An evaluation of dental operative simulation materials

Li-Hong HE, Lyndie FOSTER PAGE and David PURTON

Sir John Walsh Research Institute, Faculty of Dentistry, University of Otago, PO Box 647, Dunedin 9054, New Zealand
Corresponding author, Dr. Li-Hong HE; E-mail: lihong.he@otago.ac.nz

The study was to evaluate the performance of different materials used in dental operative simulation and compare them with those of natural teeth. Three typical phantom teeth materials were compared with extracted permanent teeth by a nanoindentation system and evaluated by students and registered dentists on the drilling sensation of the materials. Moreover, the tool life (machinability) of new cylindrical diamond burs on cutting the sample materials was tested and the burs were observed. Although student and dentist evaluations were scattered and inconclusive, it was found that elastic modulus ($E$) and hardness ($H$) were not the main factors in determining the drilling sensation of the materials. The sensation of drilling is a reflection of cutting force and power consumption. An ideal material for dental simulation should be able to generate similar drilling resistance to that of natural tooth, which is the machinability of the material.

**Keywords:** Dental simulation, Phantom material, Nanoindentation, Machinability

**INTRODUCTION**

Simulation systems and related technology have significant advantages for clinical training and have become prominent in health care educational institutions. Simulators are valuable for duplicating irreversible clinical situations and operations. For patients’ safety, it is better for trainees to practice on a simulator than a patient.

Dentistry has also benefitted from the advent of modern simulators, especially in the area of undergraduate preclinical training. Simulators have become the safe and economic choice in assisting students to improve hand skills and practice their application of textbook knowledge. Appropriate simulation on phantom teeth, under the guidance of tutors, provides a smoother transition for students into clinics and reduces the burdens of supervisors in clinics.

Various types of simulation systems are available, which genuinely mimic different clinical situations. Although there have been some efforts to develop new phantom teeth to better reflect the clinical response of natural teeth, currently, most simulators still rely on plastic phantom teeth and few reports mention the ability of these phantom materials to mimic the texture of natural teeth, which is important to give trainees the initial senses of tactile sensation associated with tooth preparation.

The aims of this study were: to compare the mechanical properties of three simulation materials with those of natural teeth; to correlate the mechanical properties with feedback from students and dentists on their experiences in cutting the materials; to assess the effect of cutting the materials and the tooth, on the condition of the diamond bur.

**MATERIALS AND METHODS**

The materials used in this study were: Nissin teeth (model A5A-500, Nissin Dental Products Inc., Kyoto, Japan), Dentoform laminated plates (Columbia Dentoform Corp., Long Island, USA), VITA blocks (prototype polymer infiltrated ceramic, VITA Zahnfabrik, Bad Sackingen, Germany), and extracted permanent teeth.

**Nanoindentation test**

A natural tooth and a Nissin plastic tooth were embedded in cold-curing epoxy resin (Epofix, Struers, Ballerup, Denmark). The embedded teeth, VITA block, and Dentoform plate, were sectioned with a high-speed cutting machine (Accutom-50, Struers) using a diamond cut-off wheel (331CA, Struers) at a spindle speed of 3,000 rpm under constant water irrigation. The cut surfaces were then polished (TegraPol-21, Struers) to a grade of 1 μm diamond polishing paste.

The indentation experiments were performed using a nano-based indentation system (Ultra Micro-Indentation System, UMIS-2000, CSIRO, Canberra, Australia). Each polished specimen was mounted with wax on a metal base. The mounting base contained a strong magnet to ensure adequate contact was obtained with the test base in the UMIS. The nanoindentation tests were performed at a load of 300 mN with a calibrated Berkovich indenter. The maximum load was held for 30 s to minimize the effect of creep on the unloading curve. The Oliver-Pharr analysis method was used by the software to calculate the elastic modulus ($E$) and hardness ($H$). Sixteen indents were made on the sample with an interval of 100 μm between indents to avoid the influence of residual stresses from neighbouring impressions. One-way ANOVA with Tukey post-hoc test ($\alpha=0.05$) was used to analyse nanoindentation.
elast modulus and hardness data by using OriginPro 8 (OriginLab Corp., Northampton, USA).

**Simulation evaluation and questionnaires**

Sixty four second year dental students without any dental experience and fifteen registered dental practitioners who teach in the Faculty of Dentistry participated in the evaluation. A sound natural tooth, Nissin tooth, Dentoform plate, VITA block, and four new cylindrical diamond burs (ISO 806 314 107524 010) (Komet, GEHR. BRASSELER GmbH & Co. KG, Lemgo, Germany) were given to each participant. The participants were asked to drill each material with a new bur using a high speed handpiece with copious water irrigation. For each material, the participants were asked to create a box (3 mm square and 3 mm deep) into a smooth surface and use a graduated periodontal probe to guide the measurement. Participants were asked to remember the sense of drilling into the material surface vertically and the sense of expanding the box laterally and compare the sensation (resistance) between the natural tooth and the other three materials. At the end, participants were asked to choose one material that most resembled the natural tooth in terms of cutting box vertically (bur penetrating) and cutting box horizontally (bur moving laterally).

All students and staff consented to take part in the study as one of the standard teaching sessions.

**Bur life comparison and SEM observation**

Five new diamond burs were used for the comparison and observation. One bur was left as control. The other four burs were used to drill different materials using a high speed handpiece under water irrigation. The same bur was used to drill one material to the depth of the diamond coating part as many times as possible (up to 5 holes) until the bur became inefficient in drilling another hole. The efficient drilling count was recorded. All materials and the natural tooth were drilled by the same operator with the same high speed handpiece.

After drilling, the burs were photographed by a digital camera (Canon PowerShot A640, Canon, Tokyo, Japan) and platinum coated and observed by a field emission scanning electron microscope (SEM) (JSM 6700 FESEM, JEOL, Tokyo, Japan).

## RESULTS

### Nanoindentation elastic modulus and hardness

The sample nanoindentation force-displacement curves (Fig. 1) indicated that the indenter tip penetrated more deeply on Nissin tooth and Dentoform plate. These results indicated that Nissin tooth and Dentoform plate had much lower elastic modulus and hardness than the natural tooth ($p<0.05$) (Table 1). In contrast, VITA block had a very similar force-displacement curve to enamel (Fig. 1). VITA block was softer than enamel but had higher $E$ and $H$ than dentin ($p<0.05$) (Table 1).

### Questionnaires

As illustrated in Fig. 2, the results from participants (student and dentist) evaluations are widely scattered and inconclusive. On the students’ part, regarding the bur penetration, nearly half (42%) of the students chose the Nissin tooth, followed by Dentoform plate (33%) and VITA block (25%). For the lateral expansion of the

![Fig. 1 Sample nanoindentation force-displacement curves of different materials.](image)

### Table 1 Nanoindentation elastic modulus and hardness of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$ (GPa) (mean±SD)</th>
<th>$H$ (GPa) (mean±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissin tooth</td>
<td>9.62±1.79</td>
<td>0.63±0.07</td>
</tr>
<tr>
<td>Vita block</td>
<td>30.14±2.96</td>
<td>2.36±0.57</td>
</tr>
<tr>
<td>Dentoform plate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>white layer</td>
<td>6.28±0.09</td>
<td>0.25±0.01</td>
</tr>
<tr>
<td>yellow layer</td>
<td>8.22±0.80</td>
<td>0.31±0.05</td>
</tr>
<tr>
<td>Natural tooth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>enamel</td>
<td>87.95±4.16</td>
<td>4.67±0.37</td>
</tr>
<tr>
<td>dentin</td>
<td>20.80±1.62</td>
<td>0.42±0.06</td>
</tr>
</tbody>
</table>

Note: all results are statistically different to each other ($p<0.05$)
preparation, 48% of the students preferred the Nissin tooth, 28% the VITA block and 24% the Dentoform plate. However, the Faculty practitioners had a slightly different interpretation, with over half (53%) selected the Dentoform plate, followed by VITA block (27%) and Nissin tooth (20%). Regarding the lateral expansion, 67% of the dentists chose the VITA block, followed by 20% the Nissin tooth and 13% Dentoform plate.

**Bur life comparison and SEM observation**

The new diamond bur was able to drill more than 5 holes in the natural tooth and VITA block, and 3–4 holes in the Dentoform plate, but just 1–2 holes in the Nissin tooth before it became inefficient at drilling into the material. SEM images (Fig. 3) show that the surfaces of the burs were coated by debris to different extents, with Nissin and Dentoform materials having greater tendency to coat the burs, and VITA block being the closest to natural tooth in terms of the pattern of debris distribution on the bur.

**DISCUSSION**

Materials selected for this study have wide representation. The Nissin tooth is made of a homogeneous fibre reinforced plastic material. Although the material is softer than natural tooth, the product has a track record of over ten years. Dentoform laminated plate is manufactured from a resin that is specially formulated to simulate the hardness of a human tooth, and is designed to mimic tooth structure and to give the user different drilling sensation as they pass from one layer to the other. However, our nanoindentation tests found the mechanical properties were very similar between layers. The sudden change in sensation during drilling might be caused by the thick glue interface between the layers. VITA block is a polymer infiltrated ceramic developed for CAD/CAM purposes. However, due to its composite nature, the material is much softer than traditional ceramics and might be a good phantom tooth candidate.

Elastic modulus and hardness are two basic mechanical indices used to describe and compare materials. Elastic modulus quantifies the stiffness of a material while hardness is a reflection of the material’s ability to resist permanent deformation. In this study, the elastic modulus and hardness of the phantom materials were significantly lower than sound...
enamel. A more detailed comparison of the mechanical properties of different phantom materials has been published elsewhere. The mechanical results imply that the phantom materials would cut more easily with clinical burs than a natural tooth due to their softness. However, both students’ and dentists’ evaluation results were widely scattered, which contradicts the mechanical prediction. Moreover, although a significant portion of participants chose the plastic materials (Nissin tooth and Dentoform plate) as most resembling the natural tooth in terms of vertical penetration, they found the plastic materials were more difficult to penetrate vertically than the natural tooth (based on the individual comments).

Regarding the lateral expansion of the cavity, two-thirds of the dentists felt that the ceramic material (VITA) most resembled the natural tooth, while students had a mixed selection again.

The sensation of the drilling is a reflection of cutting force and power consumption, which is in the field of machinability of materials. Machinability is a complex concept related to the mechanical properties of the material, and the interaction between the tool and the material while cutting. Classic machinability tests on cutting tool materials include tool life tests, surface finish tests, cutting force tests, power consumption tests, and cutting temperature tests. Usually, a material that can be cut without rapid tool wear/damage is thought to be machinable. The scattered questionnaire results can be partially explained by the machinability of the material. The preliminary tool life comparison did help to explain the scattered results. For the vertical penetration, although the bur and material were water cooled, in considering the depth of drilling (~4 mm), it would not be surprising if water did not reach the tip of the bur. As a result, after the first drilling of Nissin tooth, the new diamond bur was heavily coated by burnt and molten plastic, which made the second attempt very difficult. Similarly, the Dentoform plate generated a lot of plastic debris and coated the bur surface after a few trials. Moreover, it was very difficult to remove the coating stuck on the surface of the bur. In contrast, due to the high melting temperature of hydroxyapatite crystals in natural tooth and ceramic particles in VITA block, the coatings on the surfaces of the burs were much lighter and self-cleansable. Therefore, the bur life for these materials was much longer. With a heavily coated bur, it is easy to understand why over half of the students and dentists found the soft plastic materials more difficult to drill.

When it comes to the lateral expansion of the cavity on different materials, dentists found that VITA block had more resistance than Nissin and Dentoform materials. This is due to the higher elastic modulus and hardness of the ceramic material, and during the lateral movement, water can easily cool and clean the bur surface to remove the debris. Therefore, the softness of the material dominated the ease of lateral drilling, which is reflected in the results of the questionnaire, that two-thirds of dentists found VITA ceramic more resistant to lateral expansion than plastics. Regarding the scattered students’ evaluation on lateral expansion, individual communication after the survey illustrated that, due to lack of experience, some students pushed the drill too hard against the material during lateral expansion. As a result, insufficient water cooling resulted in coating of bur by molten plastic.
More factors influence the evaluation of machinability of a material, for example, cutting tool material, geometry of cutting tool, edge preparation, machining conditions, etc. This is the first time that the machinability of materials has been considered in the selection of dental phantom materials. More tests on different burs, drilling force and conditions, and material edge chipping rate need to be done to establish evaluation criteria for future phantom materials selection.

An ideal material for dental simulation should have a similar drilling sensation to a natural tooth. To achieve this purpose, the material should be able to generate similar drilling resistance as that of natural tooth. The factors that need to be considered include the mechanical properties and, more importantly, the machinability of the material. During our simulation teaching, we found the tips of the burs were usually coated by the molten burnt plastic which made the cavity preparation very difficult and uncontrollable. Repeated poor quality cavity and crown preparations may limit the confidence and progress of students. Moreover, this may add complexity to a student’s learning experience. From this point of view, within the limit of the study, VITA block shows the best performance as phantom material while the current plastic phantom materials are too soft and uneconomic regarding the short bur life.

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REFERENCES