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Assessment of slot sizes in self-ligating brackets using electron microscopy

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Objective: To measure the slot dimensions of 0.022 inch self-ligating upper central incisor brackets from six manufacturers using electron microscopy, to compare the measured dimensions with the manufacturers' published dimensions, and to determine if the walls of the slots were parallel.
Materials: Six self-ligating upper central incisor brackets from four manufacturers (SmartClip and Clarity SL, 3M Unitek, Monrovia, CA, USA; Speed, Strite Industries Ontario, Canada; Damon MX, Ormco, Orange, CA, USA; In-Ovation R and In-Ovation C, Dentsply GAC, Bohemia NY, USA) were imaged with a scanning electron microscope and the slots heights measured. Intra-operator repeatability and accuracy were determined.
Results: All brackets had slot sizes that were significantly larger ($p < 0.05$) than the stated 0.022 inch. Speed brackets were 5.1 per cent larger (0.02311 inch) and the closest to the published dimension. The SmartClip brackets were 14.8 per cent larger (0.02526 inch) than the quoted slot size of 0.022 inch. In most brackets the distances between the slot walls was generally greater further from the bracket bases.
Conclusions: The actual measurements of upper central incisor self-ligating brackets from six manufacturers were larger than the manufacturers' stated dimension, and the walls of the slots diverged from the bracket bases.
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Introduction

Pre-adjusted self-ligating edgewise orthodontic brackets are claimed to be accurately manufactured to each manufacturer's prescription, allowing a tooth to be moved predictably in three dimensions. There has long been an assumption that the quoted dimensions of bracket slots are indeed accurate. In fact, several studies have shown discrepancies between the published and actual dimensions of orthodontic brackets.[1–3]

The importance of accurately published dimensions of bracket slots was underlined by Kusy and Whitley.[4] They emphasised that clinicians should be aware of the exact dimensions so that the critical contact angle for binding can be calculated. This angle is thought to be important for the efficient treatment of patients, as binding and the resistance to sliding mechanics can occur if the contact angle between the archwire and bracket increases, but it can be somewhat compensated for by the use of slightly oversized brackets and undersized archwires.

The aims of this study were to measure the slot dimensions of 0.022 inch self-ligating upper central incisor brackets from six manufacturers, to compare the measured dimensions with the manufacturers' published dimension of 0.022 inch, and to determine if the walls of the slots were parallel.

Materials and method

Five randomly selected, upper left central incisor 0.022 x 0.028 inch self-ligating brackets from the

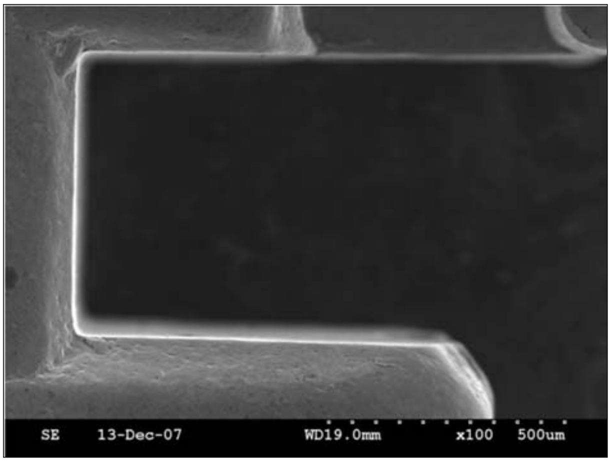

Figure 1. Speed bracket (Original magnification x100).

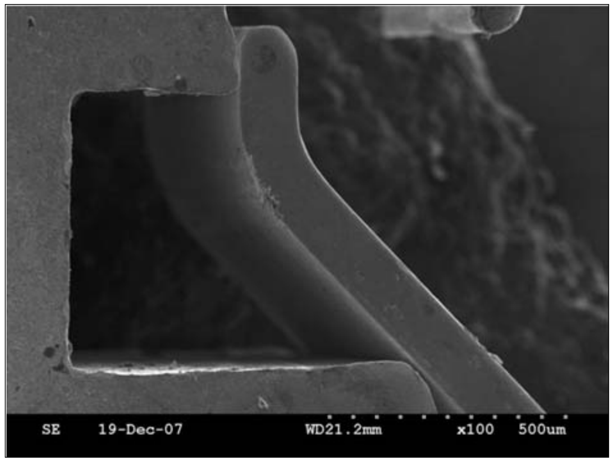

Figure 2. In-Ovation R bracket (Original magnification x100).

following manufacturers were used: SmartClip and Clarity SL (3M Unitek, Monrovia, CA, USA); Speed (Strite Industries Ontario, Canada) (Figure 1); Damon MX (Ormco, Orange, CA, USA); In-Ovation R (Figure 2) and In-Ovation C (Dentsply GAC, Bohemia, NY, USA).

The brackets were mounted on electron microscope stubs with conductive putty with the self-ligating spring or clip either fully open or removed to provide a clear view of the slot walls. They were orientated on the stubs so that the mesio-distal axes of the bracket slots were perpendicular to the bases of the stubs and the microscope table. The putty allowed the brackets to be manipulated in the electron microscope to ensure that the edges of the slots could be imaged. Non-metallic brackets were sputter-coated with gold to a thickness no greater than 20 nm in order to allow accurate scanning and measurement.

Each bracket was scanned individually in the scanning electron microscope (Hitachi S-3500N High Technologies Corporation, Berkshire, UK) to produce an image from which digital measurements could be taken. Images were captured, saved as TIFF Images and exported to Quartz PCI 5.1 (Quartz Imaging Corporation, Vancouver, Canada). The distances or heights between the walls of the slots were measured on x100 images and compared to the dimensions published by each manufacturer.

Data were analysed using the statistical package Stata 10.0 (StataCorp 2003, College Station, TX, USA). Significance was predetermined at a level of $\alpha = 0.05$. Student's *t*-test was used to compare the slot heights. The method errors were determined using a standard calibration chart prior to measurements being taken, and the measurements were repeated two weeks later. The successive measurements were accurate and repeatable to greater than 99 per cent.

Results

The results are given in Tables I and II.

The mean slot heights ranged from 0.02311 inch for the Speed brackets to 0.02526 inch for the Smartclip brackets (Table I). Smartclip brackets were the most variable in slot size (SD: 0.00073 inch) and In-Ovation R brackets the most consistent in size (SD: 0.00021 inch). The discrepancies ranged from 5.1 per cent for the Speed brackets to 14.8 per cent for the SmartClip brackets (Table II).

All brackets were statistically significantly larger than 0.022 inch and most brackets had divergent slot walls: the distance between the slot walls was generally greater further from the bracket base.

Discussion

Although the results of this study agree with previous studies of the slot sizes of conventional brackets, our use of electron microscopy has enabled a high degree of accuracy of measurement. We found the slot sizes of self-ligating brackets to be significantly larger than the manufacturers' quoted size of 0.022 inch and the slot walls to diverge from the base of the slot. The

Table I. The measured slot heights of self-ligating brackets, in inches.

Bracket	Mean (Inch)	SD (Inch)	Minimum	Maximum	*p*
In-Ovation R	0.02385	0.00021	0.02362	0.02417	**0.001**
SmartClip	0.02526	0.00073	0.02390	0.02626	**0.001**
Speed	0.02311	0.00026	0.02260	0.02358	**0.001**
Damon MX	0.02478	0.00033	0.02429	0.02516	**0.001**
Clarity SL	0.02409	0.00043	0.02331	0.02472	**0.001**
In-Ovation C	0.02450	0.00060	0.02362	0.02547	**0.001**

Significant values in bold
Probability associated with the *t*-test for slot height = 0.022 inch

Table II. Percentage differences between the measured bracket heights and quoted height of 0.022 inch.

	Per cent > 0.022 inch
Speed	5.1
In-Ovation R	8.4
Clarity SL	9.5
In-Ovation C	11.4
Damon MX	12.6
SmartClip	14.8

slots in brackets from the same manufacturer may vary in size as well.[2,3]

Manufacturing and material parameters affect the amount of play in the torque dimension.[2] Fischer-Brandies et al. measured five commercially available archwires and brackets with computer-aided light microscopy and reported that although the brackets were on average 0.8 per cent larger than the dimensions quoted by the manufacturers, the archwires had significantly smaller cross-sections.[2] The slot – archwire difference was thought to be a major contributor to torque play. This rather large discrepancy, as compared to the findings of our study, may be a function of the relative accuracy of the two measurement techniques or, indeed, the different brackets measured.

The greatest amount of play is in the torque plane.[5] When using a full-sized archwire, there is still a 6-degree loss of torque, as calculated from bracket slot size tolerances, but this can extend to 100 per cent torque loss in a low torque prescription.[6] These are theoretical calculations that do not necessarily represent actual values. For ease of use and patient comfort it has been suggested that some play between the wire and slot walls is reasonable,[1] providing torque to teeth such as the upper incisors is not compromised. Incorrectly torqued teeth may affect the final occlusion, anterior tooth guidance and space in the arch.

The method of manufacture affects the accuracy of the slot walls and contributes to loss of torque. Brackets cast from moulds are affected by shrinkage and milling introduces various imperfections such as grooves and striations and uncovers porosity in the slot walls. To compensate for manufacturing imperfections and to ensure that the imperfections do not interfere with archwire engagement, manufacturers deliberately increase the slot dimensions and bevel the edge of archwires.[1] Torque-induced stresses such as notching of the internal surface of walls of a bracket slot further increase bracket – wire play. Fischer-Brandies et al.[2] suggested these stresses can lead to a further 0.016 mm widening of bracket slots. We should, however, expect manufacturers to produce brackets and wires to accurate dimensions as these are variables that can be controlled.

The effects of manufacturing inaccuracies on the clinical performance of orthodontic appliances has highlighted the need for a regulatory body, supported by an appropriate legal framework, that ensures minimum standards of these devices. The German tolerance limits published in 2000 specify the tolerance limits for orthodontic bracket slots should be no more than 0.056 ± 0.04 mm.[7] The American Standards Association 2004 also stipulated their bracket tolerances for slot height must be within 0.0025 mm.[8] The Medical and Healthcare Products Regulatory Agency (MHRA), set up in April 2003, is the UK government agency responsible for ensuring that medical devices work and are acceptably safe. The MHRA have produced specific regulatory guidance for manufacturers of dental appliances and prostheses. The Medical Devices Directive provides guidelines, which enable manufactured devices to meet the requirements set. Some dental appliances, made to specific prescriptions, may be defined as custom-made devices and the requirements of the Medical Devices Directive will apply to those who wish to manufacture these products.[9]

Conclusions

1. The slot heights of upper left central incisor self-ligating brackets from six manufacturers were greater than the manufacturers' stated dimension of 0.022 inch. The differences ranged from 5.1 per cent larger (Speed) to 14.8 per cent larger (SmartClip) than the 0.022 inch dimension published.

2. There was considerable variation in slot sizes between different bracket systems.

3. The walls of the slots diverged from the bracket bases.

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