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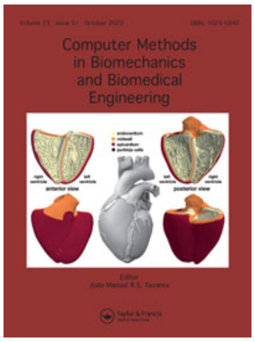

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Clinical and numerical study of a statically determinate lingual mechanism for orthodontic tooth displacement

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1. Introduction

Numerical simulation of long term orthodontic tooth movement could help clinicians to plan more efficient and mechanically sound treatments (Burstone 2015). It remains a challenge and no prospective model exists yet. Finite element analysis (FEA) has been used by several authors to perform such simulations, but these studies usually lack of experimental calibration or validation (Schneider et al. 2002; Kojima and Fukui 2012; Chen et al. 2014). Moreover, a proper definition of the boundary conditions of the model is a critical issue as most of the orthodontic forces are statically indeterminate (Hamanaka et al. 2017).

Our main objective was to perform a numerical study of orthodontic tooth displacement based on precise clinical data. We collected monthly three-dimensional (3D) displacement data of two canines submitted to a known force system. Then, we calibrated a preliminary patient-specific FEA model from these acquisitions.

2. Methods

2.1. Clinical procedure

This study was approved by the local ethical committee (CPP Paris Ile-de-France 1) and included one 28-year-old patient. At the level of the maxillary arch, our orthodontic treatment plan aimed at correcting the teeth crowding with avulsion of upper premolars, recoil of the canines and repositioning of the incisors.

We bonded on the canines a personalized lingual device, designed with CAD software and manufactured by selective laser sintering (A in Figure 1/Top). We ligatured another rigid arch in three temporary anchorage devices placed in the palate (B in Figure 1/Top). We linked these two arches using two open Ni-Ti springs of 100 cN each (C in Figure 1/Top).

2.2. Data acquisition

We segmented a Cone-Beam CT 3D imagery of the patient to reconstruct the initial 3D surface models of the bone and the canines. We performed monthly an intraoral scan of the maxillary arch to track the canines displacement, and used these scans to reconstruct intermediate 3D surface models (Bouton et al. 2017).

2.3. Finite element analysis

We imported into COMSOL Multiphysics software part of the initial 3D model (Figure 1/Bottom) including the trans-canine arch, the canines, part of the maxillary bone and the periodontal ligament. The latter was artificially created by dilatation operations.

We modelled teeth as rigid bodies and all other mesh parts but bone as homogeneous and isotropic elastic materials. In order to mimic bone remodelling, we used a Zener model for bone. Long-term shear modulus was set close to zero so as not to restrain tooth movement, instantaneous elastic moduli were given values typical of alveolar bone (cortical bone was not modelled), and a parametric analysis was performed to identify the characteristic time best matching clinical data.

In order to quantitatively compare the simulated displacements with the clinical ones, we calculated the rigid body translations and Euler extrinsic angles of the canines at simulation times corresponding to each clinical step.

3. Results and discussion

The clinical procedure lasted 7 months, leading to models T0 (initial model) to T7 (final model).

Clinical and numerical translations of the right canine (T_α, $\alpha = \{x,y,z\}$) are shown in Figure 2, top left panel, and relative errors $ET_\alpha = (T_{\alpha,clin} - T_{\alpha,sim})/T_{tot,clin}$ in Figure 2, bottom panel ($T_{tot,clin}$ is the

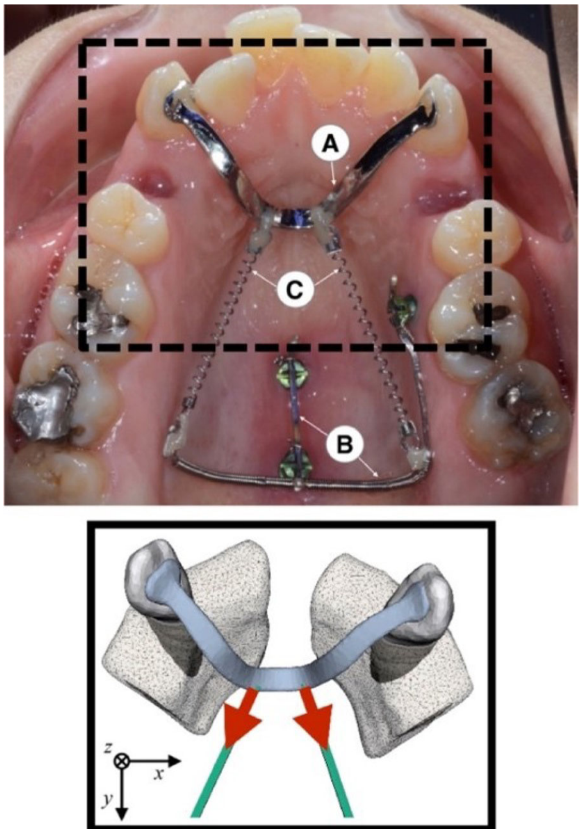

Figure 1. Top: Individualized lingual mechanism used in this study. Bottom: Numerical model.

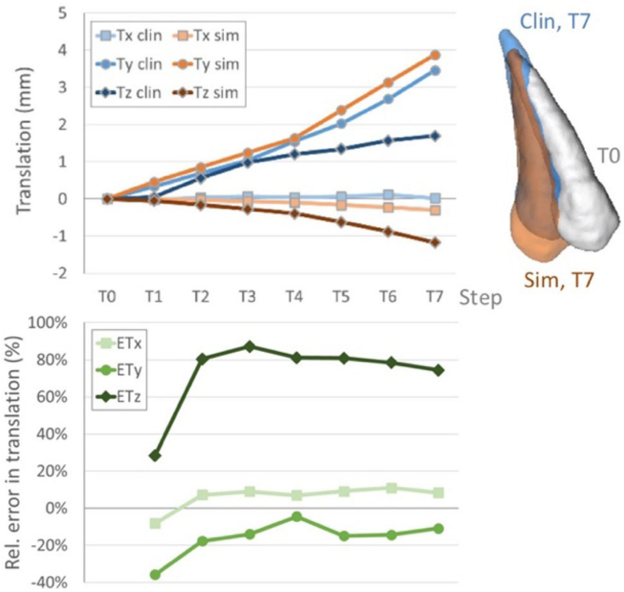

Figure 2. Right canine. Top left: Clinical and simulated translations. Top right: Initial (T0) and final (T7) configurations. Bottom: Relative errors in translations.

Euclidean norm of the clinical displacement). Results obtained for the left canine are very similar.

Clinical movement combined recoil (positive T_y), tipping (rotation around the x axis, about 10° at T7), and an unexpected intrusion (positive T_z). Simulated displacements (both translations and rotations) showed overall a good agreement with clinical data (the error on tooth recoil ET_y was smaller than 20%) but a small extrusion (negative T_z) was found. This difference may be due to functional forces not accounted for in the model.

4. Conclusions

We collected original clinical data on long-term tooth displacement of one patient using a personalized orthodontic device designed so as to deliver a statically determinate system of forces. Nevertheless, an unexpected intrusion was observed pointing out the relevance of physiological functional forces.

Moreover, we developed a preliminary patient-specific FEA model that, despite its simplicity, was able to capture the main features of orthodontic movement but the tooth intrusion. This underlines the importance of clinical calibration and validation of FEA models of orthodontic displacement before considering them as clinically relevant.

Among the simplifying assumptions of our model, our perspective is to improve the bone remodelling model (Bourauel et al. 2000; Wang et al. 2014) and to make a first step toward a mechanobiological approach (Van Schepdael et al. 2013).

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