aviesan
alliance nationale
pour les sciences de la vie et de la santé

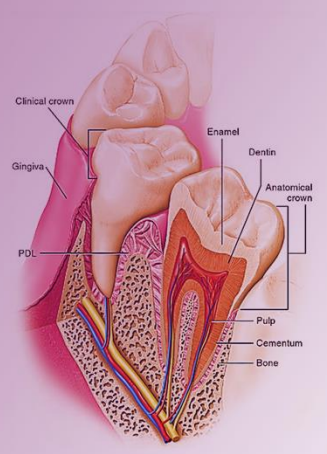
Institut Thématique Multi-Organismes
Technologies pour la santé

Theoretical and numerical multiphysics modeling of orthodontic teeth displacement accounting of oxygen diffusion effects

Camille Spingarn, Shanshan Wang, Yves Rémond, Daniel George
Laboratoire Icube, Université de Starsbourg, CNRS, 67000 Strasbourg

1. Context

In case of **misaligned teeth**, an orthodontic treatment is applied generating the teeth realignment through **orthodontic appliances**. These apply loads on the teeth that will be transmitted to the jaw bone and will lead to bone remodeling accordingly to the local biology (vascularization, bone density, etc …).

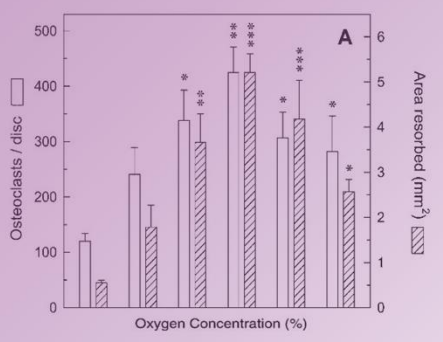


Structure of the teeth and surrounding tissues. Nanci, 2007.

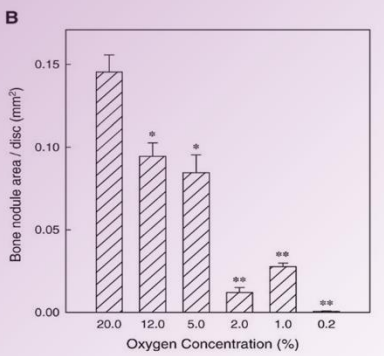
In the current work, we try to predict the **bone remodeling** generated by this protocol being patient dependent through a theoretical numerical model that will simulate the bone remodeling on the dental arch. The orthodontist would therefore be able to predict the repositioning of each teeth over a long time scale allow him to **optimize** the procedure.

2. Role of the Oxygen in orthodontic bone remodeling

The periodontal ligament (PDL) surrounding the teeth is highly vascularized. The blood feed the cells within the PDL and particularly the ones responsible for bone remodeling (osteoclasts for bone resorption and osteoblasts for bone formation). It was showed that the number of osteoclasts increase in hypoxia while the number of osteoblasts decrease (Arnett, 2003; Utting, 2006).

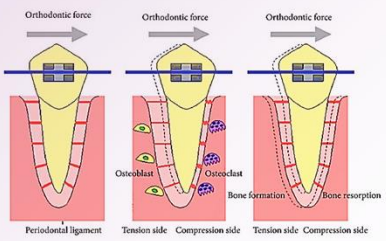


Effect of oxygen on osteoclasts and on resorption rate at 20%, 12%, 5%, 2%, 1%, and 0.2% O_2. Source: Utting *et al.* 2006.



Inhibition of bone mineralization by osteoblasts with decreasing oxygen concentration. Source : Arnett, 2003.

Orthodontic treatment compresses the PDL on one side generating blood volume decreased and stretches on the other side generating blood volume increased. Oxygen supply is thus altered and cell population changes.



Schematic of PDL volume and cell poulation variation with applied force. (Source : http://www.pinnacledentalcare)

3. Proposed theoretical numerical model

Orthodontic force

Mechanical equilibrium : $\underline{\underline{\sigma}} = \underline{\underline{K}} : \underline{\underline{\epsilon}}$

Ligament compression / Ligament tension

Zargham et al., 2016
Beaupré et Carter, 1986

Oxygen variation with deformation :

$\Delta V_{vascularisation} = Tr(\underline{\underline{\epsilon}})$
$\%O_2 = f(\Delta V_{vascularisation})$

O2 arrival decrease / O2 arrival increase

Cell numbering with oxygen variation :

$P_m = f(\%O_2)$

Osteoclasts multiplication / Osteoblasts multiplication

Utting et al., 2006
Arnett et al., 2003

Bone density variation with mechanobiolgical stimulus :

$$S^*(\boldsymbol{X},t) = [\int_\Omega U(\boldsymbol{X}_0,t) * d(\boldsymbol{X}_0,t) * exp(-D\|\boldsymbol{X}-\boldsymbol{X}_0\|) * d\boldsymbol{X}_0] - S_0(\boldsymbol{X},t)$$

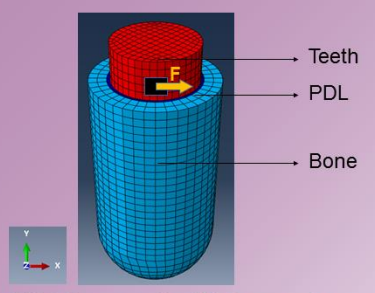
Resorption / Reconstruction

$$\frac{\partial \rho_{bone}}{\partial t} = A_b.synt_{bone}.S_+ + A_b.res_{bone}.S_-$$

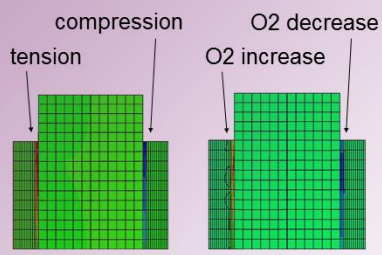
Tooth displacement

On going …

4. Preliminary results



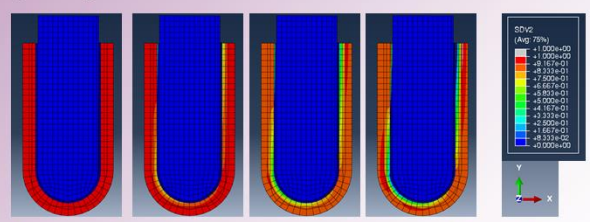
Validation on simplified geometry and boundary conditions.



Strain distribution

Oxygen variation

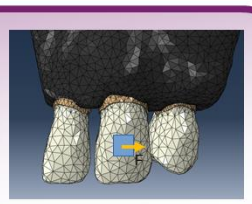
Oxygen percentage variation leads to cell multiplication and bone density change



Bone density evolution according to time around the teeth.

5. Conclusion

A theoretical numerical model is build to account for oxygen concentration and cell density variation as a function of applied external forces for orthodontic applications. Preliminary results on bone remodeling show the bone density change as a function of the ligament cell activation. Results should be compared to patients data for validation.



References :

Arnett T *et al.*, Journal of cellular physiology, 196, 2-8, 2003.
Cattaneo P.M., *et al.*, American journal of orthodontics and dento-facial orthopaedics, 133, 5, 2008.
George D, et al, Bio-Medical Materials and Engineering, 2017, 28(S1), S15-S27.
George D. *et al.*, 9th European Solid Mechanics Conference, 2015.
Madeo A. *et al.*, Comptes rendus Mecanique, **339**, 10, 2011.
Schmitt M. *et al.*, Comp Meth Biomech Biomed Eng, 19, 171-179, 2015.
Spingarn C, et al, Bio-Medical Materials and Engineering, 2017, 28(S1), S153-S158.
Utting, *et al.*, Experimental Cell Research, 312, 1693-702, 2006.
Wagner D, et al, Bio-Medical Materials and Engineering, 2017, 28(S1), S169-S177.
Wagner D, et al, Bio-Medical Materials and Engineering, 2017, 28(S1), S179-S184.