Nanoindentation of Human Teeth

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Introduction

Nanoindentation is a relatively new technique that allows researchers to determine the mechanical properties of different materials by creating microscopic indentations in the material's surface using a diamond tip. Based on the indentation, the nanoindenter continuously measures variables such as applied force, displacement into the material surface, and time of loading, which are used to derive the hardness, modulus of elasticity, and other mechanical properties. Researchers are able to control certain variables of the nanoindenter such as the force applied and the time of loading.

Objectives

Based on published research papers regarding the indentation of human tooth enamel, it is predicted that the hardness and modulus of elasticity of human enamel is approximately 5 GPa and 70 GPa[2], respectively. The results of the indentations will confirm or deny whether the tests had been done on enamel or another part of the tooth, such as dentine, which lies beneath the enamel. This research focused on the mechanical properties of human enamel and dentin. Because the indentation of human teeth has not been done before at the University of Wyoming, this study focused on the best ways to prep the human teeth, to become familiar with the nanoindenter, and to ensure that the area tested has an appropriate hardness and modulus of elasticity.

Acknowledgements

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Results

The properties examined for this research were the modulus of elasticity (E) and the hardness (H). The equations are as follows:

$$E = \frac{[(1-\nu^2)\sqrt{\pi}S]}{2\beta\sqrt{A}}$$

$$H = \frac{P_{max}}{A}$$

Where S is the unloading stiffness, A is the contact area, β is the correction factor given by 1.05 for the Berkovich indenter, and P_{max} is the maximum load applied. From these equations, the average modulus of elasticity was found to be 54.2 GPa while the hardness was 0.51 GPa for Input 1 as defined in the Method and Procedure section.

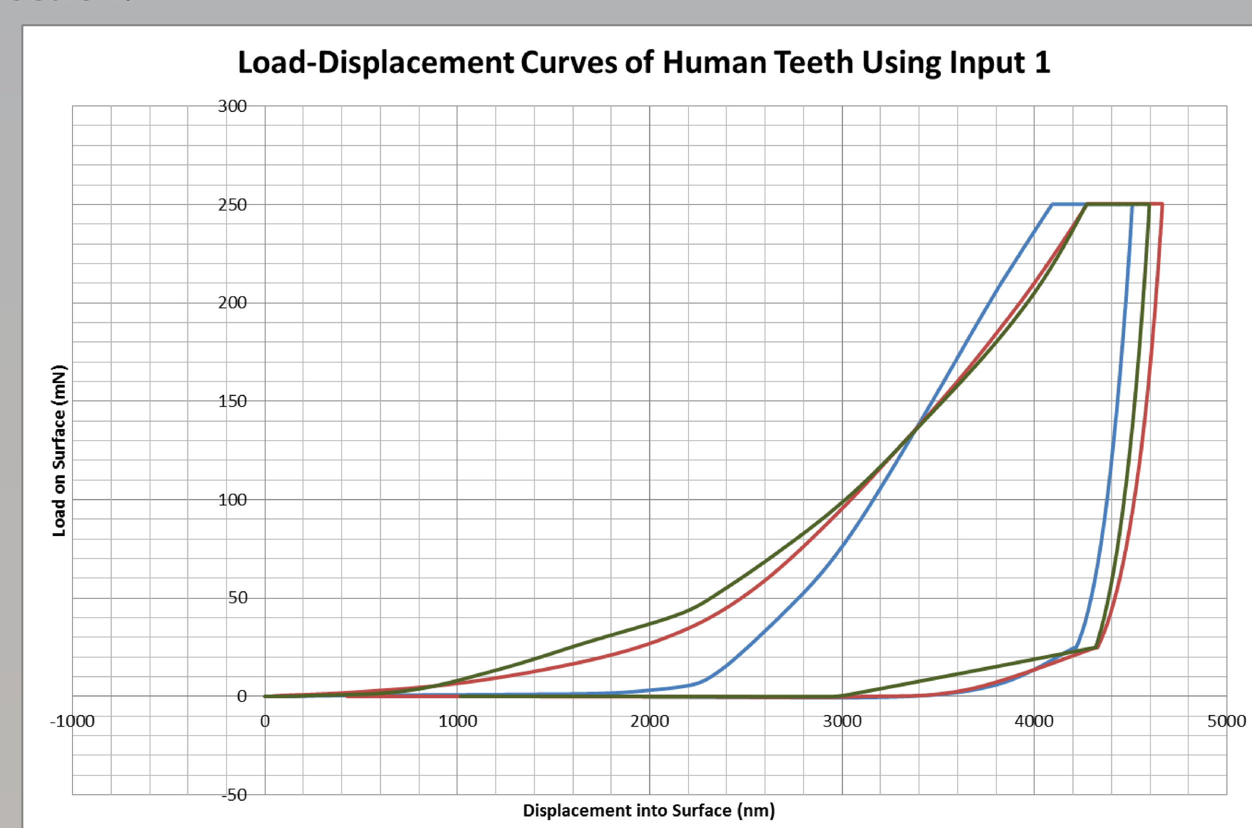

Figure 1. Loading and Unloading using Input 1.

Input 2 produced a much smaller average modulus of elasticity of 25.4 GPa and a hardness of 0.51 GPa. The smaller modulus of elasticity for Input 2 indicates the area indented was dentin which has an estimated modulus of 20-25 GPa[2].

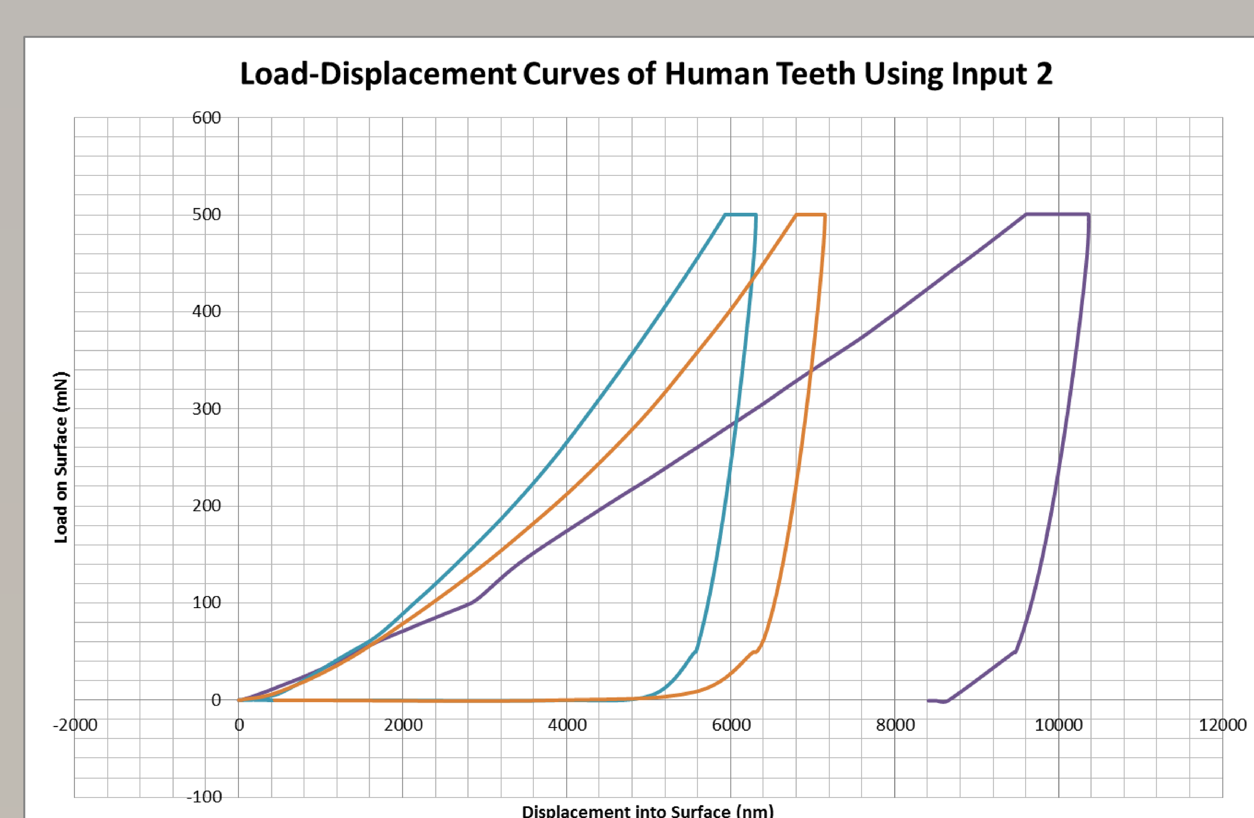

Figure 2. Loading and Unloading using Input 2.

Conclusions

While the average elastic modulus 54.2 GPa for Input 1 is smaller than the expected modulus of enamel (approximately 70 GPa[2]), it is still significantly higher than the expected modulus of elasticity range for dentin of 20-25 GPa[2]. Because of this, the area indented was likely enamel. Research in the past has shown that dental treatments such as whitening can decrease the elastic modulus of enamel to values as low as 32.7 GPa[1]. The tooth used for Input 1 could have been subjected to a similar dental treatment.

For Input 2, the indents resulted in an average modulus of 25.4 GPa, which is the expected modulus for dentin as previously stated. The area of indentation for this set was performed on the side of the tooth and the root was very exposed. Therefore, it is likely that the test site was on the root where the outer layer is dentin as opposed to the crown of the tooth which has a thick layer of enamel.

The hardness for Input 1 was 0.51 GPa, which was much smaller than the expected 5 GPa hardness of enamel. The teeth used for this research were preserved in a glycerin preserving solution and it is likely the enamel absorbed a small amount of the preserving fluid, causing it to become more ductile and lowering its hardness. This is also a possible explanation for the low modulus of elasticity.

For Input 2, the hardness was also 0.51 GPa, equal to Input 1. The similarity between the two is because the teeth used in both sets were preserved in the same type of fluid. However, the hardness of dentin ranges from 0.5 to 0.7 GPa[1]. Because of this, it is inconclusive as to whether the fluid affected the hardness of the tooth used for Input 2.

Based on the results of both sets of indentations, certain precautions should be taken when choosing a site for indentation to ensure the correct region is tested. Also, because the preserving fluid appeared to affect the results, the indentations should be performed as soon as possible after extraction to prevent moisture effects.

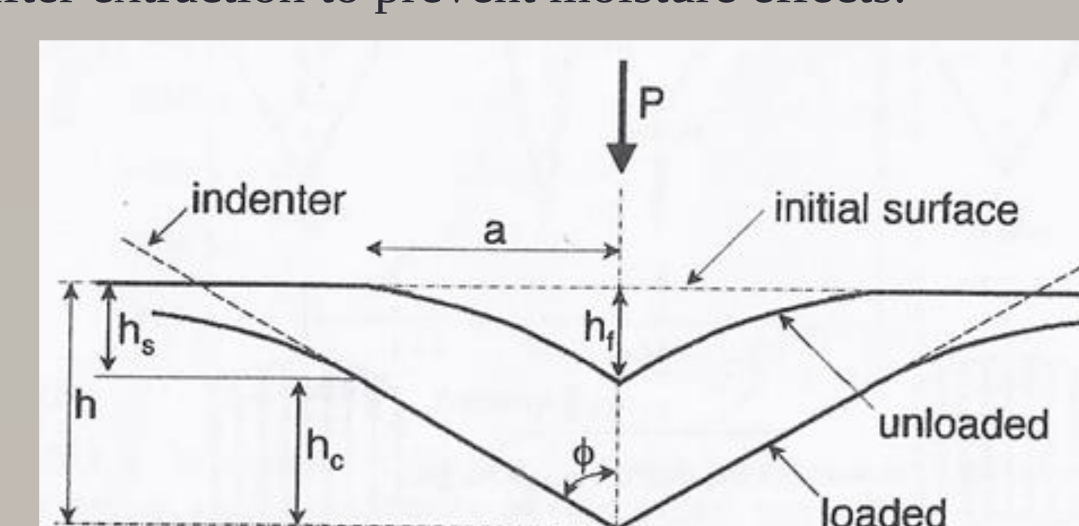

Figure 3. Diagram of indentation process.

Method and Procedure

The material properties of enamel were examined using a G200 Nano Indenter by Agilent Technologies. This instrument has the capability to perform micro- and nanoindentations that are controlled through computer software. The tip used in this experiment was a Berkovich diamond tip that has the geometry of a pyramid. Indentations were performed using two sets of input values:

1. Maximum force of 250 mN, peak hold time of 100 seconds, time to load of 30 seconds, a mean approach velocity of 20 nm/s, and a Poisson's ratio of 0.25.
2. Maximum force of 500 mN, peak hold time of 10 seconds, time to load of 30 seconds, a mean approach velocity of 20 nm/s, and a Poisson's ratio of 0.28.

To conduct this research, online training for research involving human subjects was completed through the Institutional Review Board (IRB) to ensure this research posed no harm and did not violate any personal rights by using teeth samples from human subjects. The teeth were prepared by the consulting dentist, Dr. Melissa Watt. To prepare the teeth samples, Dr. Watt cut along the length and width of the teeth (also known as the occlusal and facial/lingual sides) so the enamel was the appropriate size using a specialized saw under a water bath. This also allows for the indentation to be done on other components of the tooth, such as the dentin, and shapes the tooth to the correct size for indentation. The teeth were then mounted and after the actual indentation was complete, the hardness and modulus of elasticity were derived through the data analysis of the load-displacement curves using Microsoft Excel.

References

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