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Development of a novel intraoral measurement device to determine the biomechanical characteristics of the human periodontal ligament

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ABSTRACT

Periodontal diseases like gingivitis and periodontitis have damaging effects on the periodontium and commonly affect the mechanical properties of the periodontal ligament (PDL), which in the end might lead to loss of teeth. Monitoring tooth mobility and changes of the material properties of the PDL might help in early diagnosis of periodontal diseases and improve their prognosis. It was the aim of this study to develop a novel intraoral device to determine the biomechanical characteristics of the periodontal ligament. This includes the measurement of applied forces and resulting tooth displacement in order to investigate the biomechanical behaviour of the periodontium with varying loading protocols with respect to velocity and tooth displacement. The developed device uses a piezoelectric actuator to apply a displacement to a tooth's crown, and the resulting force is measured by an integrated force sensor. To measure the tooth displacement independently and non-invasively, two magnets are fixed on the teeth. The change in the magnetic field caused by the movement of the magnets is measured by a total of 16 Hall sensors. The displacement of the tooth is calculated from the movement of the magnets. The device was tested in vitro on premolars of four porcine mandibular segments and in vivo on two volunteers. The teeth were loaded with varying activation curves. Comparing the force progression of different activation velocities, the forces decreased with decreasing velocity. Intensive testing demonstrated that the device fulfils all requirements. After acceptance of the ethical committee, further testing in clinical measurements is planned.

1. Introduction

Tooth displacement under physiological loadings (chewing, swallowing and clenching) and application of orthodontic forces depend on force magnitude, point of force application, root morphology and the state of health of the surrounding tissues. The tooth's root is supported by the periodontium, which consists of the root cementum, the periodontal ligament (PDL), the alveolar bone and the attached gingiva. Of these structures the PDL is of particular importance since it is thought to mediate forces acting on the teeth and the surrounding anatomical structures.

The PDL is a complex fabric of collagen fibres, blood vessels, nerves, fluid, etc., filling the periodontal space between root and bony socket, enabling the root a transverse and vertical intrinsic mobility (Berkovitz, 1990; Berkovitz and Moxham, 1982). The most classical studies consider the PDL as an isotropic and linear-elastic material (Andersen et al., 1991; Tanne and Sakuda, 1983; Williams and Edmundson, 1984; Wilson et al., 1994); however recently, increasing evidence has been reported on anisotropic material characteristics of the PDL, in which collagen fibres play an important role (Provatidis, 2000; Qian et al., 2001). In some numerical studies linear or bi-linear elastic and isotropic behaviour is assumed (Clement et al., 2004; Kawarizadeh et al., 2003, 2004; Poppe et al., 2002). Other recent studies use a viscoelastic approach to describe the material behaviour of the PDL (Qian et al., 2009; Tohill et al., 2009).

Due to its structure, the biomechanics of the PDL is highly elaborated to describe. The elastic nature of collagen fibres and the damping behaviour of the fluid phase are responsible for the nonlinear and time-dependent behaviour of the PDL. Up to now,

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