The application of X-ray microtomography for the assessment of root resorption caused by the orthodontic treatment of premolars

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Summary. The purpose of this study was to demonstrate potential application of micro-computed tomography in the morphometric analysis of the root resorption in extracted human first premolars subjected to the orthodontic force. In one patient treated in the orthodontic clinic two mandibular first premolars subjected to orthodontic force for 4 weeks and one control tooth were selected for micro-computed tomographic analysis. The hardware device used in this study was a desktop X-ray microfocus CT scanner (SkyScan 1072). The morphology of root’s surfaces was assessed by TView and Computer Tomography Analyzer (CTAn) softwares (SkyScan, bvba) which allowed analysis of all microscans, identification of root resorption craters and measurement of their length, width and volume. Microscans showed in details the surface morphology of the investigated teeth. The analysis of microscans allowed to detect 3 root resorption cavities in each of the orthodontically moved tooth and only one resorption crater in the control tooth. The volumes of the resorption craters in orthodontically-treated teeth were much larger than in a control tooth. Micro-computed tomography is a reproducible technique for the three-dimensional non-invasive assessment of root’s morphology \textit{ex vivo}. TView and CTan softwares are useful in accurate morphometric measurements of root’s resorption.

Key words: orthodontic treatment, root resorption, microtomography.

INTRODUCTION
Orthodontic tooth movement is based on cellular activation in the periodontal ligament (PDL). Different tissue reactions are observed at the compression and tension side of surrounding tissues \cite{1,2}. Compression is connected with ischemia and necrosis of PDL, the affected area is called hyaline zone \cite{3,4}. This sterile necrotic tissue is removed by macrophages, foreign

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body giant cells and osteoclasts from adjacent undamaged areas [1, 4]. These cells also resorb bone adjacent to the necrotic PDL area and remove it together with the necrotic tissue in a process termed “undermining resorption” [1, 4]. Orthodontically-induced inflammatory root resorption is a part of the hyaline zone elimination process. The initial removal takes place at the periphery of the hyaline zone, where blood supply to the periodontal ligament does not change or is even increased [4]. During the elimination of necrotic tissue, the outer surface of root, which consists of the cementoblast layer, can be damaged. In result the underlying mineralized cementum becomes exposed to odontoclasts-multinucleated cells which precursors are recruited by activated endothelium from the bone marrow [3]. Odontoclasts resorb mineralized dental tissues, i.e. cementum and dentin. Another mechanism of root resorption is also possible. Orthodontic force itself may directly damage the outer cemental surface [1, 2, 4]. In the clinical settings root resorption is difficult to be quantitatively assessed by the X-ray methods. In this paper we demonstrate that the microscan tomography may be applied to numerically assess root resorption in extracted teeth that were previously subjected to the action of orthodontic force.

MATERIALS AND METHODS
Three human first premolars (from child of 12 years old) scheduled for extraction for orthodontic reasons were selected for the micro-tomographic analysis. Two premolars were subjected to orthodontic force for 4 weeks, one tooth was free of any force application. After extraction the teeth were stored in 10% formalin solution. The hardware device used in this study was a desktop X-ray microfocus CT scanner (SkyScan 1072, bvba, Aartselaar, Belgium). The scanning procedure was completed for all teeth using 10W, 100 kV, 98 µA, a 1.0 mm aluminum filter and 15x magnification, resulting in a pixel size of 19.1 µm x 19.1 µm. Approximately 4 hours were needed to complete scan of one tooth. During acquisition, hundreds of two-dimensional (2D) projections through 180° of rotation were saved in a digital format. In order to gain the third dimension (3D), the data stored as projections were then transformed into new two-dimensional images (cross-sections) with a pixel size of 19.1 µm x 19.1 µm and a slice thickness of 13.0 µm. The 3D image was achieved by juxtaposition of 2D images of adjacent slices.

The morphology of all roots’ surfaces was assessed by using software TView (SkyScan, bvba), which allows observing of all microscans and identification of root resorption craters. Since the beginning and the end of the crater along root’s axis could be identified at single microscan, the length of the craters was measured with the accuracy up to 0.001 mm. The Computer Tomography Analyzer (CTAn) (SkyScan, bvba) software was used for the determination of crater’s volume (Figure 1).

RESULTS
Micro-computed tomography (micro-CT) allowed for the detection of 3 resorption craters in each premolar subjected to orthodontic force and only one resorption crater in control tooth. In our study craters of volume higher than 0.001 mm³ were included into...
analyses because smaller craters were considered as unimportant. The length of assessed resorption craters differed from 0.651 to 1.987 mm. The volume of craters differed from 0.019 to 0.342 mm$^3$ (Table 1).

**DISCUSSION**

Our pilot study showed the possible application of micro-computed tomography for the detection and analysis of root resorption craters. Orthodontically-induced root resorption has mainly been detected with 2-dimensional measurement techniques such as radiographs [5-7], light microscopy [8-10] or scanning electron microscopy (SEM) [11, 12]. Radiographs are not suitable method for the quantitative analysis of root resorption because magnification errors may lead to the underestimation or overestimation of the extent of this process [13]. The more accurate methods are micro-computed tomography [13, 14] and SEM with special software [15, 16]. Dudic et al. in their research compared the detection of root resorption by radiographs and micro-computed tomography and concluded that less than half of the cases with root resorption identified using a CT scanner were identified by radiography [17], some of resorption craters that were “visible” on radiographs were not identified by CT scanner. Hohman et al. compared the SEM method with micro-CT and concluded that in assessment of tooth morphology more easily applicable and accurate method is micro-computed tomography [18]. Although the microcomputed tomography cannot be at present used for in vivo clinical studies because of a long exposition time, we showed that it may serve as a precise analytical technique for the investigation of teeth morphology [19].

**Conflict of interest statement**

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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| Table 1 | The number, length and volume of detected craters in human premolars |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Force application | Number of craters | Length of crater (mm) | Volume of crater (mm$^3$) |
| Tooth 1 | yes | 3 | 0.843 | 0.048 |
| | | | 1.914 | 0.082 |
| | | | 1.987 | 0.342 |
| Tooth 2 | yes | 3 | 0.804 | 0.082 |
| | | | 0.765 | 0.033 |
| | | | 0.995 | 0.019 |
| Tooth 3 | no | 1 | 0.651 | 0.034 |


