Nanoscratching Determines the Functional Width of Interfaces

The Dentin-Enamel Junction

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Interfaces in biological tissues often show unique structural characteristics and a zone of gradual transition of properties. This transitional zone relates to the functional width of the interface. The dentin-enamel junction (DEJ) unites two mineralized tissues with very different matrix composition and physical properties. Its excellent biomechanical properties have drawn interest as a biomimetic model for joining dissimilar materials. The determination of the functional width of this junction, however, is difficult due to the small size and the irregular structure of the interface. The structure of the DEJ is generally described as having 25 to 100µm diameter scallops with their convexities directed toward the dentin. These scallops contain microscallops and finer structures. Besides the unique structure, the presence of a smooth gradient of mechanical properties at the junction is thought to contribute to the interfacial bonding between enamel and dentin and is considered an important toughening mechanism that reduces stress concentrations. Measurements of the functional or mechanical width of an interphase require either a number of independent measurements of properties spanning the interphase, e.g. indentations, or a technique that provides continuous data collection across the interphase. The latter approach was applied here by performing nanoscratches across the DEJ using the Hysitron 2D transducer attached to a Nanoscope III Atomic Force Microscope.

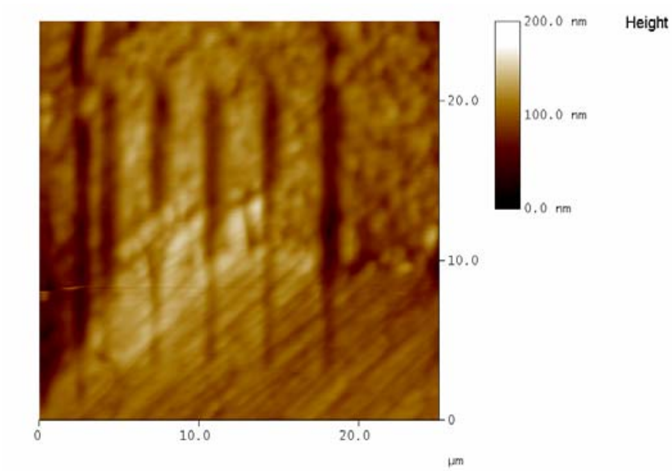

Fig. 1
In-situ *image of scratches across the dentin-enamel junction reveal large differences in the deformation of each zone.*

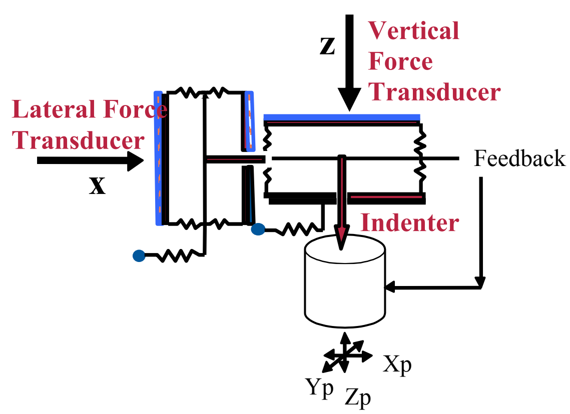

Fig. 2
Schematic of Hysitron electrostatically actuated 2D scratch transducer.

The AFM allowed the exact positioning of the indenter onto the enamel, dentin, and the DEJ. Friction coefficients for each of these tissues were obtained from 10µm-long scratches using a spherical diamond indenter at loads in the range of 50 to 600µN which are controlled by the vertical force transducer (Fig. 2). A second transducer connected to the "floating" plate of the vertical force transducer records lateral or frictional forces through the entire length of the scratch. Friction coefficients (µ) were calculated from the quotient of lateral to normal forces for each tissue and plotted versus lateral displacement, as shown in Fig. 3. Due to the higher content of organic phases, friction coefficient is higher in dentin (µ = 0.31) compared to enamel (µ = 0.14). Scratches across the interface between enamel and dentin, as shown in Fig. 1, show a sharp decrease of friction coefficients from the level of dentin to the level of enamel. The functional width of this junction is defined by the width of the slope of friction coefficients. From measurements of 50 scratches across this junction, we calculated an average width of the DEJ of 2.0 (± 1.1)µm.

Conclusions

The observed functional width is significantly smaller compared to findings by other methods, such as nano- and microindentation (1), but is believed to be more accurate due to the increased resolution of the scratching test (2). Compared to the indentation methods, the continuous recording of a physical property by scratch testing increases resolution by avoiding steps between indentations. Furthermore the low depth of the scratch (0 – 80nm) increases the resolution in the z-axis.

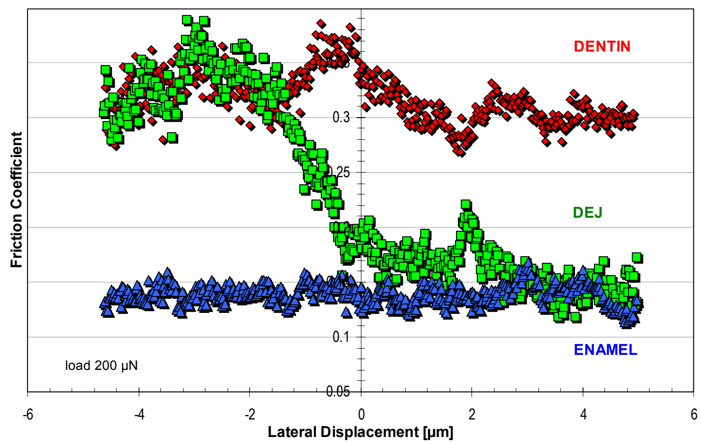

Fig. 3
Friction coefficient measurements reveal the width of the dentin-enamel junction.

1 Marshall GW, Balooch M, Gallagher RR, Gansky SA, Marshall SJ. Mechanical Properties of the Dentinoenamel Junction: AFM Studies of Nanohardness, Elastic Modulus and Fracture. *J Biomed Mater Res* 54:87-95, 2001.

2 Habelitz S., Marshall S. J., Marshall G. W., Jr., Balooch M. The functional width of the dentino-enamel junction determined by AFM-based nanoscratching. *J Struct Biol* 135, 294-301, 2001.

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