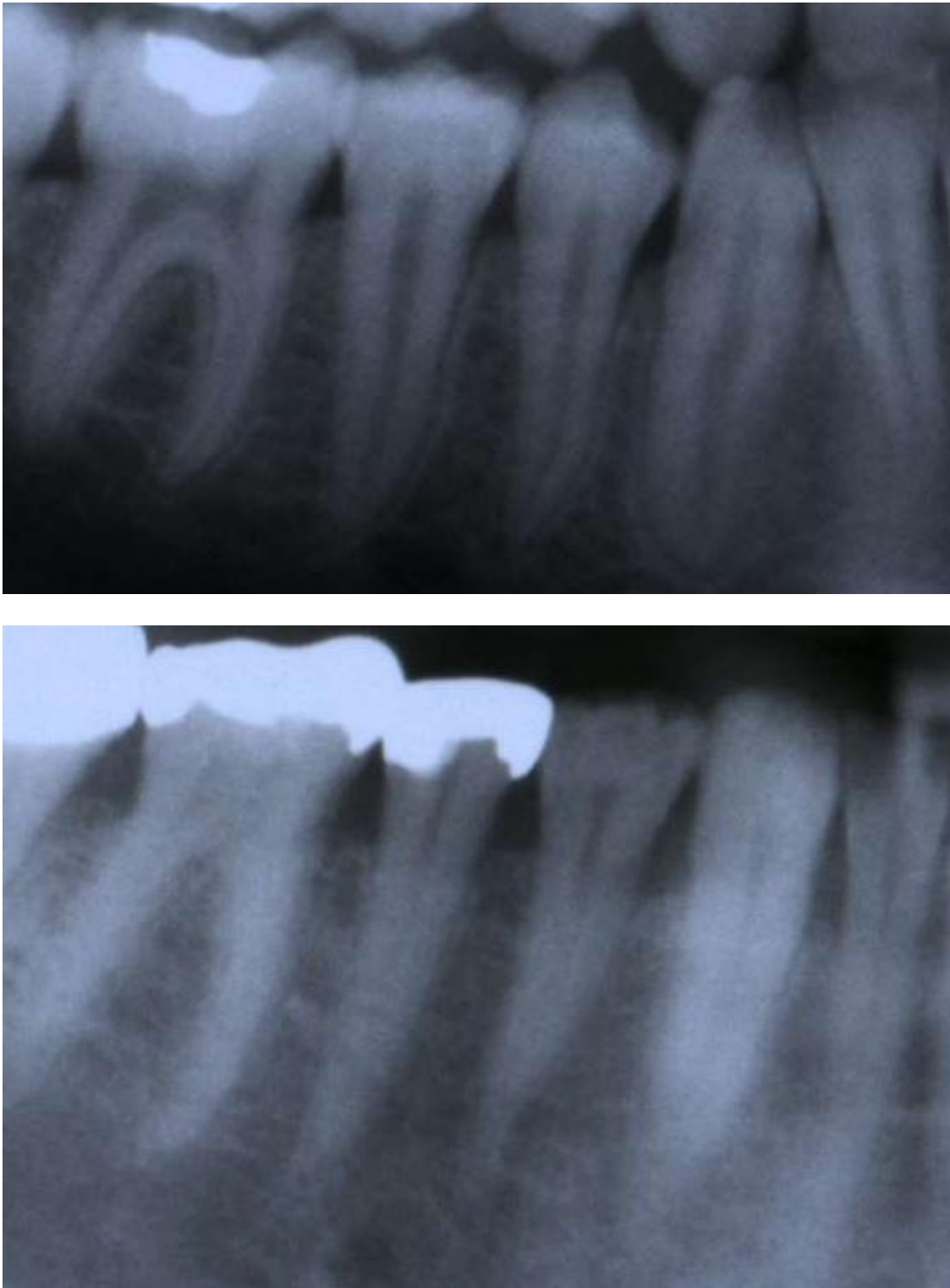
### Discussion of potential bias

Due to the design of data collection, there was a time lapse between the two images obtained from each patient, ranging from few days to 4 years, on average 2 years. In regard of the loss of image quality with increasing age estimated to be 1.1 scale points per decade, the time lapse may be expected to be associated with an average change of image quality by 0.22 scale points. This quantity is small compared to the effects presented in the results section, hence the resulting bias is modest (if present at all). Indeed, when we performed our computations again with adjustment for the putative time lapse bias, the results were not altered. We conclude that the influence of the time lapse can be neglected.

## Explanations of the results

We first look for an explanation why higher age is associated with lower image quality. It is known that secondary dentin causes a narrowing of the dental pulp.<sup>3</sup> This effect is stronger in the elderly<sup>4</sup> and so it has been used to establish formulas for forensic age estimation.<sup>5-7</sup> The same phenomenon which plays an important role in forensic science seems to be responsible for the correlation of age with image quality. Narrowing of the pulp lowers its recognisability, thus it is plausible why the corresponding ratings for image quality are worse. If this would be the right argument, only ratings for this particular item but not the ratings for other anatomical structures unrelated to the pulp should depend upon age. Indeed, the analysis illustrated in Figure 3 shows that a significant correlation with age is present only in the dentoalveolar region, but not in the maxillary and mandibular bone structures. Going more into detail, we found that the quality ratings related to all pulps under examination contributed the main part of this correlation, while the ratings for crowns and fillings were not at all correlated with age. In addition, regressive changes occurring along with ageing, e.g. microvascular calcification, may have caused that the periodontal ligament spaces and the periapical regions may appear somewhat blurred and cloudy on the images. This will, of course, contribute to lower quality ratings, but the correlations between age and the ratings for the respective structures were of minor extent. After all, narrowing of the pulps used in forensic age estimation turned out to be the key explanation for the relationship between age and subjective image quality. An illustration of the effects discussed here is given in Figure 4.

Now we deal with the age-by-device interaction, i.e. with the question why lowering of image quality in elderly was stronger with the VVE than with the OPC device. Decline of bone mineral content and density is a further phenomenon correlated with age,<sup>8,9</sup> and changes in bone tissue texture may affect image quality. It seems plausible that X-ray image quality is only marginally lowered by declining bone mineral content or density when using a sufficient dose of radiation



**Fig.4:** Regio 42 through 46 in the panoramic images of two female patients of different ages: 18 years (upper panel) and 58 years (lower panel). Both images were obtained with OPC. Narrowing of the pulps and microvascular calcification in the older subject makes it more difficult to recognise the dentoalveolar structures.

like done with OPC. By contrast, image quality may be more affected when a reduced radiation dose is applied like done with VVE. This is exactly what we observed in our data (Fig.2). Moreover, loss of bone mineral content concerns basically all, not particular, bone structures, thus its influence (if present at all) should be seen in all anatomical regions we considered. This matches our results as the age-by-device interaction was not a region-specific effect (Fig.3, middle panel). Note that decline of bone mineral density is not so closely correlated with age as are other age-related anatomical changes, so it does not provide reliable information in forensic age estimation. Again, this is consistent with our observation: the variance of image quality in the dentoalveolar region explained by the age was much higher than the variance of image quality explained by the age-by-device interaction (see Fig.3).

Finally, we should examine the possible reason why women and men differ in their panoramic image qualities. Recall that in a panoramic imaging device the X-ray tube and the screen are flexible parts which move around the patient's head fixed in the centre of the device (Fig.5A). The movement of a panoramic imaging device is adapted to a human "standard" skull such that the distance between the anatomic structures of interest and the screen is all the time kept optimal to obtain an image of high quality (Fig.5B). The standard is based on the averages of measures of the skull geometry in the population. Any individual departure from the standard may cause that the distance between skull and panoramic screen is no longer optimal at least in certain positions of the device (Fig.5C). This may obviously result in suboptimal image quality. The more individual a skull is (the more it departs from the "standard" geometry), the higher is the risk of suboptimal distances during panoramic imaging and hence the risk to obtain an image of low quality (Fig.5D). Now forensic knowledge comes into play. Some forensic methods to predict sex are based on geometric properties of the skull.<sup>10</sup> Studies which aimed to develop such methods found that the distances between certain landmarks have higher variance in men than in women.<sup>11</sup> More important, the correlations of such distances were found to be stronger in women than in men.<sup>12</sup> In

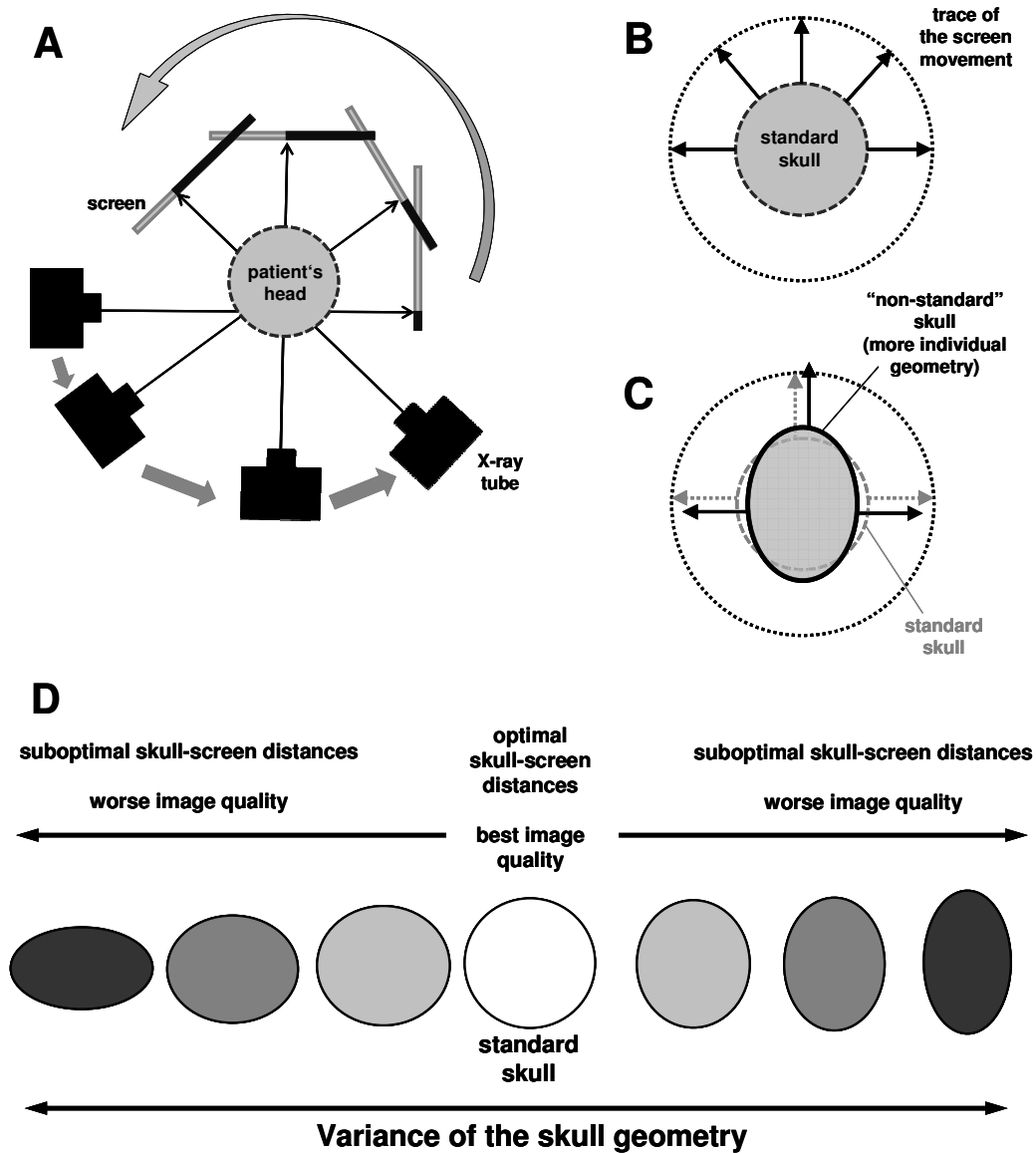
other words, the variability of the individual shape of skulls is larger in men than in women. In combination with the considerations above, this implies that more men than women are at increased risk to provide panoramic images of low quality, and hence the average quality of panoramic images is better in women than in men. It is noteworthy that this effect occurs predominantly in particular anatomical structures. Among the three anatomical regions we considered, the variances of geometry were reported to be largest in the maxilla.<sup>11,12</sup> This is consistent with our data: the mainpart of the difference between sexes was found in this region (Fig.3, lower panel).

## CONCLUSIONS

The immediate clinical implication of our findings, in particular of the age-by-device interaction, is that loss of image quality associated with reduced radiation dose does not occur in all age groups. It is possible for young subjects to use lower radiation doses without significant loss of image quality, which is especially interesting in regard to the risk of cumulative exposure to radiation over lifetime.

This may also have implications in the context of criminal proceedings. Here the question is often whether a subject under investigation, not possessing personal documents, has reached the age of criminal responsibility (i.e. 14 years in Germany). Assessment of the mineralisation of the third molars is then routinely performed. However, German radiation law and safety regulations require to justify any application of radiation in living individuals. In case the subject does not agree, the X-ray procedure must be ordered by a judge who may have concerns when that person is potentially a child. Thanks to our results we can state that panoramic imaging using a reduced (and hence much less harmful) radiation dose is able to provide images of first class quality in young subjects. This argument may influence the judge's decision in favour of the diagnostic procedure.

Another implication arises in the context of the identification of dead bodies. Here dental films are used for imaging purposes.



**Fig.5:** Movement of a panoramic device during imaging (A). The distance between screen and target object is designed to be optimal for a standard skull to obtain high quality images (B). Distances may not be optimal for a more individual skull geometry departing from the standard (C). Higher variance in the skull geometry is associated with more suboptimal distances and hence with a higher risk of worse image quality (D).

Our results about the associations between age and image quality should generalise to other X-ray imaging techniques if our explanations are valid. (By contrast, the effect of sex should not generalise as our arguments were largely based on the special properties of panoramic imaging

devices.) If so, we should conclude that imaging with high radiation dose should be used throughout as dead bodies can not be harmed by radiation, but low image quality due to low radiation dose with subsequent requirement of another image can be avoided. In particular in the setting of a

mass disaster the workflow of the identification team should be rapid and not be slowed down by the need for any repeat procedures.

A consequence outside forensic science is that research on image quality of dental radiographic devices should include age and sex into analysis. Demographic imbalances between patient groups subject to comparison or age selection may bias the outcome. Note for example that it follows from the age-by-device interaction that a comparison of OPC with VVE with a sample of students aged 20 years would have resulted in a marginal non-significant difference. In the same study carried out with elderly aged 65 years, the difference between devices would have been four times larger and highly significant.

Finally, as a more general conclusion, it's an example that forensic odontostomatology and anthropology are not simply sciences about dead bodies, but clinicians many benefit from knowledge of these domains. It was demonstrated that some clinical phenomena relevant to patients may be understood by applying well-established results of forensic research, while there is, at first glance, no straightforward explanation relying on daily clinical experience. It is therefore worthwhile to disseminate the results of forensic research more widely, not confining oneself to forensic applications.

**Conflict of interest:** None declared.

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