14th Swiss Conference on Biomaterials, May 8th, 2008, Basel Switzerland

Measuring dynamic stiffness of human teeth by Single-Impact Micro-Indentation (SIMI). A feasibility study.

W. Baschong[1], F. Schmidli[2], M. Imholz[1], B. Goepfert[3], A.U. Daniels [3], D. Wirz[3]

[1]Clinic for Dental Surgery and [2]Material Science Institute , Dental School, University of Basel, Switzerland,

[3]Laboratory for Orthopaedic Biomechanics, University of Basel, Switzerland

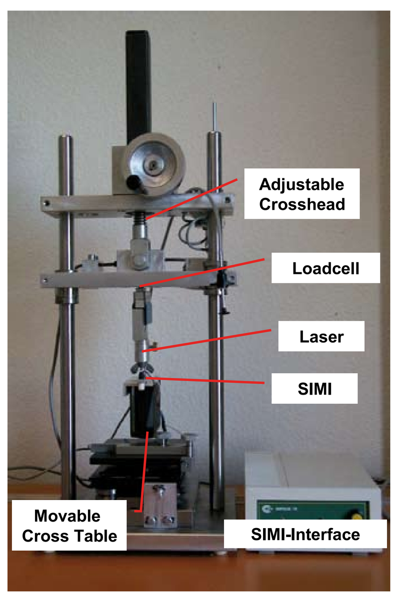
INTRODUCTION

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 EY) 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 Ø=arctan(E'/E''). The loss angle describes the damping behaviour of viscoelastic structures.

MATERIAL & METHODES



Modified SIMI

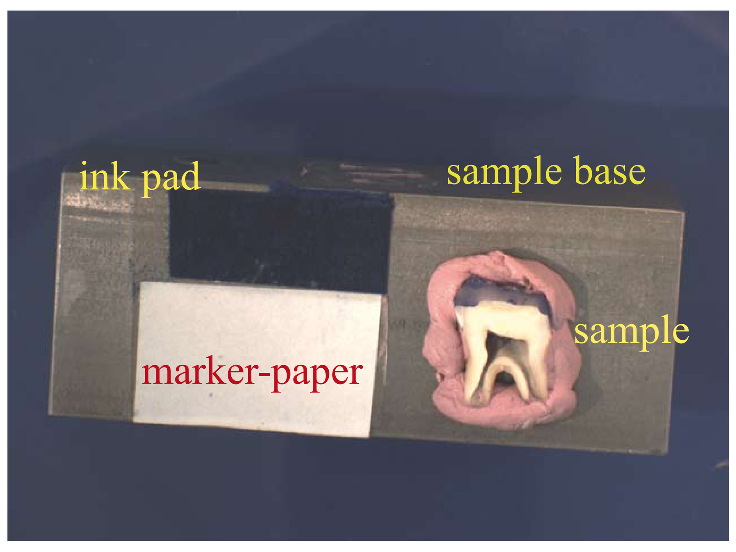
SIMI mounted into a stand with an adjustable cross head [3] was further equipped with a sliding cross-table mounted on a horizontal guiding rail with fixed sliding distance. A laser was attached to the SIMI casing to shine parallel to the fall direc-tion of the indenter (1 mm Ø spherical steel tip).

Measuring

1) The sample base (3 x 3 x 7.5 cm steel block) with the wax-stabilized sample (e.g. tooth section) and the positioning control (ink pad with adjacent marking paper) is fitted in the sample holder of the cross-table.

2) For indentation SIMI is lowered to the sample surface with the adjustable cross head . An initial electromotive force is generated by the load cell. The indenter is released manually.

Upon data registration the indenter is repositioned by lifting the SIMI unit via the cross head and readjusting the EMV of the load cell. Given values are averages of 10 consecutive indentations



Sample base made of stainless steel with marker limit, ink pad, paper and sample, her tooth section

Calibrating-positioning

3a) With the cross-table in front-position the indenter places above the ink bed. Its tip is colored by repetitive indentation of the ink pad.

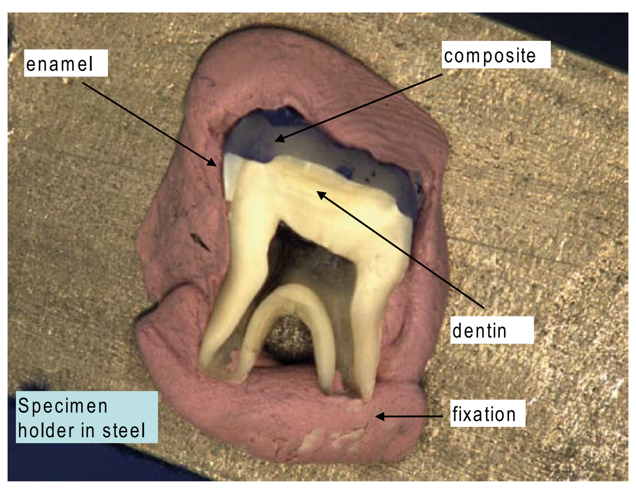
3b) With the cross-table in back-position the indenter places above the marking paper. Repetitive indentation of the marker paper reveals the precise position of the indenter as a colored spot.

4) The laser shining perpendicularly to the marked area is now fine-adjusted to the marker point.

5) Still in back-position the site of interest (e.g. specific locus on tooth section) is placed under the laser point by means of the cross-table drives.

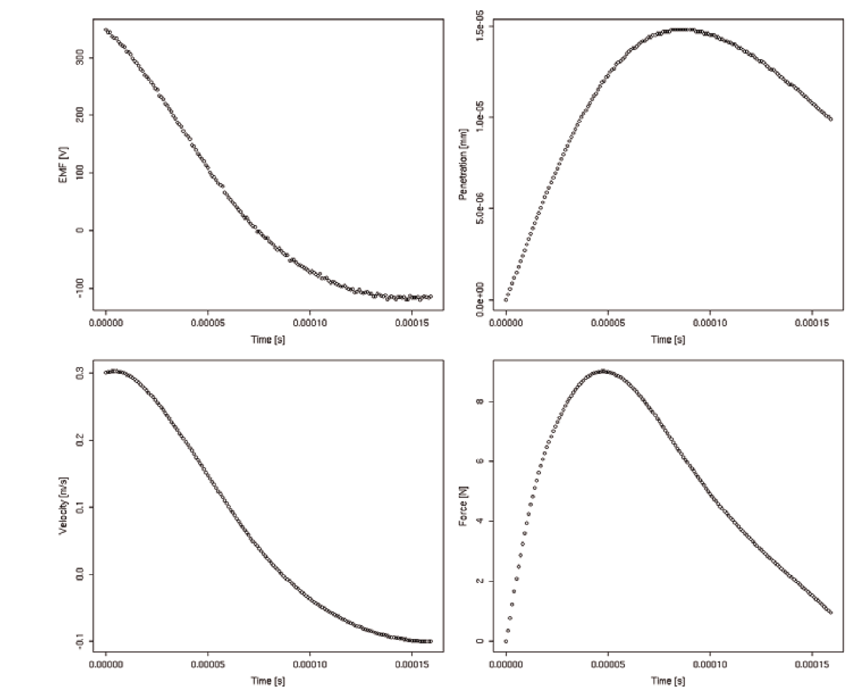
6) Sliding the cross-table in front-position places the site of interest precis-ely under the indenter tip.

Sample preparation



Tooth section

3rd molars were PMMA embedded, cut into 2-3mm sections and then ground parallel. Sections were placed onto the sample base and stabilized laterally with wax.

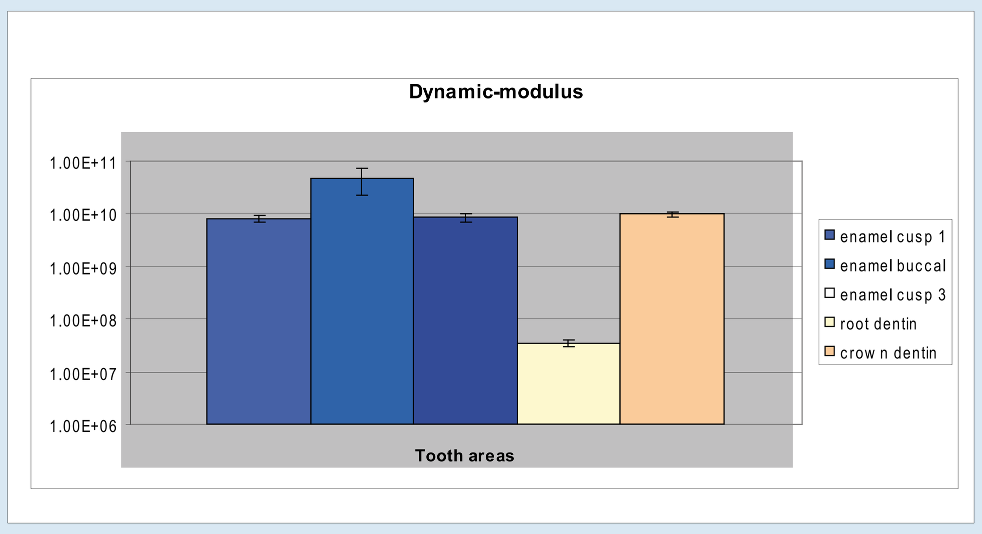


Calculating : EMV: Electromotive force vs. time, recorded as the permanent magnet behind the SIMI indenter falls through the coil above the specimen. Positive values indi-cate indenter motion downward, and negative values indicate motion upward (rebound). Note that the absolute value of EMF is much smaller when leaving the surface (here t=0.16ms) than when hitting the surface at (t=0s). This indicates a high-energy loss during the indentation. velocity, penetration and force are calculated out of the EMV - data [3][Wirz et al]. The time shift between penetration and force indicates as well a high loss angle.

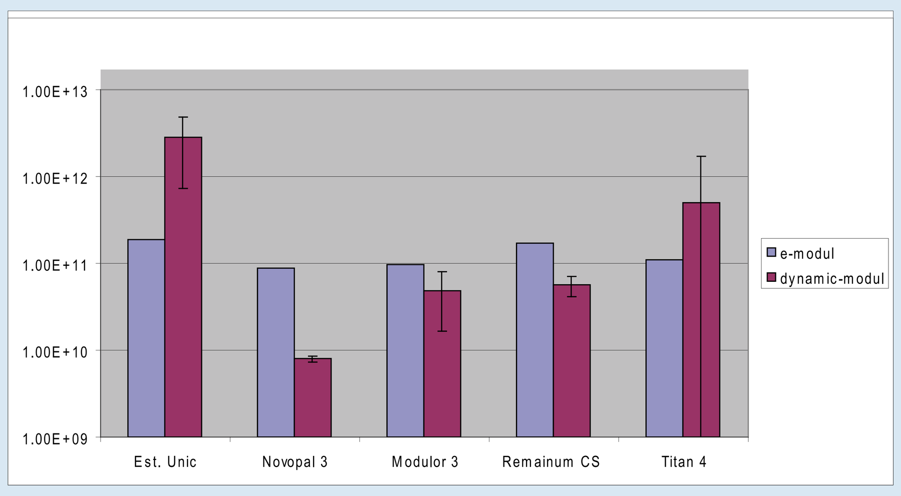
RESULTS

E* and loss angle Ø (brackets) of dental structures and repair materials measured 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°



Dynamic modulus measurements E* on different sites, on a single tooth section



Difference between E* and EY on dental alloys
E* (right) measured with SIMI compared to E (left) provided by manufacturer

Vickers measurements on the same spot as the (non destructive) SIMI-measurements.
Indentation pattern of 4 hardness measurements on enamel with a Vickers indenter (Vickers hardness 100p Leitz Durimet).

DISCUSSION

In this first set of measurements on sectioned teeth, SIMI modulus (E*) data were not strictly analogous to reported EY values [1]. However, micro-dynamic and quasi-static nano-indentation data rarely agree. Factors contributing to observed discrepancies: (i) Vis-coelastic material moduli are highly dependent on loading geometry and rates. (ii) Most reported EY 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 ap-proaching 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 loss angle.

In the future, measurement of site-specific variations in dynamic impact stiffness (E* and loss angle) 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.

CONCLUSION AND ACKNOWLEDGEMENT

SIMI is a simple device for quantitative functional characterisation of load-bearing tissues. To our knowledge SIMI did provide for teeth first concomitant data on both E* and loss angle. Site specific variation in loss angles actually describing how specific dental structures absorb a dynamic impact's energy, may turn out to have a major influence mechanical behaviour of teeth in health and disease.

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

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. Correspondence: werner.baschong@unibas.ch