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Feature article

Fracture behaviour of teeth with conventional and mini-invasive access cavity designs

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ABSTRACT

Presented work is targeted toward fracture analysis of endodontically treated human teeth. Three sets of teeth were loaded by compression simulating natural loading conditions. For this purpose, each tooth was mounted into the resin in the axis angle declination of 30° and kept all the time in saline up to the moment of test to simulate the intraoral environment. Two access cavity designs – mini-invasive (conservative) and conventional (traditional), were analysed. Fracture behaviour of treated teeth with mini-invasive access was compared with conventional and with the intact set of teeth. Complex monitoring of the fracture process together with loading traces enables to characterise typical fracture features and crack propagation schemes. The extensive fractographic analysis reveals the effect of adhesive bonding on the crack propagation. Also, fracture initiation and damage accumulation were identified. The quality of newly developed mini-invasive design in comparison with the conventional one was proved.

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1. Introduction

The investigation of fracture of composite materials and its mechanisms under mechanical loading are of scientific interest for decades due to their complicated structure [1]. The toughening mechanisms acting in the case of brittle matrix composites are beneficial for overall mechanical response and its reliability during application [2]. A similar situation can be observed in the case of natural materials where similar toughening mechanisms play an important role [3]. Rapidly developing research area deals with bio-inspired materials where the effort is dedicated to the manufacturing of artificial materials possessing similar behaviour as the natural one [4–6]. In the medicine, the combination of natural and artificial materials is very common when damaged or missing tissue reconstruction is needed. The behaviour of such a complex structure which is comprised of different composites is an important issue [7,8]. In the field of dentistry, the combination of natural composite material (tooth) and artificial man-made composite materials (restorative materials) is frequently clinically applied. In recent years, the concept of minimally invasive endodontics is gradually gaining acceptance in clinical dentistry even though there is only limited supporting scientific evidence [9,10]. The present concept of minimally invasive endodontics is strongly related to the preservation of sound tooth structure during access cavity opening under direct vision and instrumentation to smaller apical width and taper. Such preserved sound tooth tissue is capable of maintaining the mechanical stability of restored tooth [11,12]. The most important tooth structure responsible for long-term survival is supposed to be the pericervical dentin [13]. It is a dentin's structure located 4 mm below and 4 mm above the alveolar crest [11], responsible for distribution of functional mechanical stresses inside tooth [14,15]. On contrary, in traditional endodontics, the removal of sound tooth structure according to the concept of extension for instrument fracture prevention was favoured. Traditional endodontic access cavities, i.e. hereafter abbreviated as TEC, are adjusted for risk reduction during root canal treatment. In TEC it is more probable to find aberrant anatomy, to discover fracture lines, to remove complete pulp from all pulp horns and to minimise a chance of the instrument breakage. In minimally invasive endodontics, it is also called minimally invasive, contracted [10] or conservative endodontic access cavity, i.e. hereafter abbreviated as CEC [16] is used state-of-the-art instrumentation to minimise the access cavity. In comparison to TEC, it prefers the removal of restorative materials to tooth structure of enamel to dentin and of occlusal tooth structure to cervical dentin. It preserves parts of the pulp chamber roof and pericervical dentin. Although the preserved tooth structure may offer a benefit of improved fracture resistance [17], the scientific evidence for CEC remains scarce. So

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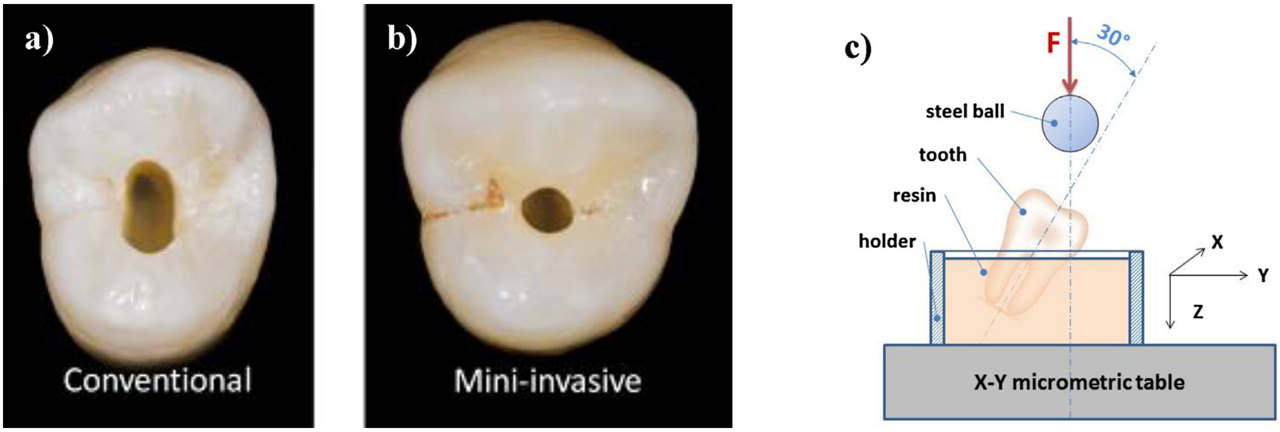

Fig. 1. Comparison of the TEC access cavity design (a), the CEC access cavity design (b), and the loading scheme (c).

far, only mandibular premolars have been studied [16], but not maxillary premolars. Maxillary premolars have a shape which facilitates the fracture of cusps under occlusal loads [18,19] and thus can be observed in the higher incidence of cusp fractures of upper premolars in the oral cavity [20,21]. Additionally, not only the shape of access cavity could play an important role but also the conditioning of the dentin before application of filling can affect (positively or negatively) the overall fracture resistance as was reported [22–24]. However, a direct comparison of fracture behaviour of CEC, TEC and intact premolars under loading was not yet reported.

The objective of this study was to assess the influence of CEC and TEC on the fracture resistance of lower (mandibular) and upper (maxillary) premolars which were reconstructed according to the concept of minimally invasive dentistry and characterisation of fracture process using fractographic approach.

2. Experimental procedures

2.1. Material

Thirty maxillary and thirty mandibular previously extracted human non-carious, mature, intact premolars were used. Subsequently, both maxillary and mandibular premolars were randomly divided into three groups – CEC group, TEC group and negative control group (n = 10 teeth/group). Teeth in CEC groups were drilled by long shank diamond bur (FGSL H.1.316.010, Komet USA, Rock Hill, USA) and were accessed by 1 mm buccal to central occlusal fossa. Access cavities were extended apically, maintaining part of the chamber roof [16]. Teeth in TEC groups were prepared according to generally accepted suggestions of traditional endodontic access cavity [25].

Root canals were negotiated using ISO 10 K-file (Flexofile; Dentsply Maillefer, Balleigues, Switzerland) all the way to the anatomical foramen. The working length was established as 0.5 mm coronally according to the anatomical foramen and root canals were shaped with primary WaveOne reciprocating instruments (Dentsply Maillefer, Balleigues, Switzerland). Canals were irrigated by 5% sodium hypochlorite using 30G irrigation needles (Navi-Tip, Ultradent, South Jorda, UT, USA). Shaped and cleaned root canals were filled with gutta percha and epoxy resin (AdSeal, Meta Biomed, Chungbuk, South Korea) using warm vertical compaction where fillings ended 1 mm apically to the orifice of the root canal. After that pulp chamber was cleaned with 96% ethanol and teeth were adhesively restored using selective etch adhesive system Singlebond Universal (3 M ESPE, St. Paul, MN, USA) and dual-cured resin composite (Dentocore, Spofadental, Jičín, Czech Republic) with Filtek ultimate (3 M ESPE, St. Paul, MN, USA).

All teeth were mounted to a self-curing resin (Dentacryl, Spofadental, Jičín, Czech Republic) at the angle of 30° from the tooth long axis and up to 2 mm apical to cementoenamel junction (see Fig. 1(c)). The comparison of access cavity of traditional (TEC) and mini-invasive (CEC) approach is demonstrated in Fig. 1(a, b).

2.2. Characterization

All specimen teeth embedded in the resin were mounted to the cylindrical holder and placed to the micrometric positioning table mounted on the base of an Instron Universal Testing Machine (Instron, Canton, MA, USA), loading was carried by a stainless steel sphere with a diameter of 3/16” fixed to the loading bar. The loading scheme is shown in Fig. 1(c). The diameter of the loading stainless steel ball was determined according to the 3D reconstruction using a laser confocal microscope Lext OLX 3100 (Olympus, Japan) of the typical tooth as is shown in Fig. 2(a). The maximal central profile was extracted and diameter of the ball was adjusted to simulate an optimal contact with the tooth surfaces (see Fig. 2(b)) with the aim to maximise stresses in the cavity location. Therefore, prior testing, each specimen was preciously positioned to obtain perfect two-point contact with the loading stainless steel sphere as shown Fig. 1(c) and fixed in this position. The crosshead speed of 0.5 mm/min was used until final fracture occurred. The acoustic emission signal was monitored continuously during loading using an IPL Analyser (Dakel, Czech Republic). A digital 2MPX USB microscope for visual monitoring of the fracture process was used. The loading curves with both the acoustic emission signal and the video captured were synchronised to allow understanding of the damage development. A scanning electron microscope Lyra XML3 (Tescan, Czech Republic) for fractographic observation of the tooth fracture surface and analysis of the surface damage in the tooth-ball contact areas was employed. The fracture forces leading to the fatal damage of the individual tooth were determined from the loading curves on the basis of video and acoustic emission signal. The statistical evaluation of obtained results was conducted using statistical software Statgraphics Centurion XV (StatPoint, USA). Average load to fracture values were calculated for each group and data were compared among particular groups with Kruskal-Wallis tests.

In the present study, no simulation of the periodontal ligament was performed. In the majority of published articles on fracture resistance of postendodontic treated endodontic treated teeth, there was no simulation of periodontal ligament [26]. Although such simulation is appreciated, standardised model for the simulation of the periodontal ligament has not been introduced yet [26].

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