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ORIGINAL ARTICLE

Spatial relation between a rigid (digital) intraoral X-ray receptor and longitudinal axes of maxillary teeth

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Abstract The purpose of this study was to quantify the existing (inevitable) angle which in intraoral radiology appears between tooth length axis and receptor caused by the anatomical situation. Especially in the upper jaw, due to its arched anatomy, a true "paralleling technique" is not achievable. The angulation necessarily causes distortion and a foreshortening of the image; hence, the foreshortened image leads to misinterpretations in diagnostics. We investigated the effects of the realistic angulation on these image deteriorating factors. Two hundred ninety-four plaster models of the upper jaw were collected, and the angles between a dummy receptor and the axes of the central incisor or the first molar were measured. For evaluation, a rigid dummy of an intraoral charge-coupled device (CCD) receptor (30 mm×40 mm) was used. The mean angulation evaluated for central incisors was 36.7° (range 19–56°) and for first molars 42.5° (range 26–56°). This leads to a foreshortening of the tooth ranging from 5.4% to 44.1% in the image, when magnification is neglected. Large angles of up to 56°, in both incisor and molar region, result in a relevant underestimation of true tooth length up to 44%. It is important to note that this error cannot be simply corrected by means of local magnification correction. Techniques should be developed that allow for automated assessment of the effective angle to provide information for distortion correction.

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Introduction

A major problem in two-dimensional (2D) radiography is the loss of information by mapping the 3D object onto a 2D image, in particular the loss of the bucco-oral dimensions. One phenomenon of this fact is the appearance of distortions of the object's image if there is a deviation from "paralleling technique", i.e., parallelism between receptor and tooth axis and a perpendicular position of the central beam to receptor and tooth axis [1, 2]. The anatomy, especially in the upper jaw, prevents this ideal parallel positioning of the receptor (Fig. 1). An angle differing from the parallel orientation between the rigid receptor and tooth axis is resulting. The amount of this angle influences the degree of distortion and foreshortening of the object of interest (tooth) in the projection, i.e., the size of the error for example in length determination of the respective tooth (Fig. 2) [3, 4]. Some approaches to assess the imaging geometry for such radiographs have been published. For instance, metallic reference spheres are commonly applied to correct for magnification in dental radiographs using the rule of proportion [7, 11]. On the other hand, techniques to standardize projection geometry [12–16], i.e., the spatial alignment between focus, receptor, and object of interest, and to correct distortion and foreshortening a posteriori have been developed [2–4, 17–19]. In a typical routine work setting, however, these techniques are too time consuming and cumbersome to be applied regularly. With the increasing spread of rigid digital intraoral receptors, the angulation phenomenon is becoming more important.

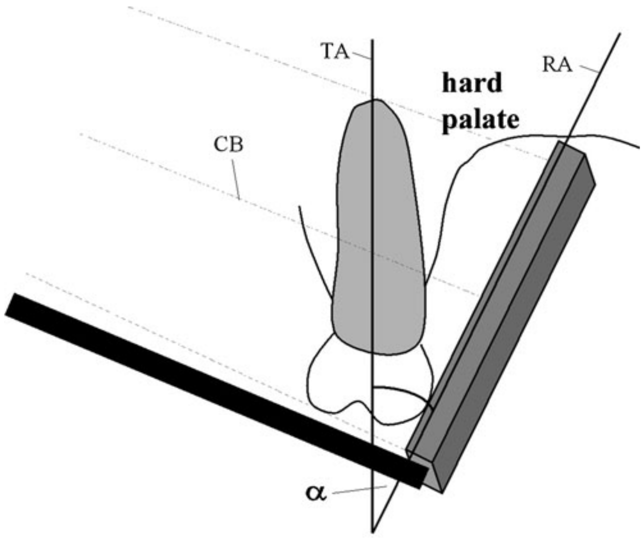

Fig. 1 When applying a typical holding device due to the arched anatomical shape of the hard palate, an angle α results between the tooth axis (*TA*) and the receptor axis (*RA*). Application of the ideal "paralleling technique" is not feasible

To assess the amount of tooth foreshortening in intraoral radiography, it is important to know the actual angle which is generated between tooth and receptor axis. This seems especially important in the upper jaw where its concavity avoids an ideal positioning of the receptor. The distortion of the imaged jaw leads to misinterpretation in assessing bone loss around teeth or dental implants [5, 6] or the bone level when choosing the size of dental implants for edentulous areas on intraoral radiographs presurgically [7–9]. It can also lead to errors in working length determination during endodontic treatment, an underestimation of the distance between the file tip and the apical foramen is reported, when the file was placed too long [10].

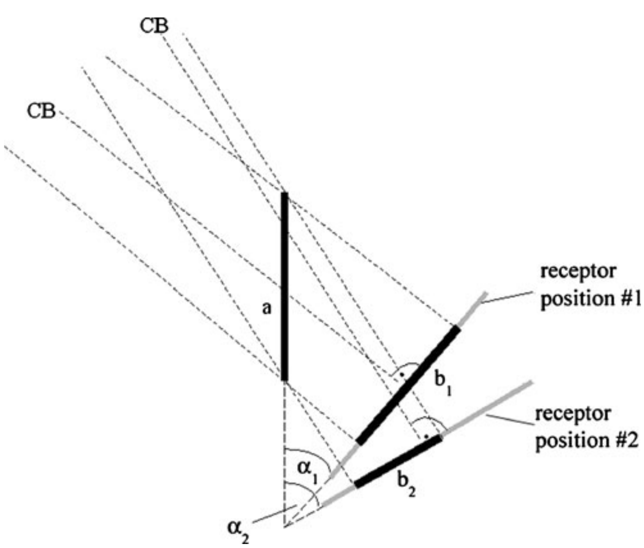

Fig. 2 Schematic drawing of the angle between object axis and receptor for two receptor positions (#1 and #2). For a larger angle ($\alpha_2 > \alpha_1$) between these axes the image of the object (*a*) is decreasing ($b_2 < b_1$). The size respectively foreshortening of the image is a function of this angle. Note that the holding device orientates the central beam (*CB*) perpendicular to the center of the image receptor

Albeit the distortion phenomenon is well known, surprisingly we did not find any published data quantitatively evaluating the spatial relation between image receptor and tooth axis in the human maxilla. Since intraoral radiography is a common and often used technique in every field of dentistry, it is important to know how large the distortion of an object of interest will be. This information could then be used to roughly estimate the ranges of measurement errors to be expected. For this purpose, we designed a study investigating the angle occurring between a rigid X-ray receptor and maxillary first molars or central incisors, respectively. The size of the effective angle provides a means to estimate the amount of tooth foreshortening, i.e., measuring errors which will appear in intraoral radiographs of that region. Some basic equations to compute the amount of distortion will be presented.

The primary objective of this study was to provide quantitative information on the angle caused by anatomical conditions that occurs between a tooth's main axis and a digital rigid image receptor in intraoral radiography. In addition, by applying some basic geometric relationships, we aimed to compute some rough estimations on the resulting amount of image distortion arising from these anatomical conditions.

Materials and methods

Plaster models of the upper jaw were collected from patients of the University Medical Center of the Johannes-Gutenberg-University Mainz in Germany which had to have the presence of at least one permanent first molar or one permanent first incisor. Primary teeth or retained teeth were excluded from the evaluation. The plaster models had to contain a complete cast of the hard palate. The measuring process started by placing a rigid dummy of a commercial CCD sensor (30 mm×40 mm) in a realistic position to receive a complete image of the respective tooth using the right-angle technique. This technique requires the central X-ray to be orientated perpendicularly to the image receptor, which is guaranteed by means of a holding device. The angle between the longitudinal axis of the receptor and the crown's vertical axis was assessed once by one observer (I. v. R.), using a measurement tool in combination with a protractor (Figs. 3 and 4). The tooth axis was defined as the line intersecting the middle of the occlusal surface and the trifurcation (molar) or the middle of the incisal ridge and the root tip (incisor), respectively (for detailed illustration see also [4]). For the central incisors, 18° was subtracted from the measured value to obtain a realistic estimation of the angle between the receptor and tooth axis according to data published in the literature [20]. This approximate estimation of the tooth axis was necessary since the exact shape of the root(s) was not known.

Because of the possible variation of the receptor position and the presumably low measuring accuracy in the evaluation process, the angles were determined without decimal.

Under the assumption of parallel X-rays from the measured angle α the length of the radiographic tooth image can be approximated by:

$$b = a \cos \alpha \qquad (1)$$

where a defines the real length of tooth axis, and b the length of the tooth's image (Fig. 2).

The fraction of foreshortening (f) of the corresponding tooth can be approximated by

$$f = 1 - \cos \alpha \qquad (2)$$

for $\alpha \in \{0°, 90°\}$, irrespective of the actual absolute magnification (Fig. 2). Due to the maxillary anatomy, this range for α is perfectly sufficient (see also Fig. 2). Of course, for an intraoral radiographic setting with a typical source-to-receptor distance of roughly 240 mm and a source-to-object distance of 220 to 235 mm, magnification cannot be neglected. For this imaging geometry, magnification would be roughly in the range of 2% to 9% of the tooth size (computed from the theorem of intersecting lines).

Altogether, 294 plaster models were measured by one observer (I. v. R), comprising 294 first molars and 252 central incisors; 53.2% of the plaster models were from female and 46.8% from male patients.

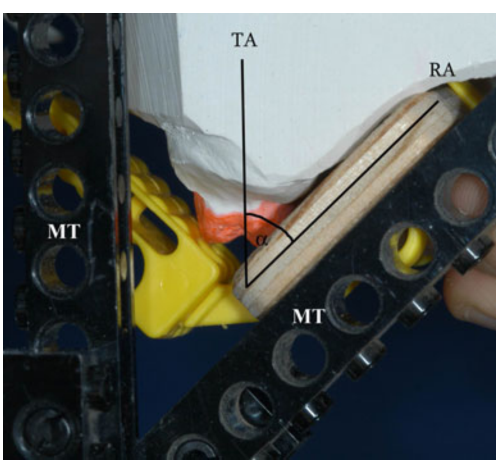

Fig. 3 The manual assessment process for estimating the angle between receptor and axis of the upper first molar (*red crown*). The angle α between the receptor (*RA*) and tooth axis (*TA*) is assessed by extrapolating the vertical axis of the crown. The angle is assessed using a measuring tool (*MT*) in combination with a protractor

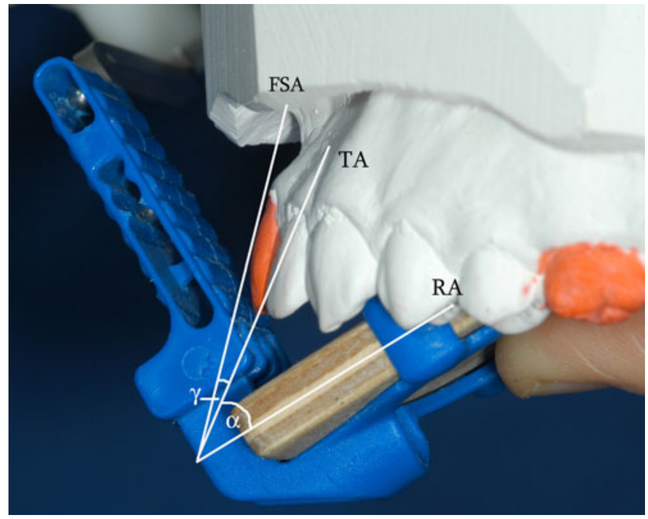

Fig. 4 Situation of the manual assessment process for estimating the angle between the receptor (*RA*) and axis of the upper central incisor (*TA*). The effective angle α between the receptor and the facial surface (*FSA*) is subsequently corrected by subtracting the angle (γ) between facial surface and tooth axis (around 18° according to [20]) from the measured angle ($\alpha+\gamma$)

The data were fed into a spreadsheet software (Microsoft Excel 2000, Microsoft Corp., Richmond, USA) and transferred to a statistical software program (SPSS Statistics 17.0, SPSS, Chicago, IL, USA) for descriptive analysis. Different groups were compared using t test. A p value≤ 0.05 was considered statistically significant.

To evaluate the intraobserver reliability of the measurement process, the angulation of 40 teeth (20 molars, 20 incisors) was measured twice, with the measurements separated by a time interval of at least 3 days.

Results

The mean age of the patients (± standard deviation (SD)) was 39.4±19.7 years, ranging from 12 to 89 years (female patients 37.6±20.2, range 12 to 89 years; male patients 41.6±18.9, range 12 to 83 years).

The angle in the molar region was significantly larger than in the incisor region ($p<0.0001$), with a mean angular disparity for the first molars of 42.5±4.5° (range 26° to 56°) versus 36.7±8.2° (range 19° to 56°) for the central incisors (Table 1, Fig. 5). A statistical difference between the genders was not observed (molars $p=0.240$, incisors $p=0.610$).

For this range of angular disparity (19° to 56°), a foreshortening of the tooth ranging from 5.4% to 44.1% will result, corresponding to a mean error of 26.3% for molars versus 19.8% for incisors (Eq. 2).

Table 1 Descriptive evaluation of the measured angulation between the rigid receptor and the tooth's longitudinal axis in degrees [°] for molars and incisors

	$Molar_t$	$Incisor_t$	$Molar_m$	$Molar_f$	$Incisor_m$	$Incisor_f$
Mean ± SD	42.5±4.5	36.7±8.2	42.1±4.9	43.0±3.9	36.5±7.4	35.7±8.5
Median	43	36.5	42	43	36	34
Range	26–56	19–56	26–52	33–56	20–56	19–52

SD standard deviation of the mean, *t* total, *m* male, *f* female

The mean intraobserver variation between the two repeated measurements was −0.6±3.4° (range −9° to 8°). Here, the sign indicates the direction of the deviation from the first assessment.

Discussion

The results of our study show a wide range of possible angulation between the tooth and receptor axis (19–56°) which is even wider in the incisor area. Consequently, a different amount of foreshortening of the tooth under investigation will necessarily occur in the image. This is due to the variable individual human anatomy of the maxilla. Our results numerically prove the assumption that in the maxilla a parallel alignment between tooth and image receptor is hardly ever feasible. This complicates an assessment of the tooth length, respectively, the length of the tooth axis, which is commonly requested for diagnostics and treatment in dentistry. The use of metal spheres only to correct magnification will not be helpful to improve this circumstance since it does not consider distortion effects. Large effective angles of up to 56°, in both the incisor and molar region, lead to a relevant underestimation of the true tooth length of up to 44%, when magnification is neglected.

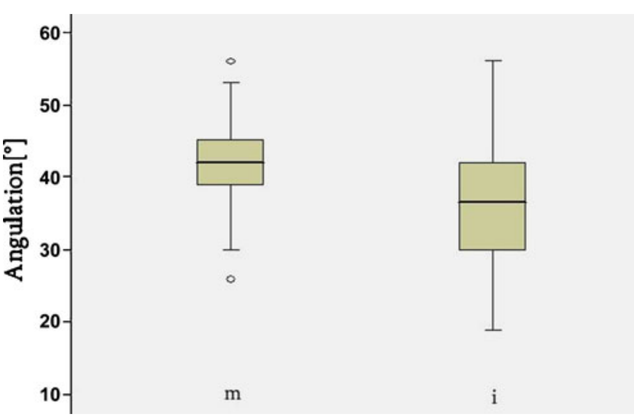

Fig. 5 Angulation between receptor and tooth axis of the upper central incisor (*i*) and first upper molar (*m*) illustrated in *box plots*. Each box defines the interquartile distance (IQR) between the 25% and 75% quartile (median: *bold horizontal line*). The *T-shaped whiskers* mark all values lying ≤1.5 IQR beyond the quartiles. Extreme values exceeding these limits are indicated by *circles*

It should be pointed out that a tooth is not a straight object and that the tooth length axis is an assumption [4], not considering the real 3D shape, like root curvatures, of the tooth.

The evaluation process in this study is not considered to be very exact because the identification of the real tooth length axis is not possible since only the crown is visible. We estimate the error for the angular assessment procedure to be roughly ±5° (with a maximum of almost ±10° as evident from the intraobserver variation). A large amount of the variation is certainly explained by the fact that for the same anatomical situation different positions of the receptor relative to the tooth are feasible. Yet even with this overall high inaccuracy in the assessment process, it is obvious that the angular disparity yields extreme distortion of the tooth image or any other object orientated collinear with its axis. This error seems to be even more pronounced for the molars. Comparing our evaluation process with the in vivo situation, it should be pointed out that the resilience of the mucosa reduces the angulation marginally. The angle of reduction α_r can be estimated from the equation:

$$\alpha_r = \arctan\left(\frac{i}{a}\right) \tag{3}$$

where i=depth of impression. For a tooth length of 20 mm, a resilience of the palatal mucosa of 1 mm yields a reduction of the effective angle α by $\alpha_r \approx 3°$.

Magnification appearing in intraoral radiographs caused by a divergent X-ray beam will be roughly 2% to 9% of the object size in a typical intraoral radiographic setup. Consequently, the displayed size is a result from two completely independent physical factors: distortion and magnification. Both are directly related to the exact imaging geometry, which unfortunately is not known in intraoral radiography. Magnification reduces the absolute distortion error but not the relative one. This is a very important phenomenon which has to be considered in any approach aiming for distance measurements or size correction.

In conclusion, we assessed the expected angular divergence in maxillary intraoral radiography between tooth length axis and the corresponding axis of a rigid image receptor. Our observations made from almost 300 human plaster models prove the theoretical expectation that the disparity is large and will result in considerably distortion. For instance, this will affect the outcome when assessing tooth length when root canal instruments or bony defects are measured as carried out in some in vivo studies [10, 21]. The assumption that linear distance measurements are sufficiently performed on intraoral radiographs without application of a meaningful foreshortening correction (see, e.g., [22, 23]) is absolutely not warranted due to the actual physical conditions. Many methods to correct the foreshortening a priori and a posteriori have been developed [2–4, 12–17]. An ex vivo study using the reference sphere method shows a mean relative length error (±SD) of 0.46± 4.27% estimating angulations between 0° and 40° (average 22.6°) using three 3.0 mm steel spheres as reference [4]. The angulations estimated here are even larger than expected in this former study. By integrating a small reference object into a holding device explicitly designed for rigid receptors, the information for computing α in an automated procedure would be available. We have just filed a patent application for a holding device of this type that allows for automated assessment of the effective angular disparity between the receptor and tooth length axis [19].

Acknowledgment This work includes parts of the thesis of Isabell von Rechenberg, entitled "Projection analysis and determination of angles between tooth's length axis and receptor in intraoral radiology in the maxilla using rigid (digital) sensors".

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Van Aken J (1969) Optimum conditions for intraoral roentgenograms. Oral Surg 27:475–491
2. Schulze R, d'Hoedt B (2001) Mathematical analysis of projection errors in "paralleling technique" with respect to implant geometry. Clin Oral Implants Res 12:364–371
3. Schulze R, d'Hoedt B (2002) A method to calculate angular disparities between object and receptor in "paralleling technique". Dentomaxillofac Radiol 31:32–38
4. Roeder F, Brüllmann D, d'Hoedt B, Schulze R (2010) Ex vivo radiographic tooth length measurements with the reference sphere method (RSM). Clin Oral Invest (in press)
5. Eickholz P, Hausmann E (2000) Accuracy of radiographic assessment of interproximal bone loss in intrabony defects using linear measurements. Eur J Oral Sci 108:70–73
6. Kim TS, Obst C, Zehaczek S, Geenen C (2008) Detection of bone loss with different X-ray techniques in periodontal patients. J Periodontol 79:1141–1149
7. Schropp L, Stavropoulos A, Gotfredsen E, Wenzal A (2009) Calibration of radiographs by a reference metal ball affects preoperative selection of implant size. Clin Oral Investig 13:375–381
8. Tyndall AA, Brooks SL (2000) Selection criteria for dental implant site imaging: a position paper of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89:630–637
9. BouSerhal C, Jacobs R, Quirynen M, van Steenberghe D (2002) Imaging technique selection for the preoperative planning of oral implants: a review of the literature. Clin Implant Dent Relat Res 4:156–172
10. Williams CB, Joyce AP, Roberts S (2006) A comparison between in vivo radiographic working length determination and measurement after extraction. J Endod 32:624–627
11. Behneke N, Tetsch P (1985) Diagnostik und Planung von Implantaten im zahnlosen Unterkiefer. Fortsch Zahnärztl Implantol 1:266–271
12. Benn DK (1990) A review of the reliability of radiographic measurements in estimating alveolar bone changes. J Clin Periodontol 17:14–21
13. Dubrez B, Jacot-Dsecombes S, Cimasoni G (1995) Reliability of a paralleling instrument for dental radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 80:358–364
14. Zappa U, Simona C, Graf H, van Aken J (1991) In vivo determination of radiographic projection errors produced by a novel filmholder and an x-ray beam manipulator. J Periodontol 62:674–683
15. Dixon CA, Hildebolt CF (2005) An overview of radiographic film holders. Dentomaxillofac Radiol 34:67–73
16. Wu JC, Huang JN, Zhao SF, Xu XJ, Zhang JC, Xia B, Dong YF (2005) Use of a simple intraoral instrument to standardize film alignment and improve image reproducibility. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 100:99–104
17. Schulze R, Bruellmann DD, Roeder F, d'Hoedt B (2004) Determination of projection geometry from quantitative assessment of the distortion of spherical references in single-view projection radiography. Med Phys 31:2849–2854
18. Schulze RKW (2010) Pose determination of a cylindrical (dental) implant in three-dimensions from a single two-dimensional radiograph. Dentomaxillofac Radiol 39:33–41
19. Schulze R, Roeder F (2009) Device, bite element and system for intraoral radiography. Patent application: DE102 00 901 7905.4, applicant: Johannes Gutenberg-University of Mainz
20. Mühlreiter E, de Jonge TE (1928) Anatomie des menschlichen Gebisses, 5th edn. Felix Verlag, Leipzig, pp 25–43
21. Jenkins SM, Dummer PM, Newcombe RG (1995) Radiographic amelocemental junction and alveolar crest: effect of x-ray beam angulation. J Oral Rehabil 22:679–684
22. Santos-Pinto L, Cordeiro Rde C, Zuanon AC, Basso MD, Gonçalves MA (2007) Primary tooth length determination in direct digital radiography: an in vivo study. Pediatr Dent 29:470–474
23. Krithika AC, Kandaswamy D, Velmurugan N, Krishna VG (2008) Non-metallic grid for radiographic measurement. Aust Endod J 34:36–38