DENTITION MODEL WITH A 3D FORCE-MOMENT SENSOR IN EACH TOOTH FOR ORTHODONTIC APPLICATIONS

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Introduction

Quantitative knowledge of the three-dimensional (3D) force-moment (F/M) systems applied to the individual teeth during orthodontic therapy is of utmost importance for an accurate control of the 3D tooth movement and for reducing traumatic side effects such as irreversible root resorption. However, suitable systems for clinical measurements are not available. To date, in-vitro studies have been performed using reduced models mainly consisting of two or three teeth. However, such models are not capable of representing the complex clinical situation of complete multi-bracket appliances. The aim of our work is the development of a dentition model including the upper and lower dental arches equipped with a 3D F/M sensor system in each individual tooth.

Methods

Our concept of a "smart tooth" comprises a microelectronic stress sensor chip [Rues, 2011] with dimensions of 2 x 2.5 x 0.4 mm³ integrated in the root of a model tooth. A critical challenge of this smart tooth design was to find a suitable compromise between sensor sensitivity and mechanical stability. For this purpose we performed a design study using finite element (FE) analysis. Prototypes of the chosen design have been tested by static loading to validate the numerical analysis and to quantify the actual mechanical stability. Fourteen smart teeth have been mounted on a base plate to set up a complete physical model of the lower dental arch with perfectly aligned teeth [Andrews, 1972].

Typical therapeutic situations (e.g. individual tooth malpositions, space closure after tooth extraction) were investigated. Orthodontic treatment was simulated by applying a fixed multi-bracket-appliance and the six components of the F/M-system were monitored at each individual tooth.

Results

The results of the FE analysis indicated that with a vertical orientation of the sensor chip (Fig. 1) a higher mechanical stability could be achieved compared to a horizontal chip orientation. Our simulations further revealed that the sensor sensitivity is affected by the thickness of the adhesive layer between the upper and lower parts of the sensor unit. The mechanical stability tests showed that the smart tooth with vertical chip orientation resists at least forces of 60N in axial direction and 72N in all other directions as well as moments of 10Ncm in all three directions.

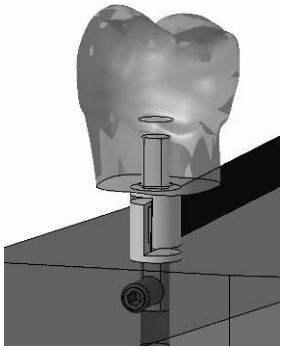

Figure 1: Smart tooth with vertical sensor chip orientation.

Discussion

Mechanical testing has shown that the presented smart tooth design withstands loads typically occurring during orthodontic therapy. The complete "smart dentition" model allows in-vitro studies on the 3D F/M systems exerted to the individual teeth by orthodontic appliances. Its compact design and the free accessibility of all dental crowns enable treatment simulation with various types of fixed and removable orthodontic appliances. Such a F/M measurement device significantly adds to the methodological possibilities for investigating and optimizing orthodontic appliances. This opens attractive prospects for orthodontic research and training of clinicians with objective 3D F/M feedback.

References

Rues *et al*, J Biomech, 44:1892-1900, 2011.

Andrews, Am J Orthod, 62(3):293-309, 1972.