Precision of Bracket Placement on Dental Models

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Bracket-placement accuracy is crucial in achieving optimal orthodontic treatment results, particularly with "straightwire" appliance designs. Precision is actually a function of the repeatability of placing a bracket in the intended position on the tooth (Fig. 1).

The methodology for evaluating bracket position is complex, however, and few relevant studies have been conducted into its effects on tooth movement.[1,2] One reason is that tooth morphology varies among patients and even among teeth in a single patient—which calls into question the entire concept of preadjusted appliances. In addition, orthodontic brackets are so small that precise measurements of their positions in space are difficult to obtain.

We have developed a novel method of determining bracket position using a three-dimensional optical measurement system, along with a series of mathematical manipulations. In the following study, we measured bracket placement according to six degrees of freedom* (three translational values and three angular values) to determine the underlying sources of bracket-positioning error.

Materials and Methods

One pair of upper and lower maloccluded stone dental arches was scanned using an LDI RPS 450 machine.** The resulting raw digital model was cleaned and desiccated to convert it into a reasonable size for handling, and a pedestal was attached digitally. Thirty-six replicas of this pair of arches were then printed using an Eden 500V printer.***

Five orthodontists placed brackets virtually on a computer, using 3D images of brackets and the tooth models. This virtual-placement exercise provided a transformation matrix that would define the three translational and three angular values of each bracket in space.

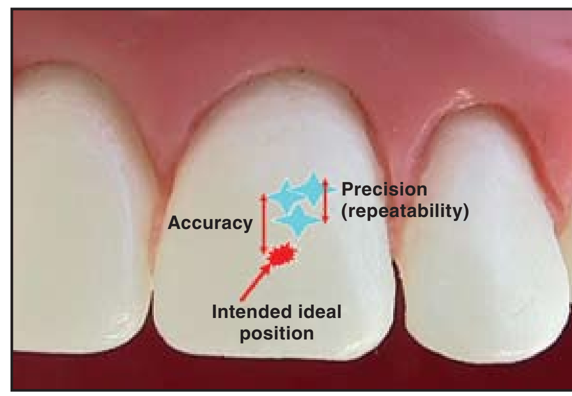

Fig. 1 Bracket-positioning precision (repeatability) and accuracy.

Each of the same orthodontists then directly bonded 3M Unitek Victory Series MBT LP metal brackets† from first molar to first molar on three pairs of arches in a dental mannequin, according to the clinician's ideal positions (Fig. 2). Each orthodontist also placed brackets on another three pairs of arches, without the dental mannequin, using any preferred indirect-bonding method. Three more pairs of arches were bonded with a digital indirect laboratory process, using bonding trays made of soft and hard silicone material.

*"Six degrees of freedom" refers to the motion of a rigid body in three-dimensional space (forward/backward, up/down, or left/right), combined with its rotation about three perpendicular axes (pitch, yaw, or roll). (definition from Wikipedia)

**Laser Design Inc., Minneapolis, MN; www.laserdesign.com.

***Objet Geometries Ltd., Rehovot, Israel; www.objet.com.

†3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

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Because the scope of this study was limited to precision, any discrepancies between the actual and virtual positions were not addressed; the virtual bracket positions were used solely as reference values. Bonding accuracy will be evaluated in future studies.

Bracket positions on the bonded dental arches were measured using a 3D optical measurement system, SmartScope,‡ which has a tolerance of ±.00015" (Fig. 3). Since the bracket slot is fairly inaccessible for direct measurement, a specially designed appendage was inserted into each slot to assist in locating the bracket position (Fig. 4). The SmartScope was used to measure *x, y,* and *z* coordinates relative to the global coordinate (0,0,0) for each of four target dots on the appendage. Through a series of mathematical manipulations, a unique set of three translational values (mesiodistal, occlusogingival, and labiolingual) and three angu-

‡SmartScope ZIP 250, Optical Gaging Products, Inc., Rochester, NY; www.ogpnet.com.

Fig. 2 Brackets bonded to dental mannequin.

Fig. 3 SmartScope ZIP 250 optical measurement system.

TABLE 1
REPEATABILITY OF BRACKET-POSITIONING MEASUREMENT SYSTEM (SIX DEGREES OF FREEDOM)

Measurement	One Pooled S.D.
Translational	
Mesiodistal	0.014mm
Occlusogingival	0.012mm
Labiolingual	0.015mm
Angular	
Rotation	0.49°
Angulation	0.49°
Torque	0.31°

lar values (rotation, angulation, and torque) was obtained for each bracket relative to the previously defined reference bracket coordinates. (See Appendix A, published in the online version of this article at www.jco-online.com.)

One arch of brackets was measured three times to determine the repeatability of the bracket-positioning measurement system. Each time, the appendages were inserted and removed. Table 1 shows one pooled standard deviation (PSTDEV) for each of the six degrees of freedom. The

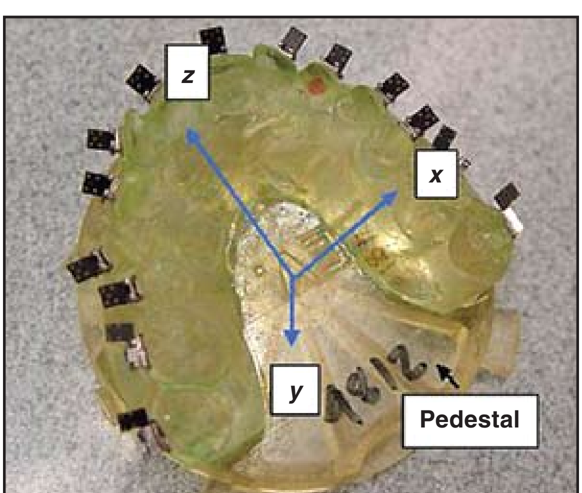

Fig. 4 Appendages inserted in bracket slots for ease of measurement.

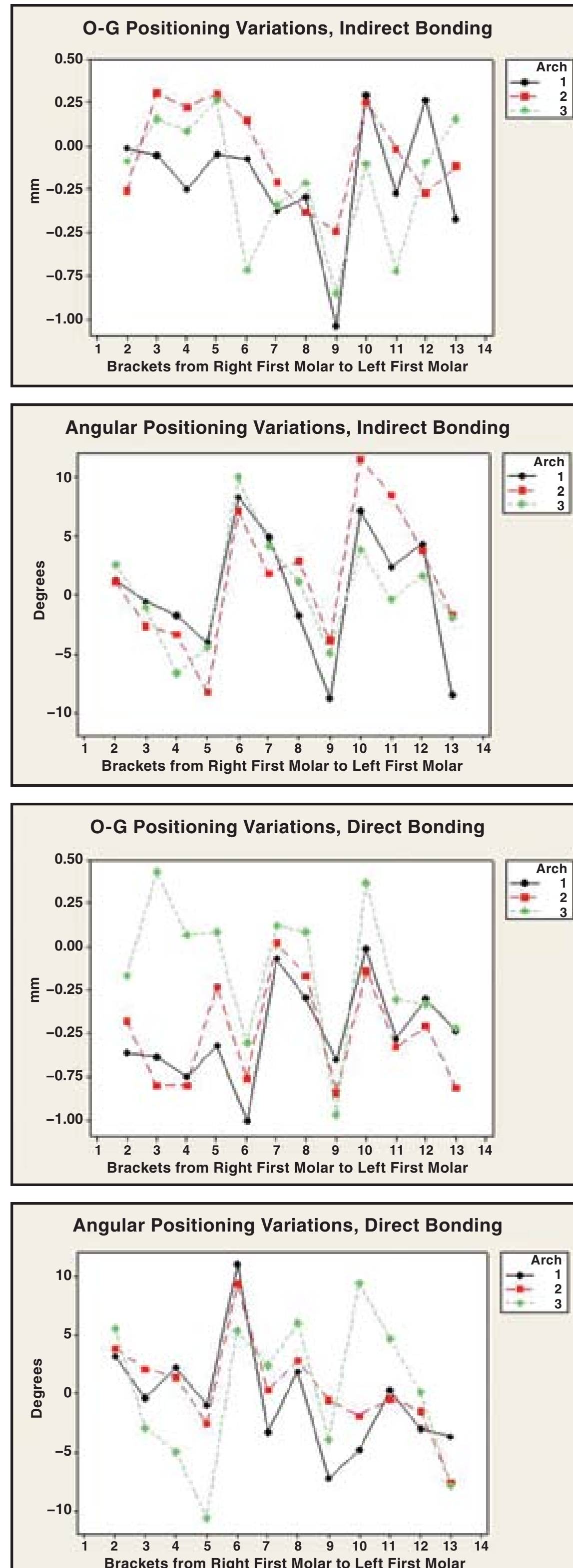

Fig. 5 Bracket-placement discrepancies relative to intended positions: brackets placed by Dr. James Mah (O-G = occlusogingival).

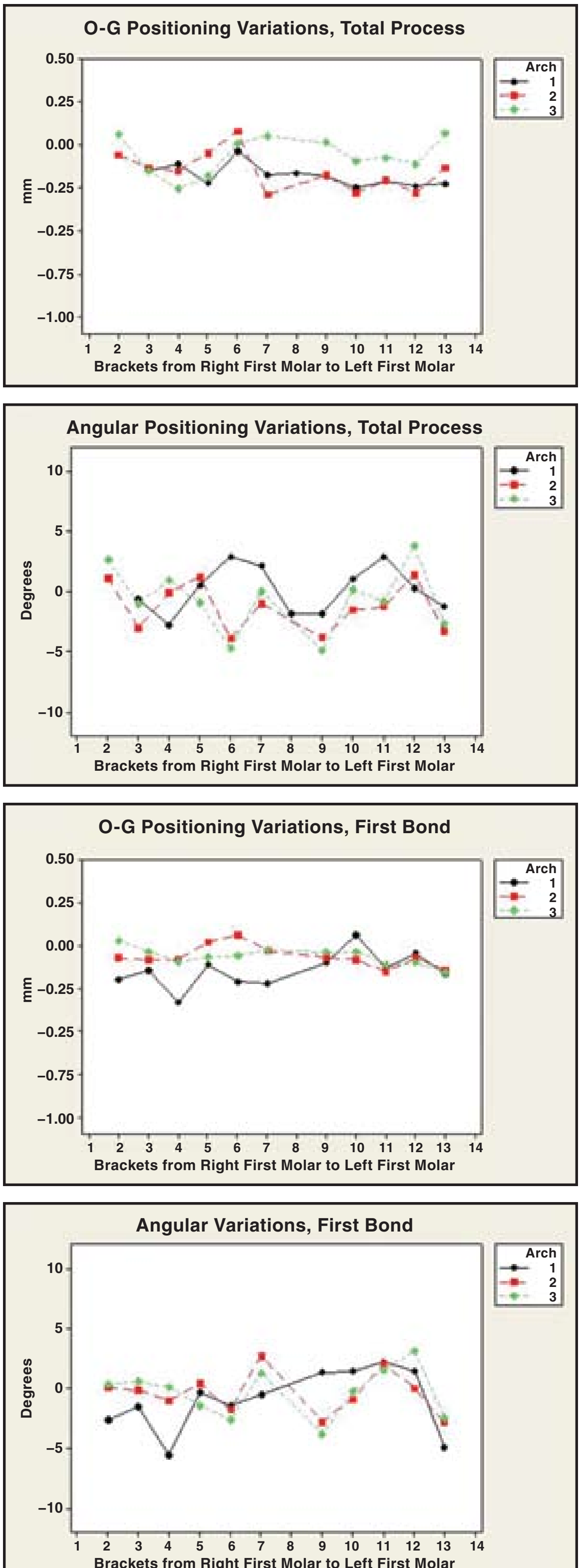

Fig. 6 Bracket-placement discrepancies relative to intended positions: brackets placed by digital indirect laboratory process (O-G = occlusogingival).

PSTDEV, used to determine the average spread of individual data points about a group mean, is calculated from the individual standard deviation (σ_i) of each bracket type as follows:

$$PSTDV = \sqrt{\frac{1}{N}\sum_{N}\sigma_i^2}$$

where N is 12, the number of brackets in an arch.

Results

One orthodontist's bracket-positioning discrepancies relative to the intended reference bracket positions are shown in Figure 5. The occlusogingival variations were in the range of .5mm to −1mm, and angulation variations in the range of ±10°. In contrast, the digital indirect laboratory process produced more consistent bracket precision relative to the intended positions (Fig. 6).

PSTDEV values were calculated for each orthodontist and for the laboratory process (Fig. 7). When the discrepancies for all five orthodontists' direct- and indirect-bonding arches were combined, 95% (2 PSTDEVs) of the brackets were repeatedly placed within ±.5mm and ±6.2°, compared to ±.2mm and ±5.2° for the indirect laboratory process. The PSTDEV values for repeatability of the measurement system (Table 1) were about 15% of the doctors' values for translational measurements and about 20% for angular measurements. In other words, the measurement system's noise level was about 1⁄7 to 1⁄5 of the signal level.

Discussion

Interestingly, despite the advantages of indirect-bonding methods such as direct vision, gauges, pencil markers, and other manual guides, the five orthodontists' bracket placement using their preferred indirect-bonding techniques was only slightly better than their simulated direct bonding on a dental mannequin (Figs. 5,7). This method of direct placement, however, was generally viewed as cumbersome and time-consuming.

The five orthodontists achieved similar precision in all six degrees of freedom. The labiolingual PSTDEV value, which is related to variation in adhesive thickness, was lower than the mesiodistal and occlusogingival values. In general, the PSTDEV values associated with rotation, angulation, and torque precision were similar.

Graphs of the orthodontists' bracket positions on the replicated arches did not usually center around zero, the intended virtual positions (Fig. 5). This placement error may have several causes. First, the orthodontist's perception of bracket position on the virtual 3D image of a tooth was probably different from that on the actual tooth. This problem may be remedied by providing more realistic 3D images of tooth models and more comprehensive training in 3D visualization. Second, the sample of three data points for each tooth was small; a larger sampling could yield more descriptive statistics. Third, because tooth anatomy is complex and variable, the orthodontists may have decided on different positions when they actually placed the brackets. Digital technology may help overcome these problems, as shown by the improved accuracy of the indirect laboratory process (Fig. 6).

Conclusion

The measurement method developed in this study, in which bracket position is fully characterized by six degrees of freedom, provides significant insight into the nature of bracket-positioning errors. It will be crucial for the profession to establish a broadly accepted and uniquely defined "gold standard" for bracket placement to measure and evaluate bracket-positioning accuracy.

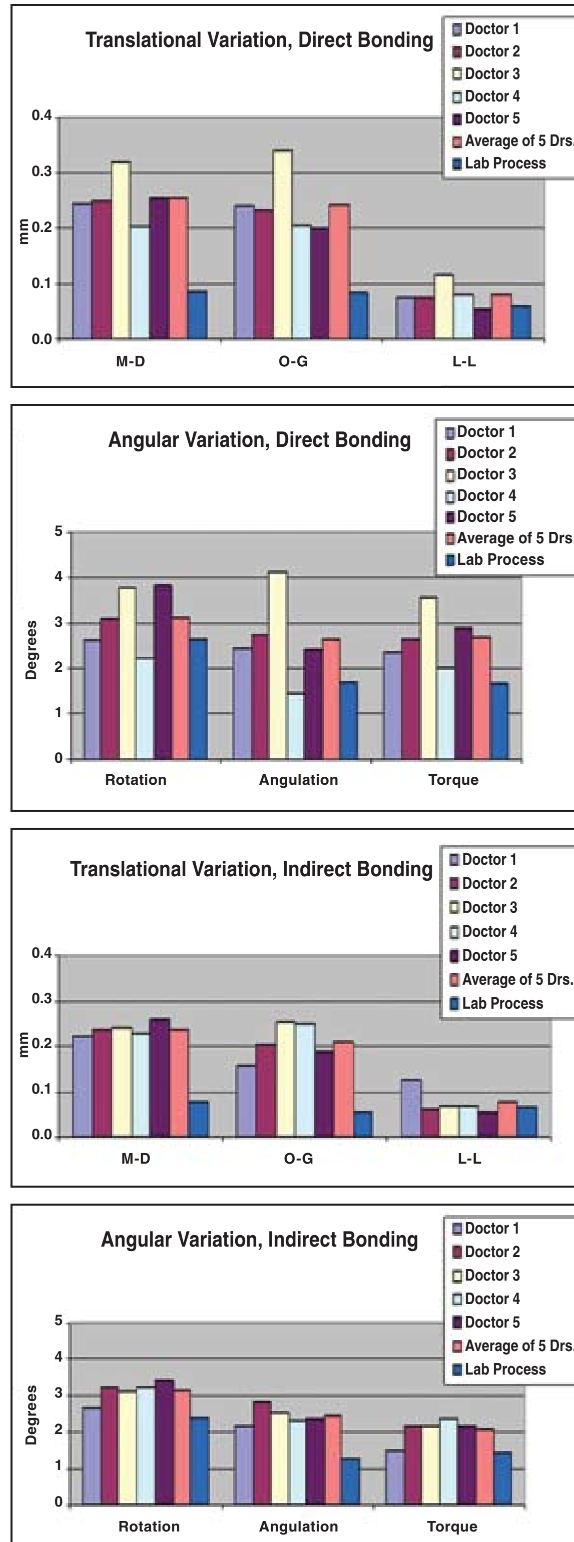

Fig. 7 Pooled standard deviations of five orthodontists compared to digital indirect laboratory process (M-D = mesiodistal; O-G = occlusogingival; L-L = labiolingual).

REFERENCES

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