Diagnosis and decision making in endodontics with the use of cone beam computed tomography
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Chapter 5
Summary and Conclusions
In the current thesis the use of cone beam computed tomography (CBCT) in endodontics has been evaluated within the framework of in vitro and in vivo studies. The possible enhancements in the diagnosis and the decision-making in endodontics have been analyzed and the factors affecting the formation of a treatment plan have been demonstrated.

Chapter 2 is dedicated to the detection of vertical root fractures of endodontically treated teeth on CBCT scans. Section 2.1 contains an in vitro study where the accuracy of CBCT scans is compared to that of periapical radiographs in detecting vertical root fractures. The influence of root canal filling material on the fracture visibility was also examined. The vertical root fractures in the teeth used were artificially created and the teeth were placed in dry mandibles for the scanning. The CBCT scanner used was the I-CAT (120 KvP, 5 mA, 10 x 16 cm field of view (FoV), 0.25mm voxel size; Imaging Sciences, Hatfield, PA). The overall accuracy of the I-CAT CBCT scanner (86%) was higher than that of periapical radiographs (66%). The presence of root canal filling material had a negative influence on the specificity of CBCT scans (p=0.032) and on the sensitivity of periapical radiographs (p=0.006).

In Section 2.2 the second in vitro study conducted as part of this thesis is presented. It examined the accuracy of five different CBCT scanners in detecting vertical root fractures. Additionally the influence of root canal filling material and the selection of the slice orientation were analyzed. The vertical root fractures in the teeth used were artificially created and the teeth were placed in dry mandibles for the scanning. The CBCT scanners used were the following: NewTom 3 G (110KvP, 2.4mA, 10x10cm FoV, 0.2 mm voxel; QR SLR, Verona, Italy), Next Generation I-CAT (120 KvP, 5 mA, 10 x16 cm FoV, 0.25mm voxel; Imaging Sciences International, Hatfield, PA), Galileos 3D (85KvP, 7mA, 15x15cm FoV, 0.3mm voxel; Sirona Germany, Bensheim, Germany), Scanora 3D (85KvP, 10mA, 7.5x10cm FoV, 0.2mm voxel; Soredex, Tuusula, Finland), and 3D Accuitomo-xyz (80KvP, 3.3mA, 3x4cm FoV, 0.25 voxel; J. Morita, Kyoto, Japan). There was a significant difference among the accuracy of the CBCT
The presence of root canal filling material negatively influenced the specificity (p=0.003) in all scanners. The use of axial slices for the assessment of the scans resulted in significantly more accurate detection of vertical fractures (p=0.0001), than the use of coronal or sagittal slices. In Section 2.3 the validity of two CBCT scanners on detecting vertical root fractures is examined in vivo. Thirty nine individuals with 39 endodontically treated teeth suspected of vertical root fracture were scanned before endodontic surgery. No fractures were visible on periapical radiographs. The scanners used were the NewTom 3G (110 kv, 3.90-5.6 mA, 0.2mm voxel; QR SLR, Verona, Italy) and 3D Accuitomo 170 (90 kv, 5mA, isotropic voxel size 0.08mm; J. Morita, Kyoto, Japan). The findings of orthograde retreatment, endodontic microsurgery, or extraction were used to verify the presence or absence of a vertical fracture. The results of this study suggest that the reproducibility and accuracy of VRF detection depend on the CBCT system used, and support the use of 3D Accuitomo 170 for the detection of VRFs in endodontically treated teeth over the use of NewTom 3G. The accuracy of 3D Accuitomo 170 (93%) is significantly higher than that of NewTom 3G (68%).

Chapter 3 contains a clinical study that examines the change in volume of periapical radiolucencies of endodontically treated teeth one year after endodontic orthograde retreatment. Forty-five endodontically treated teeth with persistent apical periodontitis requiring endodontic orthograde retreatment, from 37 individuals referred to the Postgraduate Endodontology Clinic at the Academic Centre for Dentistry Amsterdam (ACTA) from 2009 to 2011. The research protocol was approved by the VU University Medical Center Amsterdam (VUmc) ethics committee (2007/265) and the participants signed a letter of consent. For every individual there was a CBCT scan made before retreatment and a second scan a year later. The recall rate was 78% for the teeth and 73% for the patients. Two observers measured independently the volume of radiolucencies on CBCT images using the AMIRA software (5.3.4, Visage Imaging GmbH). The volumetric change in periapical radiolucencies
one year after retreatment was statistically significant (z= - 3.112, p<0.005). The volume of periapical radiolucencies reduced in 20 teeth (57%) remained unchanged in 8 (23%) and increased in 7 (20%).

Chapter 4 examines the precision of root canal length measurement on CBCT scans and the influence of tooth type (anterior, posterior) on these measurements. In total 40 root canals of 33 teeth (molars, premolars, canines, incisors) out of five dentate maxillas of human cadavers were included. Root canal length measurement was performed by a consensus panel. The CBCT scanner used was the 3D Accuitomo 170 (90KV, 5mA, 360° rotation, standard resolution, 4x4cm field of view, voxel size 0.125mm; Morita, Kyoto, Japan) and digital periapical radiographs. All teeth were extracted and the measurements made on digital images (AxioCam, Carl Zeiss), linked to stereo-zoom microscope (Stemi SV6, Carl Zeiss), were used to define the actual root canal length. For root canals of anterior teeth there was no significant difference between the periapical radiographs and the CBCT scans. For root canals of posterior teeth, CBCT images gave results significantly closer to the gold standard in comparison to periapical radiographs (t-value -1.96, critical value is 1.74 significance level of 0.05). Root canal length measurements of posterior maxillary teeth were more accurate on CBCT images than periapical radiographs.
General conclusions

The present thesis does not suggest that CBCT scans should replace the periapical radiographs for every endodontic patient. This thesis emphasizes the need for careful patient selection when CBCT scans are advised, as well as the selection of the most suitable CBCT system and settings. Furthermore, this thesis points out the importance of making the best use of available pre-existing CBCT scans before a patient is treated. A CBCT scan can be a valuable tool in establishing a diagnosis and in further treatment planning when the information arising from both clinical and periapical radiographs are not sufficient. However not all CBCT scans provide the necessary diagnostic information. Important factors that have to be considered for the justification of a CBCT scan are the radiation, the image quality and the presence of artifacts arising from radiopaque materials such as gutta-percha, intracanal posts, artificial crowns or other metallic restorations. Careful patient selection and the appropriate CBCT scanning parameters are both serving the ALARA (as low as reasonably achievable) principle.

The technology of cone beam computed tomography is developing in the last years. CBCT scans can be used for the detection of vertical root fractures in endodontically treated teeth as they have an overall higher accuracy in comparison with periapical radiographs. However the reproducibility and accuracy in vertical root fracture detection depend on the CBCT system used. The spatial resolution, the signal-to-noise ratio, the dynamic range and other CBCT-specific image artifacts have an impact on the visibility a vertical root fracture.

The volumetric changes of periapical radiolucencies after endodontic (re)treatment could serve as proxy measurements in the evaluation of a treatment outcome. Performing such measurements is quite cumbersome even with state of the art technology and as CBCT systems (both hardware and software) become more mature it is expected that such volumetric comparisons will become integrated in the standard vendor provided workflows.
CBCT images were proved to be significantly more accurate than periapical radiographs when used for root canal length measurements of posterior maxillary teeth. This statement does not suggest that periapical radiographs should be replaced by CBCT scans during every endodontic procedure. It rather emphasizes the value of CBCT scans in endodontics and supports the additional use of pre-existing CBCT scans that were made for diagnostic purposes prior to treatment.
Recommendations for the use of CBCT in endodontic practice

- For the detection of vertical root fractures on CBCT scans, the factors that have to be considered are the detector design, the voxel size, the contrast-to-noise ratio of the selected field of view (FoV), and the possible artifacts arising from radiopaque materials (e.g. root canal filling material, intracanal posts, artificial crowns, other metallic restorations).

- Removal of radiopaque materials that cause artifacts and interfere with the CBCT scan could be done prior to scanning.

- The main radiographic feature of a vertical root fracture on a CBCT scan is the presence of a radiolucent line crossing the root completely or partially on at least two consecutive slices.

- Axial slices are more accurate than coronal and sagittal in detecting vertical root fractures.

- Root canal length measurements of posterior maxillary teeth are more accurate on CBCT images than periapical radiographs.

- The CBCT slice (mesio-distal or vestibulo-oral) to be selected for root canal length measurements should include the cusp, most of root canal curvatures and the major foramen.

- It should be taken into account that there is a tendency for underestimation of the actual root canal length when CBCT images are used.