European Cells and Materials Vol. 16. Suppl. 1, 2008 (page 20) ISSN 1473-2262

Measuring Dynamic Stiffness of Human Teeth by Single-Impact Micro-Indentation (SIMI): a feasibility study

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INTRODUCTION: Teeth must bear a wide range of loads and retain their shapes during contact-induced static and dynamic stresses. In vivo, the critical contact area between opposing teeth ranges from 0.4 – 2.2 mm^2 with a maximal biting force of up to ~1000 N, i.e. conditions inducing contact stresses of 0.45 – 2.5 GPa [1] which can precipitate damage. Since damaged teeth do not heal like other mineralized tissue, functional integrity is restored by repairing lesions with xenobiotic materials such as gold, alloys (e.g. Ni-Cr-Mo alloy Remanium CS®), amalgam or polymer-ceramic composites (e.g. Filtek® Supreme). Material stiffness determines load distribution. Quasi-static stiffness (*elastic* Young's modulus E_Y) is the parameter usually reported in order to describe stiffness of mineralized tooth constituents (cementum, dentin, enamel) as well as dental repair materials. However, tissues and materials containing polymeric components and water are viscoelastic and have no elastic Young's modulus. Their stiffness depends on the conditions of measurement; especially loading rate. Therefore, to better emulate functional dental conditions, we measured stiffness in a non-destructive, dynamic impact mode. We used a Single-Impact Micro-Indentation (SIMI) instrument, developed from a handheld computer-assisted device for polymer quality control [2] and used by some of the authors to evaluate cartilage [3]. The response of viscoelastic materials to a non-destructive impact is characterised by the *complex dynamic* Young's modulus or aggregate modulus, E*, and its components--the storage modulus E' and the loss modulus E''. The latter two are usually expressed as the loss angle $\phi=\arctan(E'/E'')$. The loss angle describes the damping behaviour of viscoelastic structures.

METHODS: The SIMI device [3] with a 1 mm Ø spherical steel tip was further equipped with a sliding cross table and laser for positioning the indenter with sub-millimeter precision. 3rd molars were embedded in PMMA, then cut longitudinally in 2-3 mm thick sections and ground parallel. Sections were placed on a stainless steel block and stabilized laterally by enclosing them with wax. E* and ϕ average values (n = 10) were obtained.

RESULTS: See Table 1.

***Table 1**: E* and loss angle ϕ (brackets) of dental structures and repair materials by SIMI.*

Results [GPa, °]	Root dentin	Crown dentin	Enamel	Filtek®	Remanium®
Tooth 1	0.0025± 0.003 (19±3°)	4.3±0.4 (19±0.7°)	3.5±5 (20±2°)		
Tooth 2		7±0.1 (18±0.7°)	8.5±30.2 (17±0.8°)		
Repair material				4.2±0.1 (12.±4°)	56.5±15 7.2±0.1°

DISCUSSION & CONCLUSIONS: In this first set of measurements on sectioned teeth, SIMI modulus (E*) data were not strictly analogous to reported E_Y values [1]. However, micro-dynamic and quasi-static nano-indentation data rarely agree. Factors contributing to observed discrepancies: (i) Viscoelastic material moduli are highly dependent on loading geometry and rates. (ii) Most reported E_y values are based on micro- or nano-indentation which employs much higher stresses than SIMI. (iii) The contact surface of SIMI is > 1000x larger than that of nano-indenters. For enamel's anisotropic structures, measured stiffness is inversely related to indenter size [1]. (iv) The indenter tip used was steel (E~200 GPa) which may deform when used on materials approaching this stiffness. SIMI is a simple method for quantitative functional characterisation of load-bearing tissues. To our knowledge SIMI provided here, for teeth, the first combined measurements of E* and ϕ. In the future, measurement of site-specific variations in dynamic impact stiffness (E* and ϕ) may better describe how dental structures distribute and absorb impact loads. This may substantially improve our understanding of tooth function and the structural changes caused by disease.

REFERENCES: [1]L.H. He & M.V. Swain (2008) *J. Mech Behavior Biomed Mater* **1**: 18-29. [2]M. Vriend & A.P. Kren (2004) Polymer Testing **23**: 369-375. [3]D. Wirz, et al. (2008) Abstract, *Proceedings 16th Congress Eur Soc Biomech*.

ACKNOWLEDGEMENTS: We thank A. Filippi, G. Krastl, J.T. Lambrecht and B. Müller (University Clinics for Dentistry, Basel) for their encouragement and suggestions.