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Diagnostic of tooth fractures with the Vistascan system

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Abstract – Compared with conventional films digital radiography allows a wide range of exposure and scanner settings. The aim of this study was to investigate the diagnostic accuracy of the evaluation of tooth fractures depending on variations of exposure dose, scanner settings and surrounding tissues. Extracted human teeth were exposed separately and in a pig bone phantom before and after artificial fracture at 70 kV (Gendex Oralix DC) and three exposure settings using the Vistascan System I at three different resolution settings. Five dental observers evaluated 432 radiographs of 12 adequately fractured teeth under randomized conditions for the existence of a tooth fracture on a five-point scale. The highest value of true ratings (76.7%) with pig bone vicinity was achieved at 56 μGy (160 ms) and 20 lp mm^{-1}, followed by 71.7% at 27 μGy (80 ms) and 20 lp mm^{-1}. The worst diagnostic accuracy of 56.7% true ratings resulted from 6 μGy (20 ms) and 10 lp mm^{-1}. With radiographs of teeth in empty surroundings the rate of true decisions was in some cases significantly higher. For the diagnostics of tooth fractures with the Vistascan System I the diagnostic value seems to depend on, besides radiographic projection, the scanner resolution setting, the surrounding tissues and the exposure dose.

The correct decision on post-traumatic treatment is dependent on the exact diagnosis including the correct identification of fractures. Unfortunately the diagnosis of root fractures often is difficult (1–5), as presence or absence of pain and clinical mobility do not necessarily correlate with the presence or absence of a fracture. Radiographs might not show existing fractures if the fracture gap is not parallel to the x-ray beam which gives reason to expose at least two radiographs at different tube angulations. Still sensitivity and specificity of radiological diagnostics of tooth fractures are well below optimal (6–8) and thus an improvement is desirable. Digital radiography with storage phosphor plates offers a wide range of possibilities to select exposure dose and scanner settings. Although there are numerous studies addressing several radiographic systems (9) and varying diagnostic tasks including tooth fractures (1–7, 10–25), few of them focus on the exposure settings (26, 27) and there is always a necessity for further investigations referring to new developed systems. In 2003, the Vistascan system was introduced which marked a remarkable progress in image plate scanner resolution.

For a radiographic examination the dental practitioner needs to select scanner settings and exposure dose which might be task dependent (28). Basically the selection should be an optimum trade-off between diagnostic image quality and radiation dose. Increased dose leads to a reduction in image noise and thus might enhance the diagnostic value.

Wenzel & Kirkevang (8) in 2005 investigated the differences between two systems and between projections but not between different exposure settings, scanner settings or surrounding tissue types. The RVG-ui^{TM}-CCD sensor showed a significantly higher sensitivity than the Digora^{TM} image plate system (in orthogonal projections of 49% and 44%, respectively) and speculated about the resolution difference between the two systems being the reason. Furthermore they found a higher sensitivity for the analysis of pairs of mesially and distally eccentric exposures compared with orthogonal or vertically angulated projections.

Kositbowornchai et al. (6) compared conventional radiographs with D-speed film of 201 teeth exposed separately in empty vicinity, half of them with a longitudinal fracture. The evaluations were performed by a single observer. Their results can be recalculated to 86.1% and 75.2% sensitivity for digital and conventional radiographs respectively, the specificity would be 85.0% and 88.0% respectively. In 2003, they used the same material to investigate different zoom factors of the digital images (18). To the authors' knowledge, there is no scientific publication comparing different settings for the diagnostic of tooth fractures with the Vistascan system.

Materials and methods

Twenty-one single root extracted human teeth were exposed with the Vistascan system under a selection of settings. The radiographs were taken from the buccal side of the teeth positioning the central x-ray beam perpendicular to the tooth axis and the image plate. The exposures were once without a bone phantom and once with the tooth placed in artificial alveoli drilled with an implant burr in a native pig jaw including soft tissues. After having exposed all teeth non-fractured the roots were broken. Nine teeth were smashed into pieces and excluded. Twelve teeth which showed simple straight fractures were repositioned, glued and exposed again under the same selection of settings (Fig. 1). The gap widths of the 12 broken and refused teeth were measured microscopically from 0.98 to 77 μm, at a mean of 18.88 μm and an SD of 27.46 μm.

The exposure time of the Gendex Oralix DC® X-ray source was set to 20, 80 and 160 ms, respectively at 70 kV, 7 mA and 9.8 inch focus-sensor-distance which equals exposure doses of 6.1, 26.7 and 56.2 μGy at the x-ray tube end. The image plates were read with the first version of Vistascan® system (system and image plates both by Dürr Dental, Bietigheim-Bissingen, Germany) at scanner settings named 10 line pairs per millimetre (lp mm^{-1}), 20 and 40 lp mm^{-1} respectively. In the end 432 images were available for visual evaluation.

The radiographs scanned at the setting named 40 lp mm^{-1} were displayed in dbsWin ® version 3.2.2-G (Dürr Dental) at a zoom setting of 100% to assure the physical representation of every image pixel on the monitor. To keep the displayed image ratio constant the radiographs scanned at 20 or 10 lp mm^{-1} were zoomed by 200% and 400%, respectively. While taking care to keep the digital pixel values the displayed images were cut to identical sizes and named by insignificant numbers.

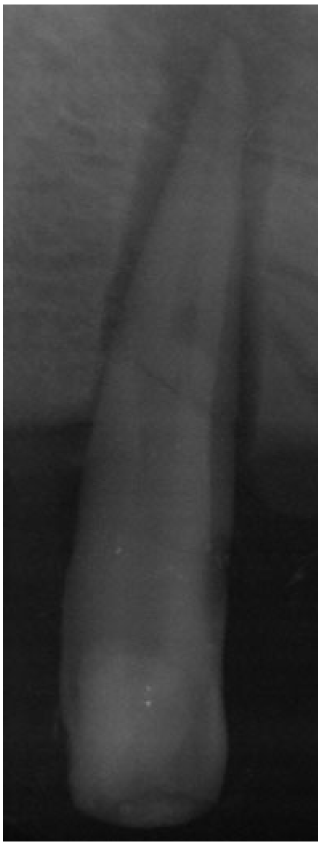

Fig. 1. Radiograph of a fractured tooth refused, glued and positioned in a bone phantom.

Five dental observers evaluated the radiographs in individually randomized order under adequate viewing conditions using MS-Paint®. The observers rated on a verbal five-point scale from 'definitely fracture' (1), 'probably fracture' (2), 'don't know' (3), 'probably no fracture' (4), to 'definitely no fracture' (5). The viewing time was limited to 90 s per image. Before the beginning of the evaluations the observers were trained at images of non-test teeth.

Results

Comparing the impact of exposure dose regardless of resolution settings the part of correct diagnoses was higher for the higher dose settings and decreased for lower doses (Table 1). At the bone phantom the part of correct diagnoses was reduced compared with exposures in empty vicinity. Calculating the impact of resolution settings regardless of exposure dose the higher ratio of true diagnoses was at higher scanner resolutions with little difference between the settings of 20 and 40 lp mm^{-1}.

Analyzing the interactions of exposure dose, resolution settings and impact of surrounding tissues (Table 2), the highest part of true diagnoses was 76.7% in bone phantom at 160 ms and 20 lp mm^{-1}, followed by 71.7% at 80 ms and 20 lp mm^{-1}. The lowest ratio of only 56.7% true ratings resulted from 20 ms and 10 lp mm^{-1}.

The evaluation error rates calculated by subtraction of the actual truth from the five-point ratings to get an error = 0 for a perfect rating and an error = 4 for a completely false rating showed a substantial difference between the cases, in which the observer had to rule out a non-existing fracture or whether an existing fracture had to be confirmed (Table 3; Figs 2 and 3). As the failure rate was highly dependant on the existence of a fracture, the ratings of radiographs representing a broken tooth were analyzed separately from those taken from an intact tooth.

Having dichotomized the five-point ratings into 'fracture' or 'no fracture' (assigning the indifferent rating 'don't know' to 'no fracture'), the best sensitivity of 60% is achieved at settings of 40 lp mm^{-1} and 80 ms in empty vicinity. The highest sensitivity in the bone surroundings is 56.7% at settings of 20 lp mm^{-1} and 160 ms, whereas the specificity is 96.7% in both cases (Table 4).

In general, bone vicinity results in a loss of diagnostic accuracy, especially when the scanning resolution is low. The ANOVA corrected according to Greenhouse-Geisser shows a high significance of the surroundings impact ($P = 0.0157$) in cases of no fracture (Table 5). If fractured, then the effect of the scanner resolution setting is highly significant ($P = 0.0063$). The trend towards an impact of high exposure dose did not prove significant ($P = 0.0848$). Applying the Freeman-Tukey-Transformation the P-value of the background for 'no fracture' was not significant anymore; the exposure dose turned significant for fractures at a P-value of 0.0025.

Discussion

Digital image plate technology came up with new parameters of scanner resolution settings and of a

Table 1. Impact of exposure dose and resolution settings: number and percentage of correct diagnoses

	Exposure dose			Resolution settings		
	20 ms	80 ms	160 ms			
Settings	6.1 μGy	26.7 μGy	56.2 μGy	10 lp mm^{-1}	20 lp mm^{-1}	40 lp mm^{-1}
Background all	476 (66.1%)	515 (71.5%)	504 (70.0%)	470 (65.3%)	512 (71.1%)	513 (71.3%)
Background empty	251 (69.7%)	267 (**74.2%**)	256 (71.1%)	252 (70.0%)	260 (72.2%)	262 (**72.8%**)
Of these fractured	45.60%	56.70%	52.80%	48.3%	52.8%	53.9%
Of these non-fractured	85.60%	86.70%	87.20%	85.6%	86.7%	87.2%
Background bone	225 (62.5%)	248 (**68.9%**)	248 (**68.9%**)	218 (60.6%)	252 (**70.0%**)	251 (69.7%)
Of these fractured	31.70%	44.40%	49.40%	33.3%	44.4%	53.3%
Of these non-fractured	71.10%	80.60%	78.90%	70.56%	78.9%	81.1%

Table 2. Interactions between exposure time and resolution settings: percentage of correct diagnoses

Exposure time	All time settings	20 ms	80 ms	160 ms
Exposure dose	All doses	6.1 μGy	26.7 μGy	56.2 μGy
Background all				
10 lp mm^{-1}	63.3%	63.3%	68.3%	68.3%
20 lp mm^{-1}	71.1%	67.1%	71.7%	74.6%
40 lp mm^{-1}	71.3%	67.9%	74.6%	71.3%
All resolutions	69.2%	66.1%	71.5%	70.0%
Background empty				
10 lp mm^{-1}	70.0%	70.0%	72.5%	67.5%
20 lp mm^{-1}	72.2%	72.5%	71.7%	72.5%
40 lp mm^{-1}	72.8%	**66.7%**	**78.3%**	73.3%
All resolutions	71.7%	69.7%	74.2%	71.1%
Background bone				
10 lp mm^{-1}	60.6%	**56.7%**	64.2%	60.8%
20 lp mm^{-1}	70.0%	61.7%	71.7%	**76.7%**
40 lp mm^{-1}	69.7%	69.2%	70.8%	69.2%
All resolutions	66.8%	62.5%	68.9%	68.9%

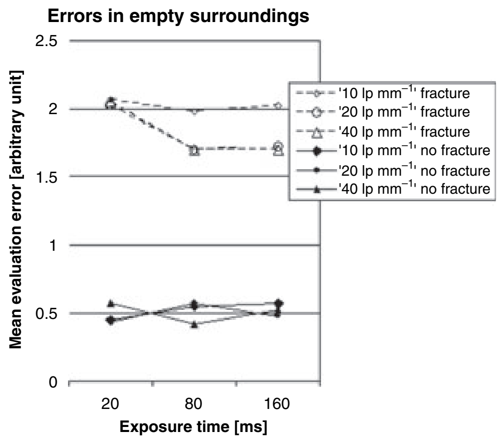

Fig. 2. Evaluation error in empty surroundings.

substantially widened exposure range, allowing different trade-offs between exposure dose and image noise and giving chance and possibly necessity to select the settings according to the diagnostic task (28). Yet the best settings for optimal diagnostic accuracy at minimal exposure dose have to be found for each indication and every system.

There are a number of investigations in which the differences between the diagnostic outcome of different exposure settings in digital radiography did not prove to be significant, e.g. Gijbels (2001; 26). In general, it seems to be difficult to achieve significance of the differences in visual evaluation of radiographs (8, 18, 29, 30) which indicates some range of exposure dose and image quality indifferent to the diagnostic outcome. In an extensive investigation, Kaeppler et al. (27) among others compared standard with halved exposure levels for panoramic radiographs with the DenOptix system and found significant differences for some anatomical structures. There are indications for which reduced settings obviously yield sufficient quality, e.g. for radiological checks of the correct length of restorative posts. On the other

Table 3. Evaluation error

			Bone surroundings				Empty surroundings			
Resolution setting	Exposure time		Mean		SD		Mean		SD	
(lp mm^{-1})	(ms)	*n*	No fracture	Fracture	No fracture	Fracture	No fracture	Fracture	No fracture	Fracture
10	20	12	1.03	2.37	0.52	0.89	0.45	2.07	0.37	1.40
	80	12	0.77	2.18	0.42	1.33	0.55	1.98	0.33	1.53
	160	12	1	2.13	0.59	1.34	0.57	2.02	0.6	1.71
20	20	12	0.83	2.18	0.53	0.89	0.43	2.02	0.42	1.71
	80	12	0.6	1.85	0.55	1.43	0.57	1.7	0.6	1.40
	160	12	0.57	1.52	0.5	1.35	0.48	1.72	0.54	1.60
40	20	12	0.68	2	0.38	1.22	0.57	2.05	0.47	1.80
	80	12	0.57	1.87	0.39	1.47	0.42	1.7	0.35	1.50
	160	12	0.65	1.8	0.55	1.53	0.52	1.7	0.61	1.45

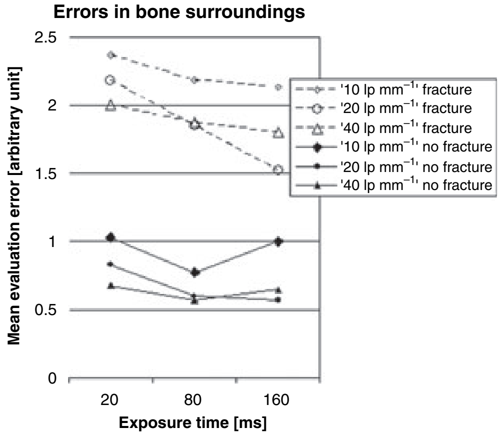

Fig. 3. Evaluation error in bone surroundings.

hand, our results suggest that some indications like tooth fractures need a higher exposure dose which provides a lower noise level of the radiographs to achieve optimum sensitivity.

Wenzel & Kirkevang (8) in 2005 published a comparison of the RVG-sensor and the Digora scanner system for tooth fractures and presented results of 75% or 70% specificity for single orthogonal projections although they could not find significance of the differences. Their speculation about the resolution differences being the reason for the differences in sensitivity seems to be confirmed by our findings of a higher diagnostic accuracy at higher resolution settings. One should note, that the setting named 40 lp mm^{-1} currently achieves a visible resolution of about 16 lp mm^{-1} probably because of the limits of present storage phosphor plates.

In addition to what we did Wenzel et al. let the observers mark the fractures they had detected and identified some ratings as false which we possibly have accepted as true. Furthermore they found a higher sensitivity for the analysis of pairs of mesially and distally eccentric exposures compared with orthogonal or vertically angulated projections, while this study is based on orthogonal settings only. We perfectly agree that Wenzel et al.'s results are a good scientific reminder of a specific recommendation for the radiological diagnostic of tooth fractures (1, 5, 31) and traditional surgical rule to use at least two radiographic projections for fracture diagnostics.

Kositbowornchai et al. (6) published a comparison of the impact of different zoom factors on the detection of root fractures in digital images. A 1:1 ratio per pixel performed best while a scale down ratio of 2:1 scored the lowest results although the differences were not statistically significant. This confirms our findings that the resolution probably is of importance and that it should be maintained up to the computer display by a 1:1 pixel representation.

In 2003, they compared conventional radiographs with D-speed film (ultra-speed) exposed at 0.8 s to a digital system (Sidexis) exposed at 0.2 s, both of them at 70 kV and 8 mA using a Heliodent DS dental x-ray unit at 21 cm focus–object distance in empty vicinity (18). The conventional film was exposed at a higher dose and performed better than the digital system at a lower dose but the differences were not statistically significant.

There is an increasing number of papers recommending three-dimensional imaging techniques for the diagnosis of tooth fractures (4, 20, 32). These imaging modalities might become a standard for the diagnosis of tooth fractures in the near future because of superior sensitivity and specificity. Because of higher exposure dose and limited availability for the dental office there is still the necessity to optimize periapical radiographs for tooth fracture diagnostics.

Table 5. Analysis of variance (ANOVA) with Greenhouse-Geisser correction

ANOVA; *P*-values	Parameter	No fracture	Fracture
Main effects	Background	**0.0157**	0.8018
	Resolution	0.0912	**0.0063**
	Exposure	0.5474	0.0848
Interactions	Background * resolution	0.1268	0.5950
	Background * exposure	0.2164	0.6252
	Resolution * exposure	0.7714	0.4552
	Background * resolution * exposure	0.6470	0.5859

Conclusions

While the beam angulation and different projections are of major importance for the radiological investigation of tooth fractures there seem to be further factors influencing the diagnostic outcome. An enhanced image resolution seems to improve the accuracy of the radiological diagnostics of tooth fractures. Using the Vistascan System the scanner resolution should be set to a value of 20 lp mm^{-1} at a minimum. The diagnostic accuracy might be reduced by the impact of the bone surroundings and is possibly dose-dependent. Using the Vistascan

Table 4. Sensitivity and specificity

Background			Empty			Bone		
Resolution			10 lp mm^{-1}	20 lp mm^{-1}	40 lp mm^{-1}	10 lp mm^{-1}	20 lp mm^{-1}	40 lp mm^{-1}
Sensitivity	20 ms	(6.1 μGy)	45.0%	46.7%	45.0%	21.7%	28.3%	45.0%
	80 ms	(26.7 μGy)	53.3%	56.7%	**60.0%**	38.3%	48.3%	46.7%
	160 ms	(56.2 μGy)	46.7%	55.0%	56.7%	40.0%	**56.7%**	51.7%
Specificity	20 ms	(6.1 μGy)	95.0%	**98.3%**	88.3%	91.7%	95.0%	93.3%
	80 ms	(26.7 μGy)	91.7%	86.7%	96.7%	90.0%	95.0%	95.0%
	160 ms	(56.2 μGy)	88.3%	90.0%	90.0%	81.7%	**96.7%**	86.7%

System I, the exposure dose should be set to 27 μGy at a minimum. More investigations addressing the optima of exposure dose and image resolution for the diagnosis of tooth fractures are necessary.

Conflict of interest statement

The Vistascan System was provided for evaluation purposes by the Dürr Dental Corp., Bietigheim-Bissingen, Germany

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