The effect of fiber reinforcement on the fracture toughness and flexural strength of provisional restorative resins

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Statement of problem. Fracture of provisional restorations is of concern, especially with long-span fixed partial dentures or areas of heavy occlusal stress. A number of different techniques for reinforcement of provisional restorations have been suggested; however, the effect of these techniques is largely unclear.

Purpose. The aim of this study was to determine the fracture toughness and flexural strength of different types of provisional restoration resins reinforced with different commercially available fibers.

Material and methods. A total of 105 specimens were prepared in this study for each test; compact tensile specimens for the fracture toughness test and rectangular specimens for the flexural strength test. The specimens were divided into 3 groups according to the type of resin used, Jet, Trim, or Temphase (n=35), and then each group was divided into 7 subgroups (n=5) according to the type of fiber reinforcement, Construct, Fibrestick, Ribbond normal, Ribbond THM, Ribbond triaxial, or Fibrenet. Unreinforced specimens served as the control. Specimens were loaded in a universal testing machine until fracture. The mean fracture toughness ($\mathrm{MPa \cdot m^{1/2}}$) and mean flexural strength (MPa) were compared by 1-way analysis of variance, followed by the Tukey standardized range test (α=.05).

Results. Fibrestick and Construct reinforcements showed a significant increase ($P < .0001$) in mean fracture toughness over unreinforced controls for all resins tested. Fibrestick increased the polymethyl methacrylate from 1.25 ± 0.06 $\mathrm{MPa \cdot m^{1/2}}$ to 2.74 ± 0.12 $\mathrm{MPa \cdot m^{1/2}}$; polyethyl methacrylate from 0.67 ± 0.07 $\mathrm{MPa \cdot m^{1/2}}$ to 1.64 ± 0.13 $\mathrm{MPa \cdot m^{1/2}}$; and bis-acryl from 0.87 ± 0.05 $\mathrm{MPa \cdot m^{1/2}}$ to 1.39 ± 0.11 $\mathrm{MPa \cdot m^{1/2}}$. Construct increased polymethyl methacrylate to 2.59 ± 0.28 $\mathrm{MPa \cdot m^{1/2}}$; polyethyl methacrylate to 1.53 ± 0.22 $\mathrm{MPa \cdot m^{1/2}}$; and bis-acryl to 1.30 ± 0.13 $\mathrm{MPa \cdot m^{1/2}}$; however, there was no significant difference between Fibrestick and Construct reinforcements in the degree of reinforcement. Similarly the mean flexural strength values were significantly increased by different combinations of fiber and resin ($P < .0001$).

Conclusion. The addition of fibers to provisional resin increased both fracture toughness and flexural strength. (J Prosthet Dent 2004;91:258-64.)

CLINICAL IMPLICATIONS

On the basis of the results of this in vitro study, the use of glass and polyethylene fibers tested may be an effective way to reinforce resins used to fabricate fixed provisional restorations.

A provisional restoration is an important phase in fixed prosthodontic therapy. It should provide both pulpal and periodontal protection, have good marginal integrity and esthetics, and have sufficient durability to withstand the forces of mastication. A fractured provisional is damaging to the rendering of prosthodontic care and may result in an unscheduled appointment for repair. Materials commonly used to fabricate provisional restorations are polymethyl methacrylate, polyethyl methacrylate, bis-acryl composite, and epimine.[1] Several investigations have compared the physical properties of these materials[2-6] and suggested the use of the bis-acryl composites because of their superior properties.

For patients with bruxism or those whose treatment plans require long-term use of provisional restorations, such as when periodontally involved teeth are retained during the osseointegration of an implant,[7] provisional restorations with improved physical properties are required. Several attempts have been reported to reinforce provisional fixed partial dentures, including the

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Table I. Study materials

Product name	Material type	Manufacturer information	Lot number
Jet	PMMA	Lang Dental Mfg Co Inc, Wheeling, Ill	40280
Trim	PEMA	Harry J. Bosworth Co, Skokie, Ill	0110-549
Temphase	Bis-acryl	Kerr Corp, Orange, Calif	109190
Fibrenet	Glass fiber	Stick Tech Ltd, Turku, Finland	2020624-W0044
Fibrestick	Glass fiber	Stick Tech Ltd	2020610-r-0061
Ribbond	Polyethylene fiber	Ribbond, Inc, Seattle, Wash	9535
Ribbond-THM	Polyethylene fiber	Ribbond, Inc	9528
Ribbond triaxial	Polyethylene fiber	Ribbond, Inc	T104
Construct	Polyethylene fiber	Kerr Corp	30869

use of metal wire,[8] a lingual cast metal reinforcement, a processed acrylic resin provisional restoration,[9] and different types of fibers such as carbon, polyethylene, and glass.[10-18]

Investigations have shown that carbon fibers produced a significant increase in the flexural strength of polymers[10-12]; however, the black color limits their use. Transverse strength was not improved by polyethylene fibers in the absence of surface treatment because of poor adhesion between the fibers and the polymer matrix.[13] When plasma-treated polyethylene fibers were used, a significant increase in strength was shown.[14] Silanized glass fibers are promising new materials because of their good adhesion to the polymer matrix, high esthetic quality, and the increased strength of the resulting composite.[15-18] Others have found that the position, quantity, and direction of the fibers and the degree of adhesion between the fibers and the polymer affect the degree of reinforcement.[19-21]

The fracture mechanics approach is considered a reliable indicator of the performance of brittle materials.[22-24] Fracture toughness is the ability of a material to resist crack propagation and may more accurately determine the likelihood of fracture of a provisional restoration in clinical practice, whereas fracture strength is the stress at which the material fractures.[25]

The purpose of this study was to compare the effects of 6 different types of fibers on the fracture toughness and flexural strength of polymethyl methacrylate (PMMA), polyethyl methacrylate (PEMA), and bis-acryl resins.

MATERIAL AND METHODS

Two laboratory tests were used for the study. For fracture toughness, compact test specimens were fabricated according to the ASTM no. E 399-83 recommendations.[26] For the flexural strength, rectangular specimens were fabricated according to the ISO14077.[27] In both tests, unreinforced resin was used as a control group.

Fracture toughness specimen preparation

The materials used in this study are listed in Table I. Compact test specimens were fabricated following ASTM no. E 399-83 recommendations, with the dimensions and shape shown in Figure 1. The specimens were in the form of a double cantilever beam, with a slot that originated from the center of one edge, extending along the specimen's center line to a 60-degree terminal apex located slightly beyond the midpoint of the specimen. Two loading holes pierced the specimen.

Five compact test specimens for each resin type/fiber reinforcement combination were made (n=105) using a specially designed stainless steel mold fabricated for the study. The design of the assembled mold provided 3 triangular ports, which allowed the escape of excess resin during mold assembly and exposure to pressure during polymerization.

PMMA and PEMA specimens were fabricated at room temperature by mixing the polymer and monomer in a clean glass jar with a stainless steel spatula at the 2:1 ratio recommended by the manufacturers. When the mix reached the dough stage, it was packed into the mold cavity slowly to avoid entrapping of air, the cover and the 2 circular rods of the mold were placed in position, and the entire assembly was placed in a hand press and compressed to allow the material to completely flow into the mold. The bis-acryl specimens were formed in the same manner, except that the material was supplied in an automixing cartridge. The mix was packed directly into the mold cavity using application tips supplied with the kit. These specimens served as controls.

The fiber-reinforced specimens were made by precutting the fibers into 12-mm lengths and wetting according to the manufacturer instructions, using the polymer-monomer mix for the PMMA and PEMA specimens and a bonding agent for the bis-acryl resin. The mold cavity was filled with the resin, and then the fibers were placed perpendicular to the end of the slot and 1 mm away from it, aligning the fibers perpendicularly to the direction of the crack (Fig. 1).

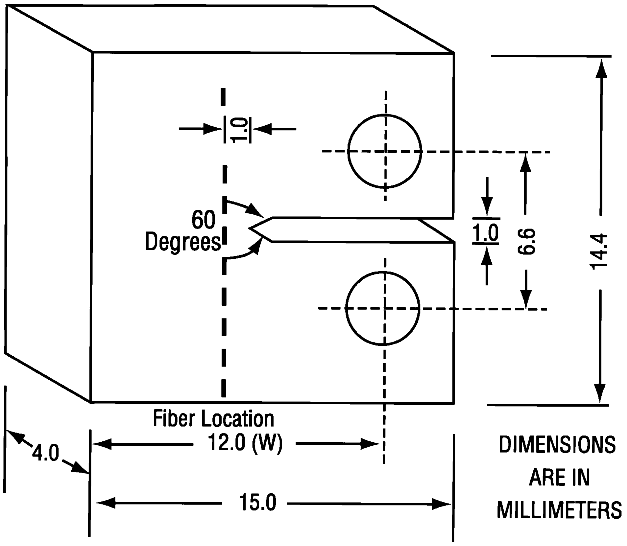

Fig. 1. Dimensions of compact test specimens for fracture toughness testing.[23] (Reprinted with permission from the Editorial Council of *The Journal of Prosthetic Dentistry.*)

After the resin had completely polymerized, the specimens were separated from the mold, and the flash was removed using a razor blade. The specimens were examined for any voids, and any defective specimens were discarded. Specimens were stored in water at 37°C for 24 hours before testing.

A precrack was placed in the compact test specimens by placing a sharp scalpel at the end of the slot and applying hand pressure (Fig. 2). Measurements of the dimensional parameters (*a, w, b*) for each specimen were recorded using a measuring microscope (Nikon Measurescope MM-11; Nikon Corp, Tokyo, Japan).

Fracture toughness testing

The specimens were tested in tension in a universal testing machine (Model 4204; Instron Corp; Canton, Mass) with the direction of the force perpendicular to the plane of the preformed crack. Each specimen was held in a specially designed tension device in the machine, and tension force was applied with a crosshead speed of 5 mm/min.

The peak force (*F*) in newtons, which caused fracture of the specimens, was recorded and used to calculate the fracture toughness (K_{Ic}) in MPa·m$^{1/2}$ from the following equation:[23]

$$K_{Ic} = pc/bw^{1/2} \cdot F(a/w)$$

Where *pc* is the maximum load before crack advance (KN); *b* is the average specimen thickness (cm); *w* is the width of the specimen (cm) and

$$F(a/w) = \frac{(2 + a/w)(0.886 + 4.64a/w - 13.32a^2/w^2 + 14.72a^3/w^3 - 5.6a^4/w^4)}{(1 - a/w)^{1/2}}$$

where *(a)* = crack length (cm).

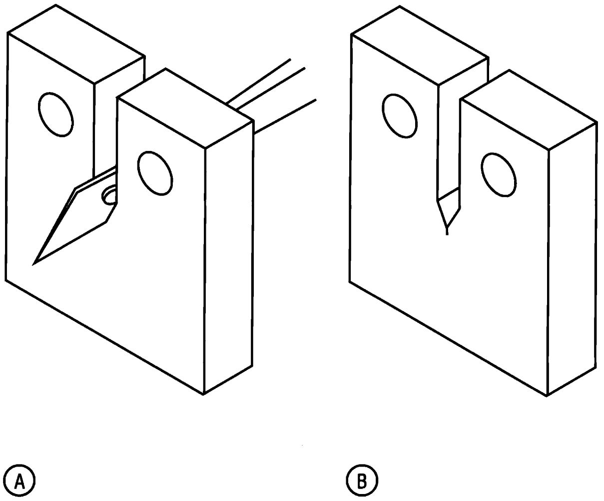

Fig. 2. Diagram representing initiation of precrack.[23] (Reprinted with permission from the Editorial Council of *The Journal of Prosthetic Dentistry.*)

Flexural strength specimen preparation

A specially designed split stainless steel mold was constructed to form rectangular specimens of dimensions 2 × 2 × 25 mm. The mold comprised a base (59.3 × 46.05 × 17 mm) and 7 U-shaped arms that, when assembled over the base, formed 6 identical spaces with the required dimensions. The details of specimen preparation were similar to the fracture toughness specimens. When the mix reached the dough stage, it was packed into the mold cavity slowly to avoid entrapping of air; the mold was then covered with a clean glass slab to remove the excess resin and kept at room temperature for 15 minutes to allow for complete polymerization of the resin. The fiber-reinforced specimens were made from precut 23-mm–long fibers, wetted using the polymer-monomer mix (PMMA, PEMA) and bonding agent (bis-acryl), and then placed in the lower part of the mold cavity and the resin applied on top.

After complete polymerization of the resin, the specimens were separated from the mold; flash was removed with the razor blade and examined for voids. Using the caliper (CD-6″ CS; Mitutoyo, Tokyo, Japan), the specimens were finished to the desired dimensions with 400- and 600-grit sandpaper and stored in water at 37°C for 24 hours.

Fracture strength testing

The flexural strength for all the specimens was determined by loading the specimens in the same universal testing machine. Each specimen was positioned on the bending fixture, consisting of 2 parallel, 2-mm–diameter supports, 20 mm apart. The load was applied with a crosshead speed of 1 mm/min, with a third 2-mm rod placed centrally between the supports.

Table II. Mean values, SDs, and Tukey standardized range test (HSD) of fracture toughness of PMMA acrylic resin reinforced with different types of fibers

Type of fiber reinforcement	Mean fracture toughness ($\mathrm{MPa{\cdot}m^{1/2}}$)*	SD	Tukey grouping†
Fibrestick	2.74	0.12	A
Construct	2.59	0.28	A
Ribbond triaxial	2.13	0.20	B
Ribbond normal	1.64	0.11	C
Ribbond THM	1.49	0.24	CD
Fibrenet	1.43	0.12	CD
Control	1.25	0.06	D

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

Table III. Mean values, SDs, and Tukey standardized range test (HSD) of fracture toughness of PEMA acrylic resin reinforced with different types of fibers

Type of fiber reinforcement	Mean fracture toughness ($\mathrm{MPa{\cdot}m^{1/2}}$)*	SD	Tukey grouping†
Fibrestick	1.64	0.13	A
Construct	1.57	0.22	A
Ribbond triaxial	1.15	0.13	B
Fibrenet	1.08	0.20	B
Ribbond THM	1.07	0.23	B
Ribbond normal	0.99	0.08	BC
Control	0.67	0.07	C

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

Table IV. Mean values, SDs, and Tukey standardized range test (HSD) of fracture toughness of bis-acryl reinforced with different types of fibers

Type of fiber reinforcement	Mean fracture toughness ($\mathrm{MPa{\cdot}m^{1/2}}$)*	SD	Tukey grouping†
Construct	1.39	0.13	A
Fibrestick	1.30	0.11	A
Ribbond triaxial	1.15	0.09	B
Ribbond THM	1.05	0.09	BC
Ribbond normal	0.98	0.07	CD
Fibrenet	0.88	0.06	CDE
Control	0.87	0.05	DE

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

Table V. Mean values, SDs, and Tukey standardized range test (HSD) of flexural strength of PMMA acrylic resin reinforced with different types of fibers

Type of fiber reinforcement	Mean flexural strength (MPa)*	SD	Tukey grouping†
Fibrestick	186.92	23.49	A
Ribbond THM	126.02	3.59	B
Ribbond normal	120.96	15.86	B
Ribbond triaxial	109.20	10.87	B
Construct	80.20	4.96	C
Fibrenet	68.38	7.25	CD
Control	52.88	4.96	D

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

The peak force (F) in newtons, from the stress strain curve of each specimen, was recorded and used to calculate the flexural strength in MPa from the following equation:[27]

$$\delta\beta = 3\mathrm{FI}/2\mathrm{Bh}^2$$

where $\delta\beta$ is the flexural strength in MPa; F is the maximum applied load in newtons; I is the supporting width in millimeters; B is the breadth of the test specimens in millimeters; and h is the height of the test specimen in millimeters.

The mean values and SDs for each group were calculated. The data of each resin type were analyzed for difference by use of 1-way analysis of variance followed by the Tukey standardized range test (HSD), using a confidence level of 0.05 to determine the mean differences. Only effects within groups were compared, because the intent of this study was not to make comparisons between the different materials tested.

RESULTS

The mean fracture toughness values for the 3 resin types with the 6 reinforcements are shown in Tables II through VII. Statistically, by using the Tukey standardized range test (HSD), the results revealed that the fracture toughness of PMMA reinforced with Fibrestick, Construct Ribbond triaxial, and Ribbond was significantly higher ($P < .0001$) than unreinforced PMMA, whereas Fibrenet and Ribbond THM were not significantly different. However, there was no significant difference between PMMA resin reinforced with Fibrestick and Construct. The flexural strength of PMMA reinforced with Fibrestick, Ribbond THM, Ribbond, Ribbond triaxial, and Construct was significantly higher ($P < .0001$) than unreinforced PMMA, whereas Fibrenet specimens were not significantly different from unreinforced resin.

The fracture toughness of PEMA reinforced with Fibrestick, Construct, Ribbond triaxial, Fibrenet, and Ribbond THM was significantly higher ($P < .0001$) than that of unreinforced PEMA, whereas Ribbond specimens were not significantly different. However, there was no significant difference between PEMA reinforced with Fibrestick and Construct. The flexural strength of PEMA reinforced with Construct, Fibrestick, Ribbond, and Ribbond THM were significantly higher ($P < .0001$) than the unreinforced PEMA, whereas

Table VI. Mean values, SDs, and Tukey standardized range test (HSD) of flexural strength of PEMA resin reinforced with different types of fibers

Type of fiber reinforcement	Mean flexural strength (MPa)*	SD	Tukey grouping†
Construct	44.08	6.03	A
Fibrestick	36.23	7.85	AB
Ribbond normal	33.09	6.34	BC
Ribbond THM	30.64	1.53	BC
Ribbond triaxial	25.72	5.78	BCD
Fibrenet	22.43	3.97	CD
Control	16.34	3.48	D

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

Table VII. Mean values, SDs, and Tukey standardized range test (HSD) of flexural strength of bis-acryl reinforced with different types of fibers

Type of fiber reinforcement	Mean flexural strength (MPa)*	SD	Tukey grouping†
Construct	199.60	52.77	A
Ribbond THM	130.41	11.45	B
Fibrestick	126.40	6.87	B
Ribbond triaxial	100.60	16.42	BC
Ribbond normal	80.65	9.5	C
Fibrenet	71.86	8.9	C
Control	62.33	8.51	C

*Differences among mean values were significantly different ($P < .0001$).
†Groups with different letter are significantly different.

Fibrenet and Ribbond triaxial had no significant difference from the unreinforced PEMA.

The fracture toughness of bis-acryl reinforced with Construct, Fibrestick, Ribbond triaxial, and Ribbond THM was significantly higher ($P < .0001$) than that of unreinforced bis-acryl, whereas bis-acryl reinforced with Ribbond and Fibrenet were not significantly different. However, there were no significant differences between bis-acryl reinforced with Construct and Fibrestick. The flexural strength of bis-acryl reinforced with Construct, Ribbond THM, and Fibrestick fibers was significantly higher ($P < .0001$) than unreinforced bis-acryl resin, whereas bis-acryl resin reinforced with Fibrenet, Ribbond triaxial, and Ribbond was not significantly different from the unreinforced bis-acryl.

DISCUSSION

The use of fibers to reinforce a provisional restoration seems to have an acceptable success rate[19]; all the more because of the recent advances in the production of improved fiber-reinforcing materials.[20] This study compared the effect of fiber reinforcement on the fracture toughness and flexural strength of 3 types of resin commonly used in the fabrication of provisional restorations (polymethyl methacrylate, polyethyl methacrylate, and bis-acryl composite). Although laboratory fracture toughness and flexural strength values under static loading may not reflect intraoral conditions; these values are nevertheless helpful in comparing materials under controlled situations and may be a useful predictor of clinical performance.

The fibers used in this study had different shapes and surface treatments; both Fibrestick and Fibrenet are silanized E-glass fibers preimpregnated with porous polymer. However, they differ in the arrangement of the fibers; Fibrestick is formed of a large number of unidirectional glass fibers, whereas Fibrenet is formed of single-layer woven glass fibers. Ribbond, Ribbond THM, and Ribbond triaxial consist of cold plasma-treated polyethylene fibers; they differ in their shape and thickness. Ribbond-THM is made from a higher concentration of thinner (smaller diameter) fibers than Ribbond, whereas Ribbond triaxial is braided in 3 axes. Construct consists of preimpregnated silanized plasma-treated polyethylene fibers.

Many investigators have confirmed the reinforcing effect of fibers on different polymer types.[10-18] This is in agreement with the results of this study, which revealed that most tested fibers increased the mechanical properties (flexural strength and fracture toughness) of provisional restoration resins. The explanation for this increase was the transfer of stress from the weak polymer matrix to the fibers that have a high tensile strength.[19] The stronger the adhesion between the fiber and the matrix, the greater the strengthening effect.[17] In fact, the presence of poorly bonded fibers, to which little load is transferred, can be almost equivalent to voids.[21]

One approach to increasing the adhesion of fibers to a polymer matrix is resin impregnation of the fibers before application. An effective impregnation process allows the resin to come into contact with the surface of every fiber. Wetting the fibers with monomer has been a commonly used method. However, although the monomer increases adhesion of fibers to the matrix, it may impair other properties because of residual monomer. The preimpregnated fibers used in the present study were developed to overcome this problem.

The degree of fiber adhesion to the polymer matrix also differs according to the type of fiber used. Kolbeck et al[15] stated that the reinforcing effect of glass fibers was more effective than that of polyethylene fibers, and this was attributed to the difficulty of obtaining good adhesion between ultra-high modulus polyethylene fibers and the resin matrix.[13] Many surface treatments of polyethylene fibers have attempted to solve this problem, including plasma spraying, chemical, flame, and radiation treatments. However, the present study showed that there was no significant difference between the reinforcing effect of Construct polyethylene fibers and Fibrestick glass fiber. The improved performance of the Construct product compared with other polyethylene fibers may be due to the use of silane, as well as plasma treatment to increase the degree of adhesion of the polyethylene fibers to the resin.

The results revealed better strengthening effects for all resins tested with Fibrestick than with Fibrenet. These findings were in agreement with the theoretical efficiency of reinforcement (the Krenschel factor), which are one half for the woven reinforcement and 1 for unidirectional fibers.[20] In addition to the Krenschel factor, the insignificant strengthening effect of the Fibrenet on most of the resins tested may be attributed to its form, which is a single layer of glass fibers arranged in woven shape; most studies showed that an increase in the quantity of the fibers in the acrylic resin polymer matrix enhances the transverse and impact strength.[21]

The present study showed that there was a difference in the results of both the fracture toughness and the flexural strength tests, which may be due to the nature of each test. Usually, during fabrication of polymer specimens, it is very difficult to eliminate all the flaws within the specimens. These flaws may have a direct effect on the flexural strength values obtained during the 3-point loading test.[24] Because of these facts, researchers believe that fracture toughness is the best mechanical property measured to predict the wear and the fracture resistance of a restorative material.[24]

When using reinforced provisional resin materials clinically, it may be beneficial to choose a combination that, although fracturing, is held together by intact fibers. This might prevent catastrophic failure and may decrease patient discomfort and unscheduled appointments. Both unreinforced and Fibrenet-reinforced specimens showed undesirable complete separation. With the remaining groups, the fibers were intact, and the fracture stopped at the fiber location, suggesting that use of these fibers may be beneficial in reinforcing fixed provisional restorations, which may be used for extended periods.

CONCLUSION

Within the limitations of this in vitro study, the following was found:

1. The use of fibers is an effective method to increase the fracture toughness and flexural strength of provisional restoration resin.
2. The surface treatment of the fibers greatly influences their effect on the fracture toughness and flexural strength of provisional restoration resin.

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Noteworthy Abstracts of the Current Literature

Simple system to record jaw movements by a home digital camcorder
Kinuta S, Wakabayashi K, Sohmura T, Kojima T, Nagao M,
Nakamura T, Takahashi J. *Int J Prosthodont* 2003;16:563-8

Purpose. Systems of recording jaw movements that are used in prosthodontics and orthodontics are too expensive and complicated for daily clinical diagnosis. This pilot study presents the development of a simple system using a camcorder and motion-capturing software.

Materials and methods. Markers to detect jaw movement were attached to the mandibular incisors of a subject. A mirror was assembled beside the subject's face to detect anteroposterior movement. Jaw movements were recorded by a home digital camcorder. Movements of the markers were analyzed by motion-capturing software and transferred to 3-D data. The results were compared with those of a conventional system. To examine the accuracy of the measurements, the markers were placed on a computer-controlled x-y working stage and displaced. The positions of the markers were measured and analyzed, then compared with the true values indicated by the x-y working stage.

Results. The trajectories of the mandibular incisors recorded by the new system were very similar to those of the conventional system. On measurement accuracy, the mean differences between the measured and true values of the vertical and transverse movements were 0.07 mm (SD 0.03) and 0.06 mm (SD 0.04), respectively. On anteroposterior movement, the difference was 0.11 mm (SD 0.05).

Conclusion. This new system can be useful for simple recording of jaw movements with satisfactory accuracy.—*Reprinted with permission of Quintessence Publishing.*