Changes in the Biomechanical Properties of the Periodontal Ligament after Orthodontic Treatment – A Combined Clinical, Experimental and Numerical Study

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Abstract Teeth are supported in their sockets by a complex multi-phasic network of fibres, fluids, vessels and cells, usually called periodontal ligament (PDL). The tasks of the PDL are multifold, such as damping of occlusal loads, distribution of forces to the supporting tissues and its biomechanical behaviour is a key to understand the nature of orthodontic tooth movement. This paper presents combined clinical/experimental and numerical investigations to determine the changes in the biomechanical behaviour in the course of orthodontic treatment.

Introduction

During orthodontic treatment with fixed bracket-wire appliances it can be observed that the mobility of a tooth in its socket increases while forces are active, and decreases over a time of several weeks up to some months to its original behaviour during the retention phase. In a clinical study we were able to determine this change of the tooth mobility in vivo using a self-developed measurement device. However it remained unclear whether the change in stiffness results from a change of the geometry of the alveolar socket or from a change of the biomechanical behaviour of the tooth supporting tissues.

Aim

The aim of the current combined clinical/numerical study was to investigate whether the changed tooth mobility can be attributed to a change of the constitutive parameters of the periodontal ligament (PDL).

Material and Method

21 patient-individualised finite element (FE) models of the right upper central incisor were created using x-ray images from a clinical study (approval of the Ethical Committee of the University of Bonn 181/13). The change of the force/deflection behaviour of orthodontically moved teeth was determined in vivo by moving the crown of the respective incisors 0.2 mm in bucco-lingual direction while simultaneously measuring the required force. The device used consisted of a computer controlled piezo actuator (PSt150/7/160V-S12, Piezomechanik GmbH, Munich, Germany) and a miniature force sensor (Typ 8416, Burster Präzisionsmesstechnik, Gernsbach, Germany, measurement range: 200 N) [1]. The crown deflections were applied with loading velocities between 0.02 mm/s and 1.00 mm/s to consider time dependant behaviour of the PDL (Fig. 1). Measurements were performed at six different times after removal of the fixed appliance, starting immediately after debonding (T1) up to 6 months later (T6). In the current study time-dependant FE simulations were performed for each patient and each velocity to determine force/deflection curves, which were then compared with the clinically measured curves. A bilinear material model was used to describe the behaviour of the PDL, using two linear phases with Young's moduli E_1 and E_2 and an ultimate strain ε_{12} that separates these two phases. By varying the material parameters in the bilinear material model, individual parameter sets were determined for each patient and each combination of measurement time and loading velocity.

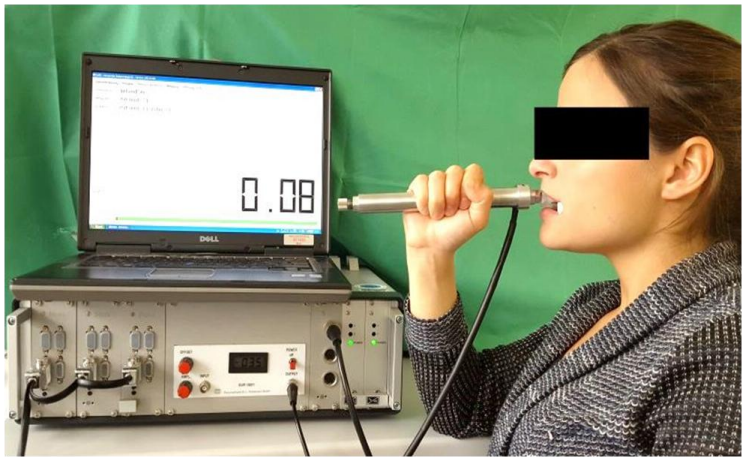

Fig. 1: Intra-oral loading device in situ. The patient holds the device and supports the holding arm during force application.

Results

Fig. 2 shows an example of measured force/deflection curves at T1 (dashed lines) and T5 (solid lines) for an individual patient. Forces increase significantly with increasing loading velocity and from T1 to T5. Using the back calculations, the numerical simulations were successfully fitted to the curves measured in vivo on all patients. The determined mean values of the bilinear Young's moduli E_1 and E_2 showed a significant increase between the values for T1 (e.g. E_1=0.37 MPa at 1.00 mm/s) to T2 (E_1=0.53 MPa). The stiffness increased with increasing loading velocity (E_2=4.0 MPa at 0.02 mm/s versus 5.0 MPa at 1.00 mm/s). For some patients, the determined values reached physiological reference values of untreated, healthy periodontal ligament after only two to four weeks.

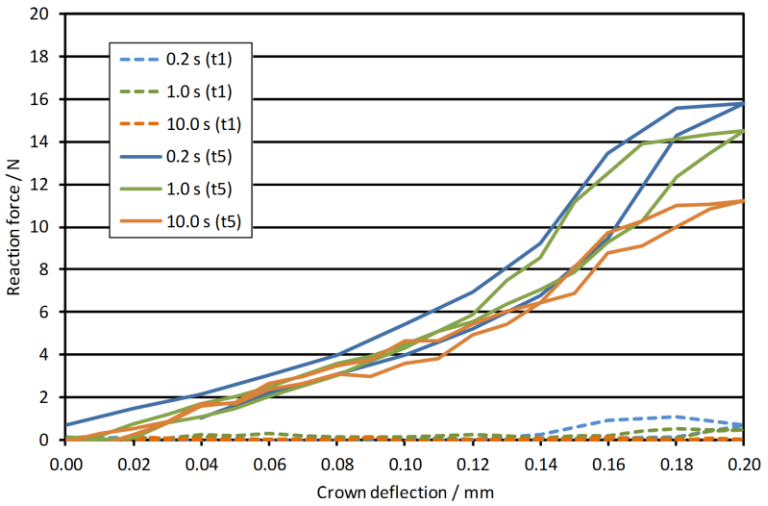

Fig. 2: Clinically measured forces at T1 (dashed lines) and T2 (solid lines).

Conclusions

The material behaviour of the periodontal ligament in the retention phase after an orthodontic treatment was reproduced successfully. The material behaviour of the PDL was restored to pretreatment values after a time of two to four weeks.

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References

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