

## IN THIS ISSUE

### LED Curing Lights

Lab Notes	2
Practitioner Input	4
Discussion	5
<b>Resin-based Cements</b>	<b>6</b>
Lab Notes	7
Practitioner Input	8
Discussion	9

### NiTi Rotary Endodontic Instruments

Lab Notes	12
Practitioner Input	14

### The Back Page

	16
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## LED CURING LIGHTS

Light-emitting diode curing lights (LEDs) offer a number of advantages over conventional quartz-tungsten-halogen (QTH) curing lights. LEDs convert electronic energy into light energy more efficiently, thereby producing less heat than QTH lights. Because of this, many LEDs run without a cooling fan making them smaller and lighter in weight, and many run on a battery allowing portability. Traditionally, LEDs were found to be more rugged and long lasting<sup>1</sup>, unlike the 30- to 50-hour lifespan of conventional QTH bulbs, which are fragile and expensive to replace<sup>2</sup>. Today's LEDs use high-powered chips that generate more internal heat than their predecessors that has the potential to damage the unit or reduce its efficiency. Manufacturers attempt to control internal heat generation by incorporating heat sinks, fans or thermostatic controls that automatically shut the unit off when it reaches a certain temperature<sup>3</sup>. The longevity of these newer LEDs is not known.

Today's LED lights are similar in intensity to QTH lights. However, curing light effectiveness is not solely dependent on light intensity: the photoinitiator in the composite resin must also be taken into account. Initiator systems are activated by light of a certain emission spectrum. The most commonly used initiator in composite resins is camphorquinone, which has an absorption range from 360 to 520 nm, with a peak at 465 nm. The optimum emission spectrum of the polymerization source for camphorquinones lies between 440 and 480 nm. Ninety-five percent of the light energy emitted by blue LEDs falls between 440 and 500 nm. In contrast, a QTH bulb emits a significant amount of its light energy outside of the 440 to 480 nm range. Therefore, more photons emitted by an LED curing lamp are likely to be absorbed by camphorquinone than photons from a QTH lamp, making the LED more efficient<sup>4</sup>. However for photo-

initiators with absorption spectra below 450 nm, LEDs may not be a suitable light source. It is, therefore, important to be aware of the peak wavelength absorbed by the photoinitiator in the material you are curing, and how that compares with the spectral emission of your curing light. Check with the resin manufacturer about compatibility. If the manufacturer does not provide compatibility information, it is best to test cure a sample of the composite before using it on a patient. It is also important to consider that a composite sample that appears hard may not be sufficiently converted (and, thus not sufficiently cured to be clinically successful). You may want to consider test curing. For example, cure a 4 mm thick composite sample for your standard curing time. If you are unable to scrape away any uncured material from the bottom surface you may use this curing time for up to a 2 mm thickness of this material in the clinical situation. Note that the darker shades of a given brand of composite almost always require longer light activation than lighter shades.

Apart from the characteristics of the light and the composite, other clinical variables such as tip to composite distance also play a very important role in depth of cure<sup>5</sup>. As the distance from the composite increases, the light intensity decreases.

We reviewed eight LED brands: blue phase (Ivoclar Vivadent), Coltolux LED (Coltene Whaledent), Elipar FreeLight 2 (3M ESPE), FLASH-lite 1401 (Discus Dental), L.E.Demetron II (Kerr Corp), Radii Plus (SDI Inc.), SmartLite iQ (DENTSPLY Caulk) and Ultra-Lume LED 5 (Ultradent Products Inc.). In addition to laboratory testing, we collected input about these products from dentists at a LED Product Evaluation Forum held at the 2005 ADA Annual Session.

<sup>1</sup>Craford MG, Holonyak KN, Kish A. In pursuit of the ultimate lamp. *Scientific American* 2001;284:63-7.

<sup>2</sup>Uhl A, Mills RW, Vowles RW, Jandt KD. Knoop hardness depth profiles and compressive strength of selected dental composites polymerized with halogen and LED light curing technologies. *J Biomed Mater Res* 2002;63:729-38.

<sup>3</sup>Rueggeberg FA, Blalock JS, Callan RS. LED curing lights—what's new? *Compend Contin Educ Dent*. 2005;26(8):586, 588, 590-1.

<sup>4</sup>Albers HF. Resin Polymerization. In: Albers HF ed. Tooth-colored restoratives. Principles and techniques. London: BC Decker in 9th Ed. 2002. p. 81-110.

<sup>5</sup>Sfondrini MF, Cacciafesta V, Scribante A, Boehme A, Jost-Brinkmann PG. Effect of light-tip distance on the shear bond strengths of resin-modified glass ionomer cured with high-intensity halogen, light-emitting diode, and plasma arc lights. *Am J Orthod Dentofacial Orthop*. 2006;129:541-6.

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**blue phase**  
Ivoclar Vivadent  
800.533.6825  
www.ivoclarvivadent.us.com

**Elipar FreeLight 2**  
3M ESPE  
800.553.9215  
www.3MESPE.com

**L.E.Demetron II**  
Kerr Corp.  
800.537.7123  
www.kerrdental.com

**SmartLite iQ**  
DENTSPLY Caulk  
800.532.2855  
www.caulk.com

**Coltolux LED**  
Coltene Whaledent  
800.221.3046  
www.coltenewhaledent.com

**FLASH-lite 1401**  
Discus Dental  
800.422.9448  
www.discusdental.com

**Radii Plus**  
SDI Inc.  
800.228.5166  
www.sdi.com.au

**Ultra-Lume LED 5**  
Ultradent Products Inc.  
800.496.8337  
www.ultradent.com

Table 1. Product features according to the manufacturer.

	blue phase Ivoclar Vivadent	Coltolux LED Coltene Whaledent	Elipar FreeLight 2 3M ESPE	FLASH-lite 1401 Discus Dental	L.E.Demetron II Kerr Corp.	Radii Plus SDI Inc.	SmartLite IQ DENTSPLY Caulk	Ultra-Lume LED 5 Ultradent Products Inc.
<b>Cure time options (sec)</b>	10, 20, 30, 40, 120	No presets	5, 10, 15, 20	No presets	5, 10, 20	No presets	10, 15, 20, 30, 40, 60	10, 20, 30, 40
<b>Timer</b>	<b>Visible</b>	Time display	No	5 sec light	No	No	No	10 sec light
	<b>Audible</b>	10 sec	10 sec	5 sec	10 sec	5 sec	10 sec	No
<b>Battery number supplied</b>	1†	1	1	1	2	1	1	Corded, N/A
<b>Battery Type</b>	Replaceable Ni-MH (option for corded use)	Not Replaceable Li-ion	Replaceable Ni-MH	Not Replaceable Li-ion	Replaceable Ni-MH	Replaceable Li-ion	Replaceable Li-ion	Corded, N/A
<b>Cure time fully charged</b>	60 min	60 min	20 min	25 min	25 min (300 5 sec cycles)	3 hrs 20 min	1 hr 40 min (600 10 sec cycles)	Corded, N/A
<b>Visible charge status</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Light tip size (mm)</b>	8 (2,8,10,13 also available)	9	8 (3,13 also available)	8	8 (4,11,13 also available)	7.5	8.5	10X13
<b>Light guide features</b>	Curved and guide rotates	Integrated with light	Curved and guide rotates	Integrated with light	Curved and guide rotates	Integrated with light (bleaching and ortho heads)	Curved and guide rotates	No guide. Specialty lenses included (point cure, interproximal, transillumination)
<b>Compatibility chart</b>	For 25 products	No	For 50 products	No	No	No	For DENTSPLY products	No
<b>Other modes*</b>	Hi, Low, Soft start	No	No	No	No	Ramp (full intensity in 5s)	Standard and Continuous	Tacking mode
<b>Infection Control†</b>	Autoclave or surface disinfect	Barrier sleeves/ surface disinfect	Autoclave - light guide Surface disinfect - hand-piece and base	Surface disinfect	Autoclave	Barrier sleeves	Autoclave/ Dry heat/ Surface disinfect	Surface disinfect
<b>Warranty</b>	2 yrs	1 yr	2 yrs	1 yr	2 yrs (1yr for battery)	5 yrs (2 yrs for battery)	2 yrs (excludes fiberoptics)	2 yrs

\*Claimed to reduce polymerization contraction stress and strain, thereby improving margin integrity.

†Can be used corded or cordless.

**Lab Notes:** Each company loaned us their LED lights for testing in the ADA laboratories to determine power density (light intensity), depth of cure, temperature rise and peak wavelength. A full description of our test methods can be found on the ADA's web site at [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr).

### Lab Tests

**POWER DENSITY (commonly referred to as "Light Intensity"):** Measures the power output of the light per unit area. The ANSI/ADA specification for curing lights requires an irradiance of at least 300 mW/cm<sup>2</sup>.<sup>6</sup>

**Results:** The highest light intensities were achieved with blue phase and the L.E.Demetron II, which were both over 1000 mW/cm<sup>2</sup>. FLASH-lite 1401 with a power density of 439 mW/cm<sup>2</sup> was the lowest (Table 2).

**Comments:** Power density alone does not ensure the effectiveness of a curing light - spectral distribution is another important factor. Lights with high intensities aren't necessarily better. In addition, power density measurements vary widely depending on the equipment used to obtain the reading (see Table 2), so it is best to monitor your curing light output with only one radiometer and make comparative measurements on a daily/weekly basis. Studies have found that one-third to one-half of

QTH curing lights in dental offices were functioning at inadequate levels to cure the composite beyond the surface.<sup>7,8,9</sup> Build-up of cured resin on the tip of the light guide will reduce the effectiveness of the curing light with a LED light just as it will with a QTH light.

We measured the power density with the light tip very close to the detector. This may not always be clinically possible. As the light tip to composite distance increases, a light with greater beam divergence (light dispersion) will have a larger decline in power density, compared to a light with smaller beam divergence.<sup>10</sup> The following photographs show that there are differences in the divergence of the beams of the tested LEDs. Therefore, as the tip moves away from the composite you can expect that these lights will perform differently (i.e. the performance of LEDs with the smallest beam divergence will be least affected by an increase in the tip to composite distance).

<sup>6</sup>American National Standard/American Dental Association Specification No. 48-2004, Visible Light-Curing Units. Chicago: American Dental Association.

<sup>7</sup>El-Mowafy O, El-Badrawy W, Lewis DW, et al. Efficacy of halogen photopolymerization units in private dental offices in Toronto. J Can Dent Assoc 2005;71(8):587.

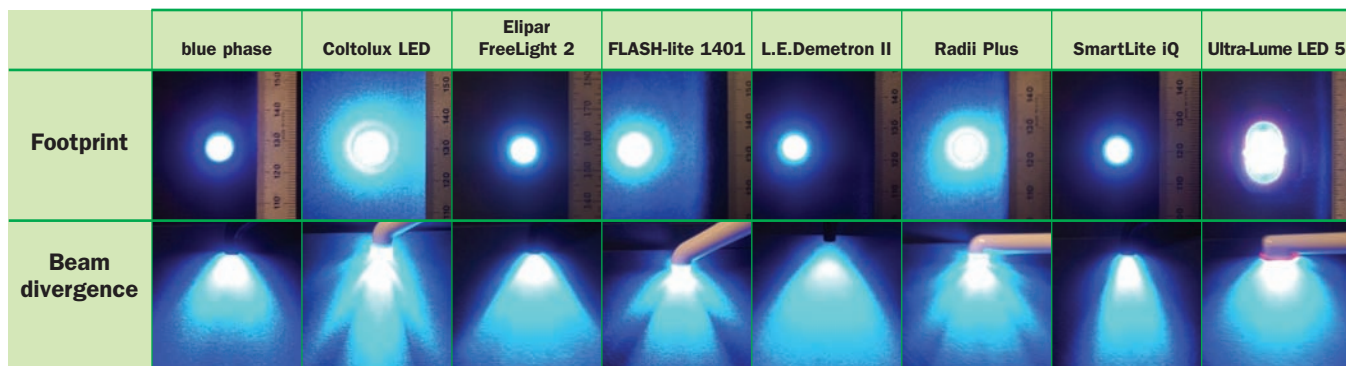
<sup>8</sup>Pilo R, Oelgiesser D, Cardash HS. A survey of output intensity and potential for depth of cure among light-curing units in clinical use. J Dent 1999;27(3):235-41.

<sup>9</sup>Martin FE. A survey of the efficiency of visible light curing units. J Dent 1998;26(3):239-43.

<sup>10</sup>Vandewalle KS, Roberts HW, Andrus JL, Dunn WJ. Effect of Light Dispersion of LED Curing Lights on Resin Composite Polymerization. J Esthet Restor Dent. 2005;17:244-55.

<sup>11</sup>Hofmann N, Klaiiber HB. Effect of irradiation type (LED or QTH) on photoactivated composite shrinkage strain kinetics, temperature rise, and hardness. Eur J Oral Sci 2002;110:471-9.

<sup>12</sup>Shortall AC, Harrington E. Temperature rise during polymerization of light-activated resin composites. J Oral Rehab 1998;25:908-13.



**DEPTH OF CURE:** Measures how deep the composite is cured beneath the surface, and is dependent on how well the light penetrates the material.

**Results:** The depth of cure achieved with Herculite (Kerr Dental), a microhybrid composite, using the L.E.Demetron II light was the highest of all the LEDs. The depths of cure achieved with Heliomolar (Ivoclar Vivadent), a microfilled composite, were highest using the Coltolux, FLASH-lite's 1401, Freelight, L.E.Demetron II and Ralii Plus lights. To cure an increment of 2 mm of Herculite, most LED lights needed at least 40 seconds; however, even with 40 seconds of curing time using SmartLite iQ, the depth of cure did not reach 2 mm for Heliomolar. (Figures 1 and 2)

**Comments:** Depths of cure are dependent on the characteristics of the curing light (intensity and spectral distribution), the composite (type, shade, opacity and photoinitiator) and clinical variables such as distance of the light tip from the composite surface. In our study we measured the depths of cure of two types of composites (microhybrid and microfilled) and one shade (A2) with the light tip placed close to the composite surface.

**TEMPERATURE RISE:** Measures the temperature increase that can occur during the curing process.

**Results:** Ultra-Lume LED 5, blue phase and L.E.Demetron II lights caused the largest temperature rise (over 12°C) over the 40 second curing time. SmartLite iQ caused the smallest rise in temperature (74°C). (Figure 3)

**Comments:** We used a thermocouple placed at the base of a 2 mm thick composite sample to measure the rise in temperature. Most of the temperature increase is the result of heat given off by the composite itself

during conversion (exothermic reaction); however, using the same composite brand with all the LEDs allows us to compare the temperature rise caused by the light source. The temperature rises recorded with these 8 LEDs is typical of what other laboratories have reported for lights with similar intensities.<sup>11, 12</sup> The experimental setup may tend to overestimate the temperature rise. This is because the clinical situation allows more efficient heat dissipation. Also, dentin has a low thermal conductivity, which protects the pulp tissue.<sup>5</sup>

**SPECTRAL DISTRIBUTION:** Measures the distribution of light across the spectral range (see Table 4).

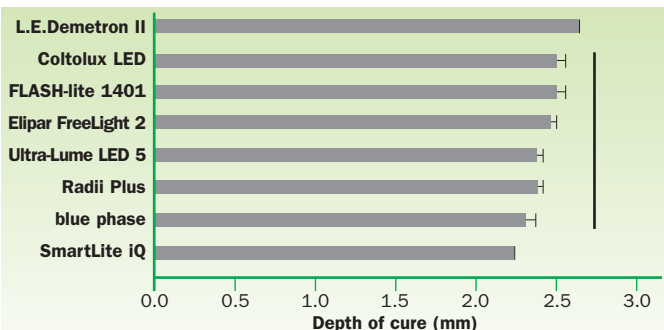
**Results:** Ultra-Lume LED 5 exhibited two spectral peaks, one at 404 nm and one at 460 nm. All the other LEDs had a single peak between 444 nm and 468 nm.

**Comments:** The spectral emissions of all the LEDs allow curing of composites that contain camphorquinone, the most popular photo-initiator, which has an absorption peak around 470 nm. The bimodal spectral emission of Ultra-Lume LED 5 purportedly allows it to cure every photo-initiated product on the market, although this claim was not tested in our lab. As noted above, blue phase and L.E.Demetron II had the highest intensities compared to the other lights. However, while use of L.E.Demetron II also resulted in higher depths of cure this was not the case for blue phase, which has a spectral peak around 444 nm - well below the absorption peak of camphorquinone (the photoinitiator in the composites used). This demonstrates the point that intensity alone does not dictate the effectiveness of a curing light.

Table 2. Power Density (Light Intensity) measured by a power meter and two radiometers

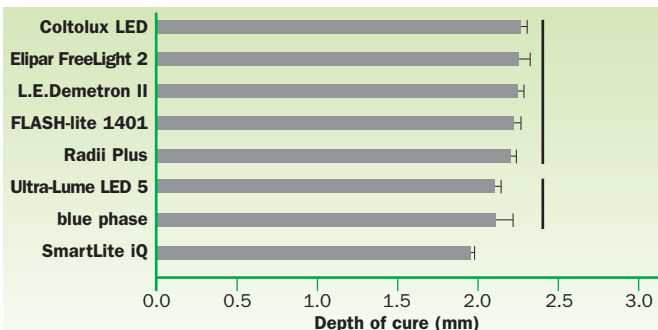
	blue phase Ivoclar Vivadent	Coltolux LED Coltene Whaledent	Elipar FreeLight 2 3M ESPE	FLASH-lite 1401 Discus Dental	L.E.Demetron II Kerr Corp.	Ralii Plus SDI Inc.	SmartLite iQ DENTSPLY Caulk	Ultra-Lume LED 5 Ultradent
PM3 Power Meter (mW/cm <sup>2</sup> )	1076	609	673	439	1010	635	544	577
Cure Rite Radiometer	1720	1158	1123	1139	1955	1834	890	1398
Demetron Radiometer	1300	850	1000	825	1400	800	750	900

Figure 1. Depth of cure - Herculite at 20 seconds



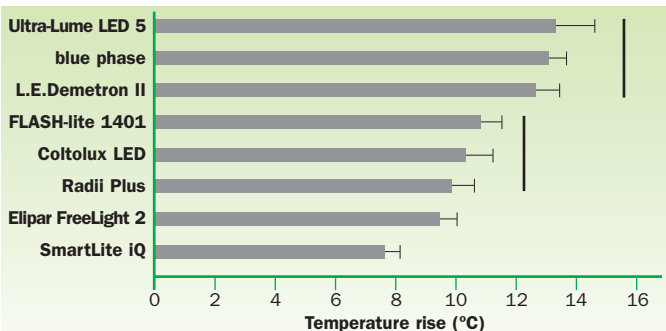
\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA followed by the Student-Newman-Keuls method for multiple comparisons,  $p > 0.05$ ). Mean based on  $n = 5$ . Composite shade = A2.

Figure 2. Depth of cure - Heliomolar at 40 seconds



\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA followed by the Student-Newman-Keuls method for multiple comparisons,  $p > 0.05$ ). Mean based on  $n = 5$ . Composite shade = A2.

Figure 3. Temperature rise at 40 seconds



\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA followed by the Student-Newman-Keuls method for multiple comparisons,  $p > 0.05$ ). Mean based on  $n = 5$ . Composite, shade = Heliomolar, A2.

### Corded or Cordless?

The advantages of a cordless light are obvious, but the disadvantages are not so apparent. When selecting a light, there are a few things to consider with respect to the type of battery and maintaining cordless operation. Consider how often and for how long you use your curing light. More frequent, light intensive procedures will require a battery that has a higher energy capacity. The lights tested used the Nickel Metal-Hydrate (Ni-MH) or Lithium-Ion (Li-ion) batteries. These batteries cost about \$100 to replace when they can no longer hold a charge. Two of the lights used a non-removable rechargeable battery (see Table 1). When they can no longer hold a charge, the light has to be replaced. To get the longest life out of a new Li-ion battery (the newest battery type), perform an initial conditioning of the battery. For the first three charge cycles, fully charge the battery overnight and allow it to fully discharge before recharging. Ni-MH batteries must also be conditioned before use and then again every 3-5 charge cycles. Li-ion batteries have a higher power density than Ni-based batteries. This allows longer battery life in a lighter weight battery. You can also recharge a Li-ion battery whenever convenient, without the full charge or discharge cycle required to keep Ni-MH batteries operating at peak performance. Lithium-ion batteries need to be used for maximum performance. If you don't use your light very often, make sure you complete a charge cycle at least once per month.

## Practitioner Input

Via a product evaluation forum at the 2005 Annual Session in Philadelphia, we collected input from dentists about their impressions of the LEDs chosen for this evaluation. Eight work stations were set up with two different brands of LED curing units at each work station. Users evaluated at least four lights and up to 8 lights by visiting two different stations and completing a survey about each light they evaluated. About 70 surveys were completed for each product.

On the survey, respondents were asked to rate their impressions of the LED lights based on esthetics, fit (according to hand size), comfort, intraoral manikin access, light guide options, infection control and counter space requirements. The pie charts indicate how often the brands rated Excellent, Very Good, Good, Fair, Poor or Not Acceptable. Dentists were also asked to rate the characteristics of the lights. For a precise breakdown of how they rated for each feature, visit [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). "N" indicates the number of survey respondents.

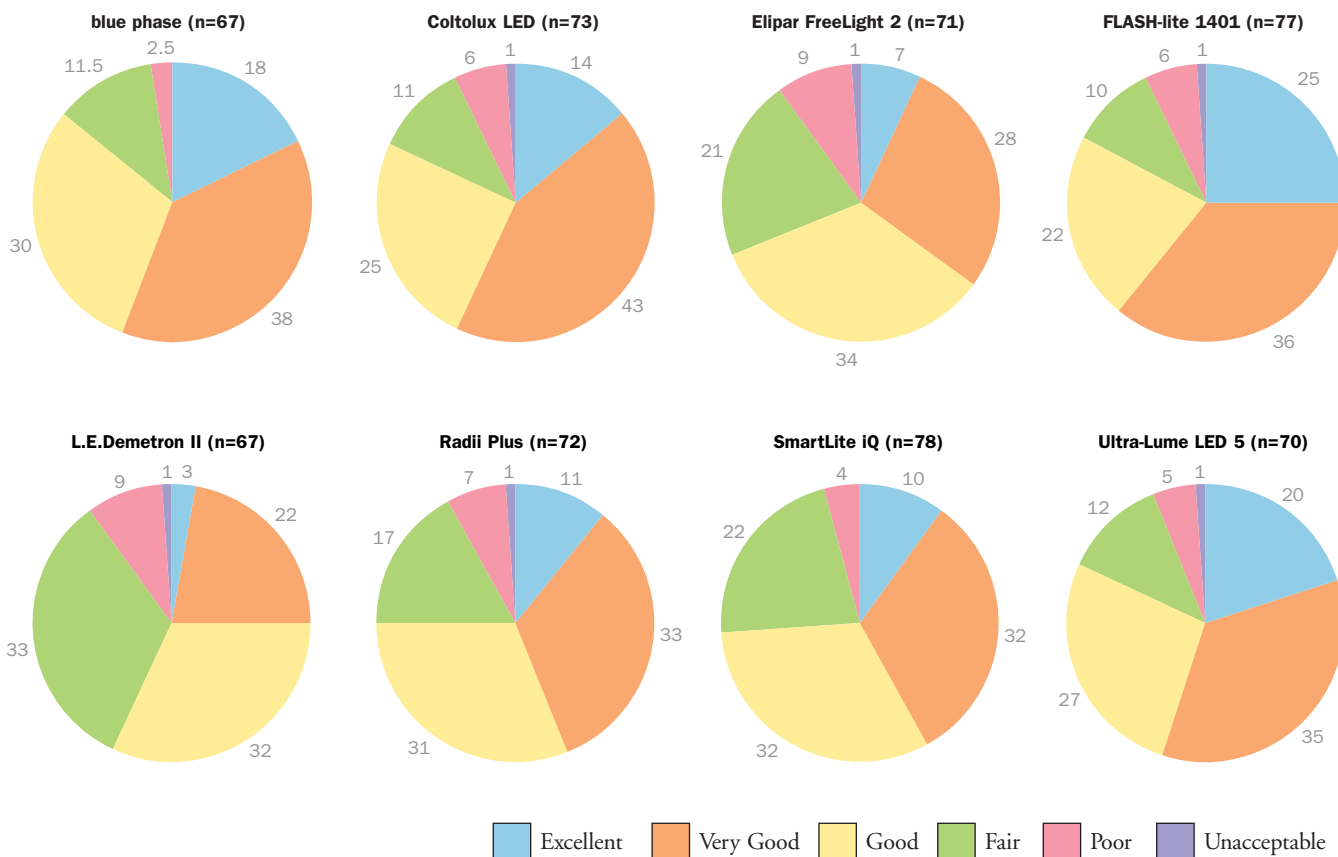


Table 4. Buyers' Summary for LEDs.

	blue phase Ivoclar Vivadent (No. of clinical survey respondents*) (67)	Coltolux LED Coltene Whaledent (73)	Elipar FreeLight 2 3M ESPE (71)	FLASH-lite 1401 Discus Dental (77)	L.E.Demetron II Kerr Corp. (67)	Radii Plus SDI Inc. (72)	SmartLite iQ DENTSPLY Caulk (78)	Ultra-Lume LED 5 Ultradent Products (70)	
Laboratory Performance	Lab Score <sup>†</sup> %	80	90	92	88	87	89	91	80
	Spectral Peak (FWHH Range <sup>††</sup> ) nm	444 (432 - 456)	468 (456 - 484)	460 (452 - 480)	464 (448 - 476)	456 (444 - 472)	464 (452 - 480)	456 (444 - 468)	460 (404) <sup>‡</sup> (448 - 472 for second peak)
	Light Intensity mW/cm <sup>2</sup>	1076	609	673	439	1010	635	544	577
Clinical Impressions <sup>§</sup>	Excellent %	18	14	7	25	3	11	10	20
	Very Good %	38	43	28	36	22	33	32	35
	Good %	30	25	34	22	32	31	32	27
	Fair %	11.5	11	21	10	33	17	22	12
	Poor %	2.5	6	9	6	9	7	4	5
	NA <sup>¶</sup> %	0	1	1	1	1	1	0	1
Price <sup>*</sup>	\$1495	\$790	\$1474	\$395	\$1267	\$795	\$1267	\$999	
Light output indicator included	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes (pass/fail indicator)	
Battery replacement price <sup>*</sup>	\$125	Cannot be replaced, must purchase new light	\$120.60	Cannot be replaced, must purchase new light	\$78.35	\$100	\$95.45	No battery, corded	

<sup>†</sup>Lab score reflects temperature rise and depths of cure for Heliomolar at 40 sec and Herculite at 20 sec and is a percentage normalized to the best performer in the category.

<sup>\*</sup>Via a LED Product Evaluation Forum held at the 2005 ADA Annual Session, dentists rated their impressions of up to 8 lights. Indicates percentage of time a rating was selected for a product.

<sup>‡</sup>Ultra-Lume LED 5 was the only light with a double peak, making it suitable for use with photo-initiator systems activated at lower wavelengths.

<sup>¶</sup> MSRP as of May 2006.

<sup>\*\*</sup>Indicates percentage of time "not acceptable" was selected for a product.

<sup>††</sup>Denotes the full width at half the height of the peak wavelength.

## Discussion

**LEDs:** Use of the SmartLite iQ resulted in significantly lower average depths of cure associated with its use for both Heliomolar and Herculite composite resins compared to the other lights. L.E.Demetron II had a significantly higher average depth of cure associated with its use at 20 seconds; however, in the clinical forum, the dentists consistently rated this light lowest because of its bulky size. Dentists participating in the forum gave the highest scores to blue phase and FLASH-lite 1401.

To calculate our Lab Score we used the depth of cure and temperature rise testing results. We normalized the Depth of Cure (at 20 seconds for Herculite and 40 seconds for Heliomolar) and Temperature Rise data to the best performance (deepest and smallest, respectively) and calculated a percentage score for each test, with the best performer earning 100. The Lab Score is the average of these three scores.

Ultra-Lume LED 5 offers the advantage of a broader spectral range, which allows more efficient curing of materials containing photoinitiators with absorption peaks below 400 nm. Although camphorquinone is the most popular photoinitiator in dental materials, some materials contain other compounds like monoacylphosphine oxide (MAPO), bisacylphosphine oxide (BAPO) or phenylpropanedione (PPD). Unlike camphorquinone which has an absorption spectrum well suited for use with a LED, other

initiators may be activated at wavelengths below the LED emission spectrum. Therefore, the LED light may not be as efficient in curing these other materials.

Although most of the LED lights don't require built-in cooling fans, they can become warm during extended use. Because of this, many lights automatically shut off to prevent overheating necessitating a cooling period before further use. To avoid this situation, L.E.Demetron II and blue phase have built-in fans. L.E.Demetron II also uses periodic level shifting technology (pulsed high and baseline output) to increase light output without increasing the internal chip temperature to levels that may damage the unit.<sup>3</sup> So although L.E.Demetron II was down-rated by clinicians because of its size, a clinician whose practice will involve frequent and continuous use of the light may find the fan a useful feature.

**Calibra**  
DENTSPLY Caulk  
800.532.2855  
www.caulk.com

**Cement-It Universal C&B**  
Pentron Clinical Technologies, LLC  
800.551.0283  
www.pentron.com

**DUO-LINK**  
Bisco  
800.BIS.DENT  
www.bisco.com

**Maxcem**  
Kerr Corp.  
800.537.7123  
www.kerrdental.com

**PANAVIA F2.0**  
Kuraray America, Inc.  
800.879.1676  
www.kuraray-am.com

**RelyX Unicem (Aplicap)**  
3M ESPE  
800.634.2249  
www.3MESPE.com

**Ultra-Bond Plus**  
DenMat  
800.445.0345  
www.denmat.com

**Variolink II**  
Ivoclar Vivadent  
800.533.6825  
www.ivoclarvivadent.us.com

# RESIN-BASED CEMENTS

Resin-based cements are composed of a matrix made up of various methacrylate monomers combined with inorganic fillers (like barium glass, ytterbium trifluoride, silica, aluminum fluorosilicate glass). The relative proportions of the different methacrylates will affect their physical properties, such as polymerization shrinkage and viscosity. As the BisGMA content increases, the shrinkage decreases; however the higher the TEGDMA content, the more flowable the cement! Inorganic fillers increase the stiffness, tensile and impact strengths, and viscosity of the cement. The type of monomer matrix and filler, and their proportions, will vary between products giving them slightly different physical properties.

In addition to the methacrylates and fillers, resin cements also contain inhibitors and initiators. Based on the type of initiator present, these cements can be classified as chemically-cured (auto-cured), light-cured or dual-cured. We tested eight dual-cure cements, which all contained a chemical activator and a photo activated initiator. While the presence of a chemical initiator-activator system results in some polymerization, the expert panel (see discussion on page 9) agreed that light activation enhances the degree of conversion of dual-cure cements, which is important for both color stability<sup>2</sup> and for durability.<sup>3</sup>

The biggest difference between the products we tested is how they achieve a bond with tooth structure. It should be noted that these cements will mostly form mechanical bonds to other dental materials, with the possible exception of resins. There are three main categories of cements 1) 3-step cements that use a

total etch adhesive technique (separate etchant, bonding agent and cement), 2) 2-step cements that use an acidic self-etching primer to demineralize the tooth followed by application of the cement, and 3) 1-step cements that use a cement-based self-adhesive system, and, therefore a separate etchant or primer is not applied to the tooth. See the Panel Discussion for the pros and cons of using these different systems (page 9). The eight brands of dual cured resin cements we reviewed are (See Table 1): Calibra (DENTSPLY Caulk), Cement-It Universal C&B (Pentron Clinical Technologies), DUO-LINK (Bisco), Maxcem (Kerr Corp.), PANAVIA F2.0 (Kuraray America, Inc.), RelyX Unicem Aplicap (3M ESPE), Ultra-Bond Plus (DenMat) and Variolink II (Ivoclar Vivadent). In addition to laboratory testing, we collected 545 survey responses about these products from dentists.

<sup>1</sup>Feilzer AJ, Dauvillier BS. Effect of TEGDMA/BisGMA Ratio on Stress Development and Viscoelastic Properties of Experimental Two-paste Composites. J Dent Res 2003;82:824-8.

<sup>2</sup>Lu H, Powers JM. Color stability of resin cements after accelerated aging. Am J Dent 2004;17:354-8.

<sup>3</sup>Foxton RM, Pereira PN, Nakajima M, Tagami J, Miura H. Durability of dual-cure resin cement/ceramic bond with different curing strategies. J Adhes Dent. 2002;4:49-59.

Table 1. Product features according to the manufacturer.

	<b>Calibra</b> DENTSPLY Caulk	<b>Cement-It Universal C&amp;B</b> Pentron Clinical Technologies, LLC	<b>DUO-LINK</b> Bisco	<b>Maxcem</b> Kerr Corp.	<b>PANAVIA F2.0</b> Kuraray America, Inc.	<b>RelyX Unicem (Aplicap)</b> 3M ESPE	<b>Ultra-Bond Plus</b> DenMat	<b>Variolink II</b> Ivoclar Vivadent
<b>Type of Adhesive System</b>	Total-etch	Total-etch	Total-etch	Self-bonding	Self-etch	Self-bonding	Total-etch	Total-etch
<b>Bonding System*</b>	Prime & Bond NT	Bond 1 C&B Primer and Adhesive	All Bond 2 One Step One Step Plus	Non Required	ED Primer II (Self-etching Primer)	Non Required	Etch 'N' Seal Tenure A&B	Total Etch Excite DSC Syntac
<b>Contains Fluoride</b>	Yes	No	No	Yes	Yes	Yes	No	Yes
<b>Try-in pastes</b>	Available	Not available	Not available	Not available	Not available	Not available	Available	Available
<b>Working Time (@ 22°C)</b>	2.5 min	1.5 min	2 min	2 min	15 min (oxygen inhibited)	2 min	4 min	4.5 min
<b>Setting Time (self cure)</b>	4 min	4 min	5.5 min	3 min	3 min	5 min	5-10 min	8 min
<b># of Shades</b>	5	3	2	5	4	5	5	6 Base 4 Catalyst
<b>Shelf Life</b>	2 years	2 years	2 years	18 months	2 years	2 years (1 month out of foil)	1 year	2 years

\*Recommended by manufacturer.

**Lab Notes:** Each cement was purchased from the manufacturer or distributor for testing in the ADA laboratories to document working and setting time, solubility and water sorption, flexural strength and modulus, film thickness, radiopacity and masking effect. In developing some of our tests and determining whether products passed or failed, we referred to the standards published by the International Organization for Standardization and those from the American National Standards Institute and the ADA.<sup>1,2</sup> A full description of our test methods can be found on the ADA's web site at [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr).

**Basic Tests**

Our Basic Tests challenge products against a performance standard, which products can either pass or fail. The Basic Tests for resin cements were Working Time, Setting Time, Water Sorption and Solubility and Radiopacity. All the products passed these tests. Here's how the tests relate to the clinical performance of resin cements:

**Working Time (Chemical Cure mode)**

**Clinical Significance:** The amount of time available for handling the cement before its viscosity significantly increases.

**Results:** All the cements performed equally well.

**Setting Time (Chemical Cure mode)**

**Clinical Significance:** The amount of time from the start of mixing until the setting reaction is complete by chemical cure mode only (at 37°C) as denoted by the exothermic reaction.

**Results:** The International Standards Organization<sup>1</sup> sets a maximum setting time of 10 minutes. All the cements tested passed according to the standard. Cement-It and Calibra had the fastest setting times. Ultra-Bond Plus had the slowest setting time. According to the manufacturer of Ultra-Bond Plus, this is because it is designed for use in cementing multiple veneers.

**Water Sorption and Solubility**

**Clinical Significance:** Water sorption measures how much water will be absorbed by a cement, which may lead to its expansion in the oral cavity. Solubility measures how much material will leach out of the cement in an aqueous environment.

**Results:** The International Standards Organization<sup>1</sup> sets a maximum sorption of 40 µg/mm<sup>3</sup> and a maximum solubility of 7.5 µg/mm.<sup>3</sup> All the cements tested passed according to the standard.

**Comments:** Maxcem was not included in this testing, because with our test methods this cement had unusually high numbers. According to the manufacturer, Maxcem contains a small amount of water making the sorption and solubility tests inappropriate for this cement. However, RelyX Unicem - another self-bonding cement - had a high sorption, but still passed the test. Because of this, we cannot comment on Maxcem's potential for long term dimensional change.

**Radiopacity**

**Clinical Significance:** This test gives an indication of whether or not the cement will be visible on a radiograph.

**Results:** All the cements satisfied the performance standards set forth by the International Standards Organization.<sup>1</sup>

**Comments:** The cements satisfied the performance criteria using a 1mm thick specimen. However, it is important to note that film thicknesses of approximately 20 µm, which are too thin to be tested in the lab, are more clinically realistic and may be more difficult to detect on a radiograph. Keep in mind that when manufacturers claim that their product is radiopaque, this is based on the ISO test using a 1mm specimen.

**Film Thickness**

**Clinical significance:** Measures the thickness of the cement layer when it is allowed to set under pressure. Greater film thicknesses will increase the potential for incomplete seating, marginal leakage, loss of marginal integrity and poor esthetics.

**Results:** All the products' resulting film thicknesses were between 16 and 22 µm. The American National Standard/American Dental Association Specification No. 27<sup>2</sup> sets a maximum film thickness limit of 50 µm. (Figure 1)

**Flexural Strength and Flexural Modulus**

**Clinical Significance:** This test gives an indication of the strength and stiffness of a cement when subjected to flexure.

**Results:** DUO-LINK had the highest strength and RelyX Unicem and Maxcem had the lowest strengths (See Figure 2). PANA VIA F2.0 had the highest modulus and Maxcem had the lowest modulus (See Figure 3). The American National Standard/American Dental Association Specification No. 27<sup>1</sup> sets a minimum strength of 50 MPa, which all the cements surpassed. (Figures 2 and 3)

**Comments:** A cement with a higher strength and modulus may provide better clinical results in high stress restorations such as resin-bonded bridge work or multi-unit prostheses. However, studies have not identified the value above which there is no longer any clinical benefit. The expert panel agreed that it is important to use the bonding systems recommended by the manufacturer, because other systems are not always compatible and may result in a weaker bond.

**Masking Effect**

**Clinical Significance:** This test measures whether or not the cement masks the color of the object behind it. This test was limited to the single shade/opacity selected for this study (i.e. translucent or similar shade).

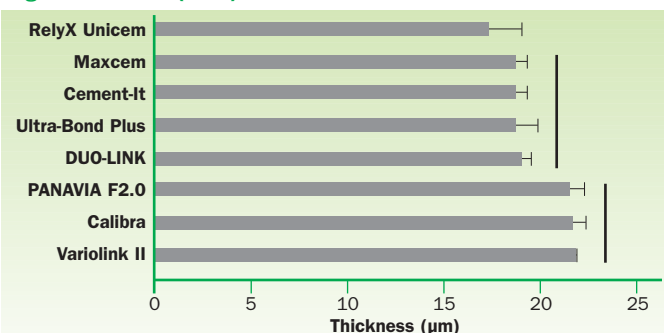
**Results:** PANA VIA F2.0 and Calibra had the greatest masking effect, while Cement-It was the most translucent (Figure 4).

**Comments:** Due to testing limitations, as with the radiopacity test, the thickness of the specimen tested in the lab was greater than what would be used in a clinical situation. However, using the same thickness for each cement specimen allows comparison between cements.

<sup>1</sup>ISO 4049:2000. Dentistry - Polymer-based filling, restorative and luting materials.

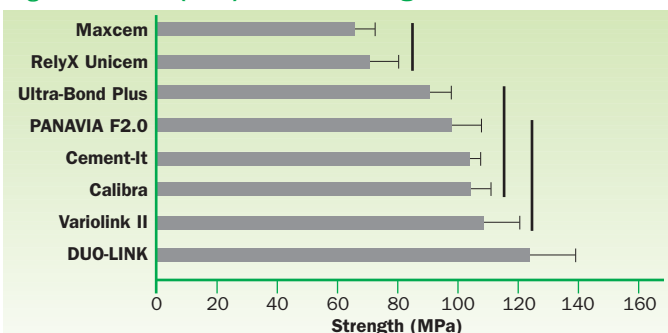
<sup>2</sup>American National Standard/American Dental Association Specification No. 27-1993, Resin-Based Filling Materials. Chicago: American Dental Association.

Figure 1. Mean (±SD) Film Thickness Values\*



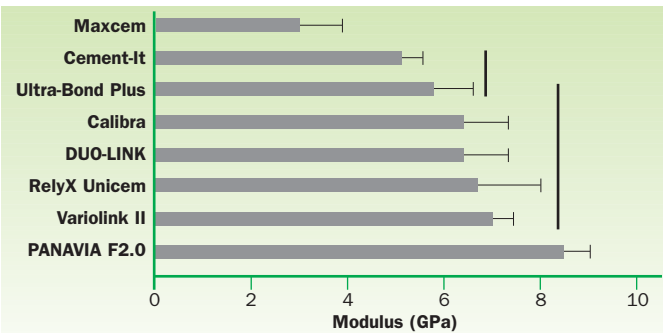
\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA, followed by the Student-Newman-Keuls method for multiple comparisons, p>0.05). Mean based on n = 5.

Figure 2. Mean (±SD) Flexural Strength\*



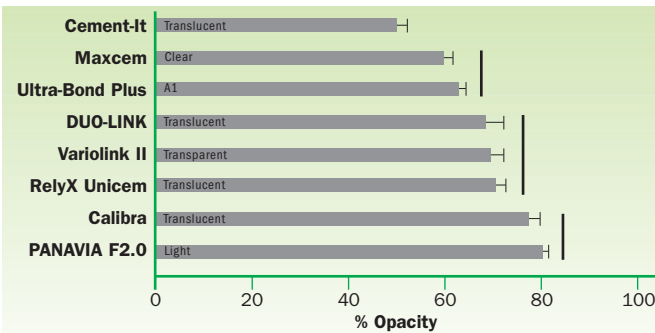
\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA, followed by the Student-Newman-Keuls method for multiple comparisons, p>0.05). Mean based on n = 5.

Figure 3. Mean ( $\pm$ SD) Flexural Modulus



\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA, followed by the Student-Newman-Keuls method for multiple comparisons,  $p > 0.05$ ). Mean based on  $n = 5$ .

Figure 4. Mean ( $\pm$ SD) Masking Effect\*

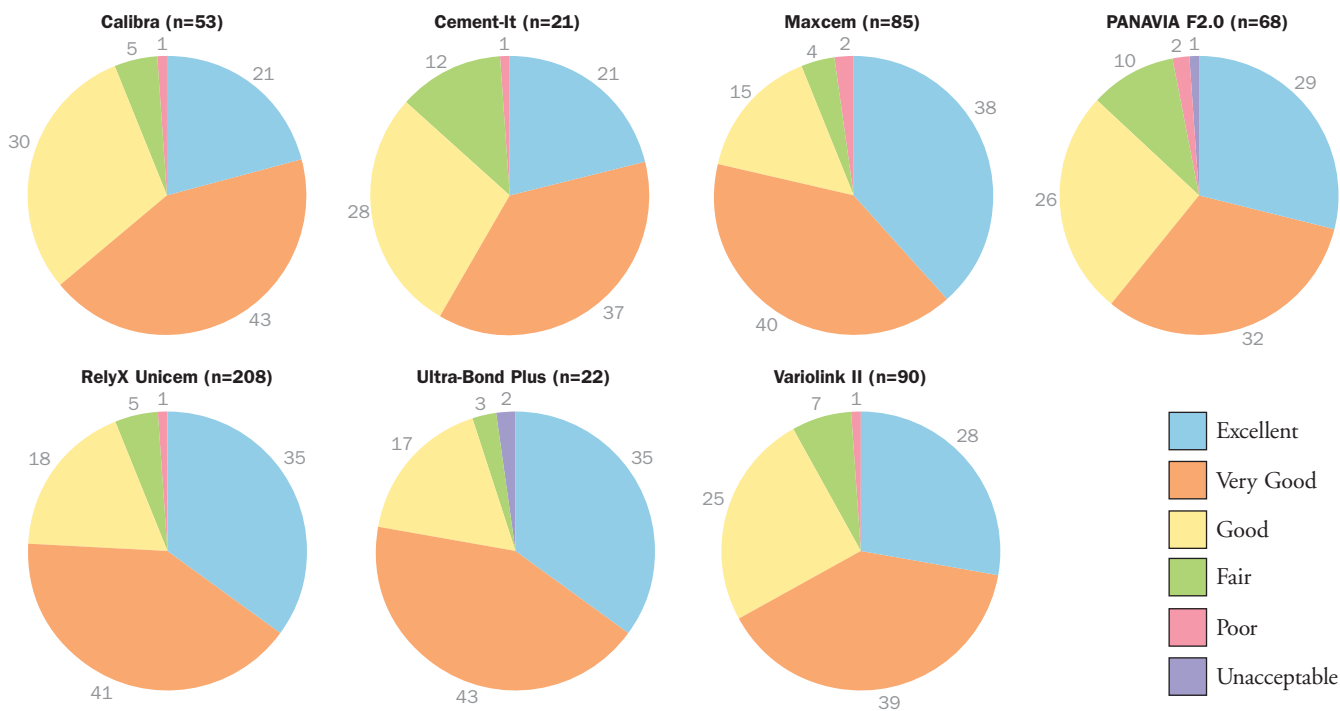


\*Vertical black bars designate products that performed equally based on statistical analysis (one-way ANOVA, followed by the Student-Newman-Keuls method for multiple comparisons,  $p > 0.05$ ). Mean based on  $n = 5$ . Comparable shades were tested and are identified within the bars.

## Practitioner Input

Through a web-based survey, we collected input from 545 dentists about the clinical performance of the resin-based cements they use.

Respondents were asked to rate the performance of cements for ease of use, versatility (compatibility with multiple materials), durability, sensitivity, numbers of shades and try-in pastes and customer service. The pie charts give an overall sense of how often the systems rated Excellent, Very Good, Good, Fair, Poor or Unacceptable. For a precise breakdown of how respondents rated each feature, visit [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). Pay special attention to the number of respondents; ratings are more reliable when they are based on the opinions of more respondents. Because of an insufficient number of survey responses, clinical data are not available for DUO-LINK.



### What dentists said...

Based on 545 survey responses.

- Bond strength, cement strength and marginal washout were considered the most important characteristics for resin cements.
- Over 80% of dentists rated Maxcem, RelyX Unicem, and Ultra-Bond Plus as “excellent” or “very good” in terms of compatibility with multiple materials.
- Based on respondents’ experience, failures were lowest when used with resin restorations, followed by noble metals and ceramics, and highest with base metal restorations. While every “failure” cannot be attributed to the product, some trends on material compatibility can be observed from the results reported.
- In general, failures attributed to the use of these products were reported to be “rare” or “very rare” with “loss of bond” being the most common cause. Secondary caries was the least common cause of failure overall.
- Over 90% of the dentists surveyed rated the degree of post cementation sensitivity with Maxcem as “excellent” or “very good”.
- High technique sensitivity was detrimental to the usefulness of Calibra, Variolink II and PANAVIA F2.0; while cost was inhibiting for Ultra-Bond Plus, Maxcem and RelyX Unicem
- Compared to others, Maxcem and RelyX Unicem were rated higher for ease of use considering recommended isolation, bonding, cementation viscosity and clean-up. While most users are happy with the products they use, these two cements were more often rated “excellent” for overall performance. Interestingly, two dentists (one for each of these products) voiced very strong dissatisfaction. Obviously, not every product will meet the needs and preferences of all users.



**Table 2. Buyers' Summary for Resin-based cements.**

(No. of clinical survey respondents*)	<b>Calibra</b> DENTSPLY Caulk (53)	<b>Cement-It</b> Universal C&B Pentron Clinical Technologies, LLC (21)	<b>DUO-LINK</b> Bisco	<b>Maxcem</b> Kerr Corp. (85)	<b>PANAVIA F2.0</b> Kuraray America, Inc. (68)	<b>RelyX Unicem (Aplicap)</b> 3M ESPE (208)	<b>Ultra-Bond Plus</b> DenMat (22)	<b>Variolink II</b> Ivoclar Vivadent (90)	
Laboratory Performance	<b>Basic Lab Tests</b>	pass	pass	pass	pass	pass	pass	pass	
	<b>Setting Time @37°C (± SD)</b>	1 min 7 sec (± 7 sec)	1 min 13 sec (+ 5 sec)	2 min 26 sec (+ 7 sec)	1 min 29 sec (+ 7 sec)	2 min 42 sec (+ 17 sec)	2 min 19 sec (+ 26 sec)	5 min 44 sec (+ 15 sec)	2 min 51 sec (+ 20 sec)
	<b>Lab Score* %</b>	78	77	87	58	84	78	76	81
Clinical Impressions*	<b>Excellent %</b>	21	21	Insufficient # of survey responses.	38	29	35	35	28
	<b>Very Good %</b>	43	37		40	32	41	43	39
	<b>Good %</b>	30	28		15	26	18	17	25
	<b>Fair %</b>	5	12		4	10	5	3	7
	<b>Poor %</b>	1	1		2	2	1	0	1
	<b>NA** %</b>	0	0		0	1	0	2	0
<b>Type of adhesive system</b>	Total-etch	Total-etch	Total-etch	Self-adhesive	Self-etch	Self-adhesive	Total-etch	Total-etch	
<b>Price* (per gram of refill syringe)</b>	\$22.95	\$6.59	\$6.63	\$8.50	\$11.67	\$4.40 (per aplicap)	\$13.89	\$10.00	

†Lab score reflects the values obtained for film thickness, flexural strength and modulus and is an overall average of all percentages normalized to the best performer for each of these three tests.  
 \*Via a web-based survey. Indicates percentage of time a rating was selected for a product. When considering the clinical data, keep in mind that ratings are more reliable when based on the opinions of more respondents.  
 ‡MSRP as of June 2006.  
 \*\*Indicates percentage of time "not acceptable" was selected for a product.

## Dentists, Educators Discuss Resin-Based Cements

### Moderator:

**Clark M. Stanford, DDS, PhD**  
 Professor, Dows Institute for Dental Research and Department of Prosthodontics  
 University of Iowa  
 Iowa City, IA

### Participants:

**John O. Burgess, DDS, MS**  
 Assistant Dean for Clinical Research  
 Professor, Prosthodontics and Biomaterials  
 The University of Alabama at Birmingham School of Dentistry  
 Birmingham, AL

**Mark A. Latta, DDS**  
 Associate Dean for Research  
 Professor of General Dentistry  
 Creighton University School of Dentistry  
 Omaha, NE

**Robert C. White, DDS**  
 Private Practice  
 College Station, TX

**Stanford:** Are there clinically important differences (chemically, physically) among the resin cements? If yes, what are key characteristics of which the clinician needs to be aware?

**Latta:** The total-etch system is probably the most complex, much more so than the self-etching system. Isolating a tooth and employing the adhesive system with these respective cements is critical to success and for post-operative sensitivity. Areas that are difficult to isolate, such as molar areas and posterior areas in the lower arch, may be less suited for a resin-cement system that uses a total-etch adhesive instead of one of the more simplified systems.

**White:** Cleanliness and isolation of the prepared tooth or teeth are very, very important. There are some critical differences between these products that some practitioners don't recognize, which unfortunately may lead them to mix the adhesive from one system with the resin cement components of another system.

**Latta:** This is the key message dentists should take note of. Dual-cured systems are technique sensitive, both in the chemistry and clinical steps used. It's far more critical with these dual-cure systems than it is with visible light-cure composites.

**Stanford:** What is a) the clinical indication for using a particular cement and b) how much adhesion do you need based on the clinical situation that is present?

**Burgess:** The clinical situation will dictate the resin cement that you're going to use. If you do not have adequate retention and resistance form on the preparation, then perhaps you need to look at the total-etch systems. I classify the eight cements we've evaluated as total-etch, self-etch and self-adhesive. The total-etcher cements use phosphoric acid, the self-etching cements require a self-etching primer, and the self-adhesive cements use no precursor, no etchants and no primers. I think the total etch system gives the highest bond strength, which would be useful when you need strong retention. However, at each step, etch, rinse, prime and bond you have the possibility for contamination—with blood or saliva—and we all know that blood and saliva lower bond strength. In the long run the simpler system may be the better system if you can only isolate for a brief time because those systems are self-adhesive—there are no other intermediate layers or primers or etchers that can possibly become contaminated. The further back you go into the mouth the more you will need self-adhesive materials. The further you go toward the front of the mouth, the more the total-etch systems can be used effectively.

*Continued on next page>>*

**Latta:** I'd like to add one caveat as it relates to ceramics and full coverage or even partial coverage ceramics. If a practitioner is doing a posterior restoration and selecting an Empress 1 or an OPC or other first generation all-ceramic system, it is critical to use a complete bonding system—a high level bonding cement that generates very high values to dentin—because evidence shows these posterior crowns have better survival. If it's a second generation, or alumina or zirconia materials, the cement does not seem to have a fracture [reducing] effect in those situations. With the first generation ceramics, however, it seems to be very critical. So that would be against the earlier advice that as you go further toward the posterior, the simplified systems may be preferred. I would add the statement, "except when you're using a first generation all-ceramic."

One of the larger clinical issues involves post-operative or post-cementation sensitivity with total-etch resin systems. When used appropriately and carefully, use of total-etch systems does not increase post-operative sensitivity compared with use of self-etching or self-adhesive systems. However, the complexity of those procedures makes it more difficult for the dentist to carefully execute the procedures, which could lead to more sensitivity. But a total-etch system used appropriately shouldn't generate more sensitivity.

**Stanford:** How important is the light-cure component?

**Latta:** Laboratory evidence suggests that the degree of conversion of the cements is enhanced with light. And that certainly would improve the physical properties. But with the self-adhesive systems, studies show that both Maxcem and RelyX Unicem bond better when they are light-cured compared with when they are completely self-cured. This is even true, when you're cementing an all-ceramic crown. The amount of light getting through the ceramic to the cement is variable depending on the thickness of the crown, as well as on the intensity of the light. Also, pure resin cements, particularly when used in veneers, or in onlays and inlays, and sometimes in very translucent full crowns tend to have a fairly significant color shift when exposed to light. If you're doing an aesthetic case, the light is very important.

**Burgess:** The color stability and durability of dual-cured cements has been examined.<sup>12</sup> When light-cured, they all performed better. The wear resistance was better, which is important when the margin is not as good as it could be. The color stability is better—you don't get the browning that circles the restoration.

1 Lu H, Powers JM. Color stability of resin cements after accelerated aging. *Am J Dent* 2004;17:354-8.

2 Foxton RM, Pereira PN, Nakajima M, Tagami J, Miura H. Durability of dual-cure resin cement/ceramic bond with different curing strategies. *J Adhes Dent*. 2002;4:49-59.

**Latta:** If you're going to use the light, light power is critical. There's tremendous variation in the light output in dental offices.

**Stanford:** Is there any reason to use cements with multiple shade options?

**White:** Depending on the circumstances, multiple shade options can help. For example, the bicuspid in a patient who has a wide smile may be a factor, particularly if you're restoring over a non-vital tooth. A deep or extended prep can help negate the color, especially at the margin. But with a high lip line or smile line the bicuspid and even the molars can be as evident as the anterior teeth.

**Latta:** And depending on the ceramic used, the cement can significantly influence anterior full-coverage restorations. The opacity of the cement may be more important than the hue. These effects are variable, depending on the thickness and opacity of the restorative material. Regarding the comment about pre-molars and a high smile line, or big smile, onlays and partial coverage restorations are important because the marginal interfaces will be visible. In these cases, a shaded cement would be important to consider.

**Stanford:** What is the expected longevity of restorations?

**Latta:** One way to answer that question is to look at early failures and late failures. If you look at the longevity of a restoration and you isolate

it into early failures, you could cite the cement itself, the application technique, product instructions, or the dentist for not following the instructions. These often are reasons for early failures. But if you get through that period with a set of restorations combined with a cement, the factors leading to failure will likely be less related to these factors, if at all. Intrinsic patient factors, hygiene, the quality of the laboratory work, the fidelity of the margins, and so on could be cited. In theory, these cements should function at least as well as non-resin cements, if used appropriately and in appropriate clinical situations. Dentists should be aware that these cements don't compensate for poor retention and resistance form. They shouldn't be used to facilitate a less meticulous preparation.

**Burgess:** One other factor reduces cement retention. Dr. White several times has raised an important point—the cleanliness of preparation—if you leave residual provisional cement on the preparation and bond to it, you dramatically reduce the bond strength of any resin cement. So cleanliness of the preparation and preparing it for the final cementation, is critical.

**Stanford:** One of the things that we can say is that the more that you have to rely on the cement for your retention/resistance form, the more risk you have for any subtle issue in the cementation process to cause early failure.

**Stanford:** Given film thickness, is marginal wear or "wash out" of resin cements a significant concern?

**Burgess:** Absolutely, especially if the marginal opening is very large and it's going to be cemented. Light-curing all margins results in increased wear resistance, and produces less solubility, water uptake and staining at marginal areas. Light-curing is essential when using dual or light cured resin cements.

**Latta:** I agree that the higher the conversion, the greater the resistance materials will have to any breakdown. However, let me offer this caveat: the size of the gap is a bigger factor in marginal washout. That's because larger gaps accommodate more and larger boluses of food, which can erode the margins. However, the higher the conversion in that area, the more resistance there is to breakdown.

**Stanford:** When would you not use a resin cement?

**Burgess:** Are there any contraindications to the use of resin cements? Well a lot of resin-modified glass ionomers are still used and I'm not sure that every restoration needs to be cemented with a resin cement. Ceramic restorations especially veneers should be bonded. However, for metal-ceramics, I probably wouldn't use a resin cement especially when you have fairly parallel walls, long walls and less reduction on the occlusal surface, I would use a resin-modified glass ionomer – as I would with an all-metal restoration. Resin-cements have some limits and they're significantly more time-consuming and more expensive in some cases than are the resin-modified glass ionomers, or even zinc phosphates.

**White:** The most critical part of the bond is resin to tooth, but if you don't follow the directions you can also have a poor bond between the resin and the ceramic surface.

**Stanford:** Should there be a consideration of caries risk when selecting a cementing media?

**Burgess:** There's not enough fluoride release in these materials to expect caries reduction from a fluoride releasing cement. Fluoride release depends upon the surface area of the cement that is exposed to the oral environment. With a thin film of 40-50 microns not enough glass ionomer is exposed to release much fluoride. We have measured the fluoride released from under orthodontic brackets and not enough cement is exposed to allow much fluoride to be released. However, if you're cementing an orthodontic band, more surface area of the cement is exposed and more fluoride is released. You'd have a lot of space between the orthodontic band, which would provide enough material to get the fluoride in and out. But a 200 micron gap filled with fluoride-releasing cement wouldn't justify consideration.

**Latta:** There's no evidence to suggest any preventive effect on secondary caries at the crown margins.

### 324 Niti

Medidenta International, Inc.  
800.221.0750  
www.medidenta.com

### EndoSequence

Brasseler USA  
800.841.4522  
www.brasselerusa.com

### K3

SybronEndo  
800.346.3636  
www.sybronendo.com

### Liberator

Miltex, Inc.  
866.854.8300  
www.miltex.com

### LightSpeed

Lightspeed Endodontics  
800.817.3636  
www.lightspeedusa.com

### ProFile Series 29

DENTSPLY Tulsa Dental  
800.662.1202  
www.tulsadental.com

### ProTaper

DENTSPLY Tulsa Dental  
800.662.1202  
www.tulsadental.com

### V-Taper

Guidance Endodontics  
866.844.3636  
www.guidanceendo.com

# NICKEL-TITANIUM ROTARY ENDODONTIC INSTRUMENTS

Nickel-titanium (NiTi) instruments differ in a number of properties including: blank design, metal treatment (or lack of), quality of NiTi, manufacturing, taper, tip design, core design, land and rake angles, pitch, helical angles, and speed requirements. Clinical performance of these systems is dependent on: cutting efficiency, shaping ability, flexibility, torque and fatigue resistance, allowing effective irrigation, sterilization, and instrument deformation and failure. Currently both tapered and non-tapered systems are available, with the tapered designs offering several different variations. The clinician can use a sequence of files that uses a common tip size but has varying tapers (for example, a 20/0.10 file followed successively by a 20/0.08, a 20/0.06, and eventually a 20/0.04 file). A second option is to use a constant-taper file system, with variable tip sizes (for example, a 35/0.04 followed by a 30/0.04, a 25/0.04, and finally a 20/0.04). Either way, the final canal shape must allow adequate irrigation and close adaptation of the obturating material. Tips have been described as either cutting tips or non-cutting tips. Cutting tips have blades that actively cut, whereas non-cutting tips guide the instrument within the canal. Cutting tips, reportedly, cut more effectively and aggressively while tending to straighten canals.<sup>1</sup> Some files claim to have “modified cutting tips” or “partially active tips.”

Fracture is a concern with NiTi instruments. The two primary causes of instrument breakage are cyclic fatigue and torsion. Cyclic fatigue is similar to taking a piece of wire, bending it and then rotating the bent wire until it breaks. This type of stress is created in curved canals as the bent file rotates. Torsion occurs when the tip or any other part of the file is bound within the canal while the shaft continues to rotate. Larger sized and greater taper files, although they are stronger, can create more torque when engaging the canal wall. In these cases, larger instruments should not be considered more resistant to fracture.<sup>2</sup>

As the instrument progresses down the canal, torque increases as a consequence of the expanded area of contact between the file and the dentinal wall, especially with increasing canal curvature. Therefore, when the file advances further into the canal, pressure should be avoided to prevent an increase in torque. Using a lubricant within the canal can reduce the friction between the instrument and canal wall. In the case of a sharp apical curve, an appropriate choice would be a file with a smaller taper (0.02), because it's least susceptible to fatigue, though this may limit the ability to thoroughly irrigate the canal.

Visual inspection of re-used instruments is not a reliable method for evaluating the potential for fracture. Studies have shown that fracture can occur without any visible signs of previous permanent deformation.<sup>3</sup>

For straight canals, file selection is primarily governed by the shape of the canal. A rapidly tapering canal may be better prepared by a larger tapered file, where a thinner less tapered canal may be better prepared by a smaller tapered file. There is less of a concern with fracture in straight canals compared to curved canals,<sup>4</sup> so the clinician can base file selection more

on the canal shape and size. In a relatively straight or a gently curved portion of a canal, consider selecting an instrument with high strength to prevent fracture due to torsion. To prevent intracanal instrument separation or fracture, gaining straight line access (coronal and radicular) is necessary to allow an uninhibited path for the file to enter the canal.

In addition, following these tips may help reduce the risk of instrument fracture:<sup>2,5</sup>

- Use a high quality electric handpiece that maintains a constant speed
- Limit the number of re-uses of these instruments to two or three
- Adhere to the manufacturers' recommendations for handpiece speed.
- Keep the instrument moving while applying minimal apical pressure.
- Keep the file in the canal for less than 10 seconds.
- Prepare a glide path in the apical 1/3 of curved canals with a small stainless steel hand file.

In this study we evaluated eight brands of NiTi rotary endodontic files namely: 324 Niti (Medidenta), EndoSequence (Brasseler), K3 (Sybron Endo), Liberator (Miltex), LightSpeed (Lightspeed Endodontics), ProFile Series 29 (DENTSPLY), ProTaper (DENTSPLY) and V-Taper (Guidance Endodontics). We measured the dimensions, maximum torsional strength before failure, angular deflection at failure, stiffness and corrosion resistance. It should be noted that, unlike hand files, that meet ISO standards, it is uncommon to find similar tip sizes and tapers as you compare brands of rotary endodontic instruments.

<sup>1</sup>Walsch H. The hybrid concept of nickel-titanium rotary instrumentation. *Dent Clin N Am.* 2004;48:183-202.

<sup>2</sup>Bergmans L, Cleynenbreugel JV, Wevers M, Lambrechts P. Mechanical root canal preparation with NiTi rotary instruments. : Rationale, performance and safety. Status Report for the American Journal of Dentistry. *Am J Dent* 2001;14:324-333.

<sup>3</sup>Marending M, Lutz F, Barbakow F. Scanning electron microscope appearances of Lightspeed instruments used clinically: a pilot study. *Int Endod J* 1998;31:57-62.

<sup>4</sup>Martin B, Zelada G, Varela P, Bahillo JG, Magan F, Ahn S, Rodriguez C. Factors influencing the fracture of nickel-titanium rotary instruments. *Int Endod J* 2003;36:262-6.

<sup>5</sup>Patino PV, Biedma BM, Liebana CR, Cantatore G, Gonzalez J. The influence of a manual glide path on the separation rate of NiTi rotary Instruments. *J Endod* 2005;31:114-6.

Table 1. Product features and recommendations for use according to the manufacturer.

	324 Niti Medidenta International, Inc.	EndoSequence Brasseler USA	K3 SybronEndo	Liberator Miltex, Inc.	LightSpeed Lightspeed Endodontics	ProFile Series 29 DENTSPLY Tulsa Dental	ProTaper DENTSPLY Tulsa Dental	V-Taper Guidance Endodontics
Speed (rpm)	350	500-600	350-500	1000-2000	2000	300	300	250
# of Uses	2	1	3-6	1-3	<8	1	1	4-6
Supplied Sterile	No	No	No	No	No	No	No	No
Taper (mm)	0.02	0.04 0.06	0.02-0.12	0.02-0.10	Taperless	0.04 0.06	Progressively tapered	0.06-0.10
Lengths (mm)	21 25	21 25 31	17 21 25 30	13-25	21 25 31 50	21 25 30	21 25	25
Tip diameters (mm)	0.15-0.80	0.15-0.60 (0.04 taper) 0.15-0.50 (0.06 taper)	0.15-0.60	0.15-1.18	0.20-1.40	0.129-1.00	0.17-0.30	0.20 0.25 0.30
Flaring Technique	Step back	Crown down	Crown down	Crown down Step back	Crown down	Crown down	Crown down	Crown down
Tip Design	Cutting	Non-cutting	Non-cutting	Non-cutting	Non-cutting	Non-cutting	Cutting	Non-cutting

**Lab Notes:** Each file was purchased for testing in the ADA laboratories to document dimensions, corrosion resistance, torsional strength before failure, angular deflection in clockwise rotation at failure, stiffness and fatigue. A full description of our test methods can be found on the ADA's web site at "www.ada.org/goto/ppr".

Here's how the tests relate to the clinical performance of the endodontic files:

### Dimensions

**Clinical Significance:** This test documents the accuracy of the dimensions of the file specified by the manufacturer, and is critical to obtaining a seal with the obturating material.

**Results:** All the files passed this test and were within 0.5mm of the length and 0.02mm of the taper specified by the manufacturer as set forth in ANSI/ADA Specification No. 28.<sup>6</sup>

### Corrosion Resistance

**Clinical Significance:** This test documents the ability of the instruments to withstand repeated steam and heat sterilizations (8 cycles each) without exhibiting signs of corrosion.

**Results:** No corrosion was observed on any of the files. Corrosion was observed in some areas of the handle of the Liberator file, which may have an effect on the chucking mechanism in the handpiece.

### Torsional Strength before failure

**Clinical Significance:** This test documents the maximum force that an instrument can withstand before fracture when twisted.

**Results:** Larger sized files exhibited a greater resistance to fracture upon twisting. The K3 size 40 files had the highest average torque value. Comparisons should only be made between files of the same size and taper, because these characteristics will affect torsional strength. Therefore, we limited statistical analysis to K3, Liberator, EndoSequence and 324 Niti. In general, there was little difference between the autoclaved and non-autoclaved values. (See Figure 1)

### Angular Deflection in clockwise rotation at failure

**Clinical Significance:** This test documents the number of rotations that the files withstood before fracturing. In the clinic, this may be applicable to cases where the file becomes bound to the canal wall.

**Results:** 324 Niti had the highest values for all of the sizes tested. Comparisons should only be made between files of the same size and

taper, as these characteristics will affect angular deflection. Therefore, we limited statistical analysis to K3, Liberator, EndoSequence and 324 Niti. In general, there was little difference between the autoclaved and non-autoclaved values. (See Figure 2)

### Stiffness

**Clinical Significance:** This test documents the flexibility of the instrument, which affects its ability to negotiate a curved canal.

**Results:** In general, there was no statistically significant difference between the autoclaved and the non-autoclaved files. K3 files were the stiffest for all the sizes tested. Comparisons should only be made between files of the same size and taper, because these characteristics will affect stiffness. Therefore, we limited statistical analysis to K3, Liberator, EndoSequence and 324 Niti. (See Figure 3)

### Fatigue

**Clinical significance:** This test documents the ability of an instrument to resist fracture when rotated in a flexed state at the manufacturer's recommended rotational speeds. This is important in estimating how many times a file can be used in a curved canal.

**Results:** In this test, files were bent at a 30 degree angle with 4.8 mm of the apical ends engaged with a cutting surface. Of those instruments recommended for use at higher speeds, only LightSpeed did not fracture during testing. Liberator failed sooner than EndoSequence, but was also tested at twice the speed. The instruments that are intended to be used at lower speeds did not fracture during the 25 hour testing with the exception of ProTaper, which failed after about 16,000 rotations (or 53 minutes). Previous work suggests that the angle and radius of curvature used in this study may not be severe enough<sup>7</sup> or the stresses applied not high enough (beyond the elastic range of the material)<sup>8</sup> to cause fracture in the allotted test time. More research is needed to determine the dependence of these parameters on fatigue life. Of the three brands of instruments that failed during testing, two of them showed a significant increase in time to failure after autoclaving as suggested in a previous study.<sup>9</sup> (See Table 2)

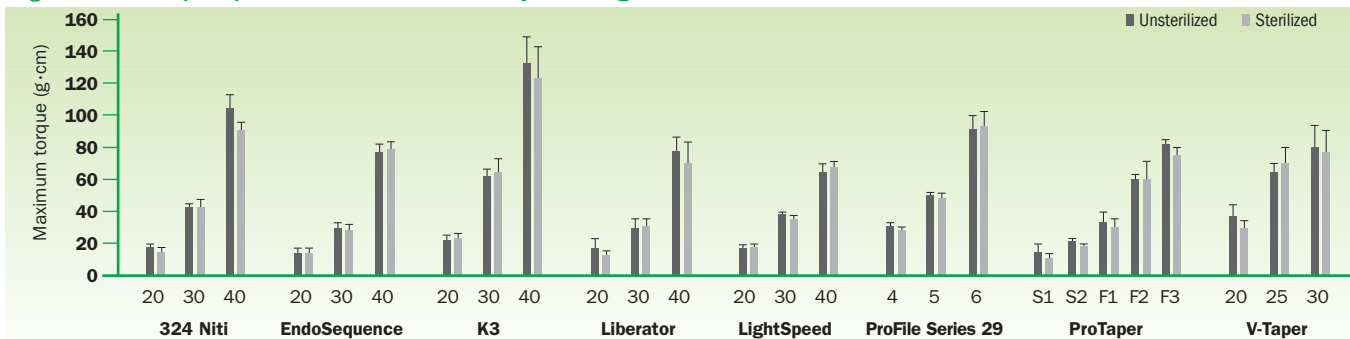
<sup>6</sup>American National Standard/American Dental Association Specification No. 28-2002, Root Canal Files and Reamers, Type K for Hand Use. Chicago: American Dental Association

<sup>7</sup>John P. Pruett, David J. Clement, and David L. Carnes, "Cyclic Fatigue Testing of Nickel-Titanium Endodontic Instruments," Journal of Endodontics, Vol. 23, No. 2, Feb. 1997, 77-85.

<sup>8</sup>K. N. Melton and O. Mercier, "Fatigue of NiTi thermoelastic martensites. Acta Met 1979; 27: 137-44.

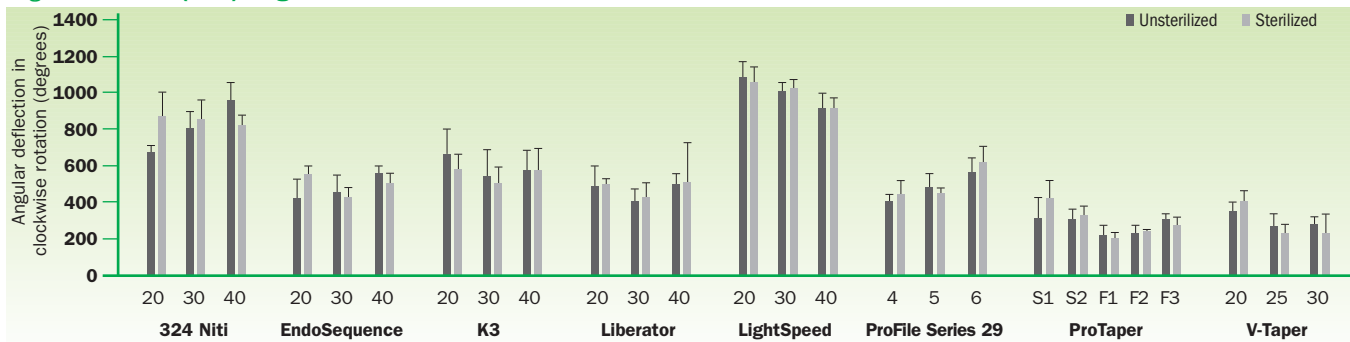
<sup>9</sup>Thomas P. Serene, J. David Adams, and Ashok Saxena, "Nickel-Titanium Instruments: Applications in Endodontics," Ishiyaku EuroAmerica, Inc., St. Louis, MO, 1995.

Figure 1. Mean (±SD) Resistance to Fracture by Twisting\*



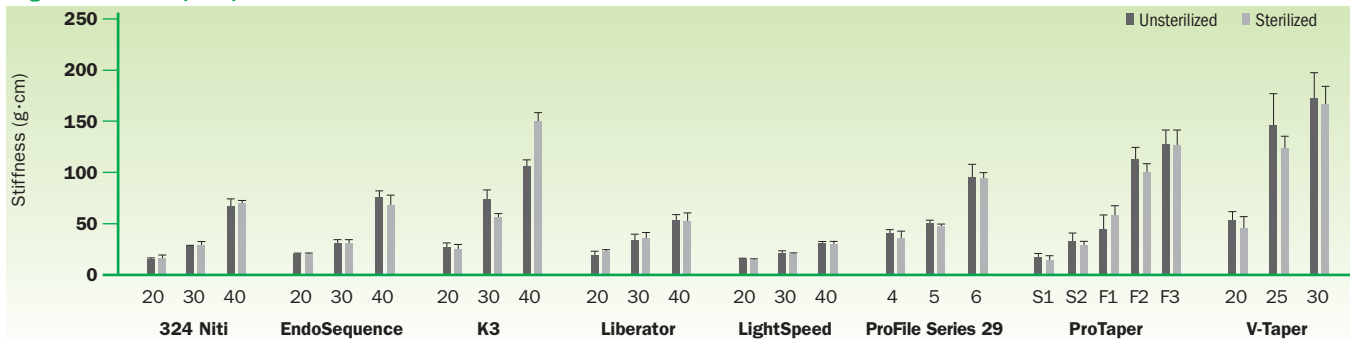
\*Mean based on n = 5.

Figure 2. Mean (±SD) Angular Deflection at failure\*



\*Mean based on n = 5.

Figure 3. Mean (±SD) Stiffness\*



\*Mean based on n = 5.

Table 2. Resistance to Fatigue\*

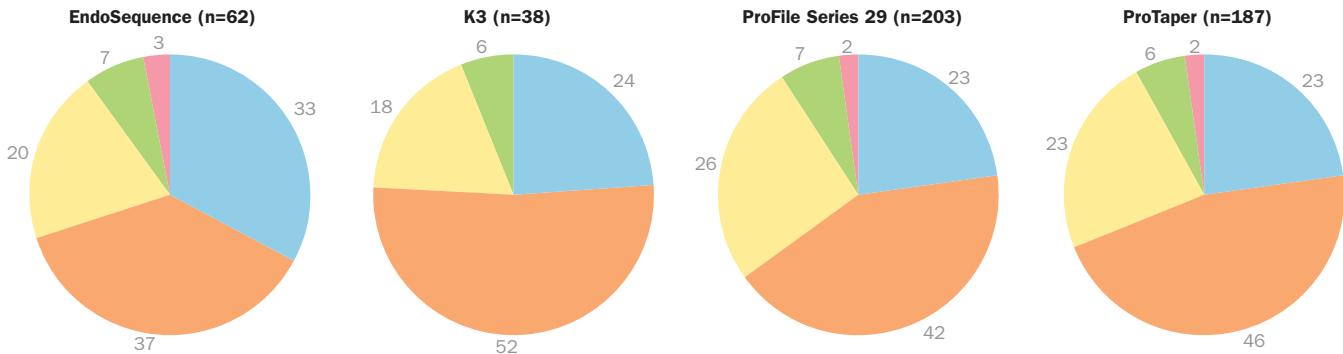
	324 Niti Medidenta International, Inc.	EndoSequence Brasseler USA	K3 SybronEndo	Liberator Miltex, Inc.	LightSpeed Lightspeed Endodontics	ProFile Series 29 DENTSPLY Tulsa Dental	ProTaper DENTSPLY Tulsa Dental	V-Taper Guidance Endodontics
<b>Manufacturer's suggested speed (rpm)</b>	350	200-1000	350	1000-2000	2000	300	300	250
<b>Testing speed (rpm)</b>	350	1000	350	2000	2000	300	300	250
<b>Non-autoclaved Time at fracture ± SD (min)</b>		10 ± 2		2 ± 0		Did not fracture during test	55 ± 21	
<b>Autoclaved Time at fracture ± SD (min)</b>	Did not fracture during test	22 ± 2	Did not fracture during test	3 ± 0	Did not fracture during test	4 files did not fracture during test 1 file fractured at 118 min	52 ± 11	Did not fracture during test

\*Mean based on the average value of at least 5 instruments.

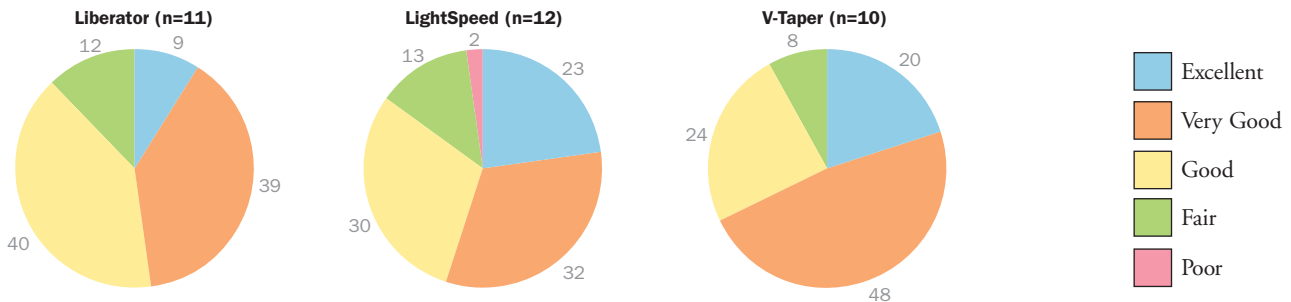
# Practitioner Input

Through a web-based survey, we collected input from 472 dentists about the NiTi rotary instruments they use. Some dentists gave input on more than one brand, for a total of 525 responses for the eight brands evaluated.

Respondents were asked to rate the performance of the files for resistance to breakage, ease of use, directions for use, and customer service. The pie charts give an overall sense of how often the systems rated Excellent, Very Good, Good, Fair, Poor or Did Not Meet Expectations. For a precise breakdown of how respondents rated each feature, visit [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). Pay special attention to the number of respondents; ratings are more reliable when they are based on the opinions of more respondents. Because of an insufficient number of survey responses, clinical data are not available for 324 Niti.



We received less than twenty survey responses for each of the instruments listed below. You should consider that ratings are more reliable when based on the opinions of more respondents.



## What dentists said ...

*Based on 525 survey responses.*

- More than half of the dentists responding to the survey were of the opinion that rotary endodontic files fracture more often than hand files. Although, some dentists responded that working at slower speeds and changing files more frequently helped reduce the number of fractures. Breakage occurred with about the same frequency for all the files, according to the survey results.
- Ledging, canal transportation or perforations occurred less often with rotary files than hand files according to two thirds of the dentists surveyed.
- Some dentists responded that access can be a problem when treating 2nd molars and patients with small mouths or limited opening.
- Dentists valued the clinical performance, ease of use of rotary files and reduction in hand fatigue; while breakage and cost were the biggest drawbacks to their use.

The ADA Clinical Evaluators endodontic specialty panel responded to questions about the impact of rotary endodontic files on clinical practice. Most responded that these products have had a positive effect by decreasing the stress and strain on the operator (versus hand files), and improving the ability of specialists and general dentists to efficiently shape canals. They cautioned, though, that faster preparation may lead to incomplete debridement and cleaning of the root canal system, an essential component of successful treatment. The rotary systems may seem easy to use, but hands-on training is very important to minimize problems. Training from other dentists, independent of the product manufacturer is highly recommended.



*Photo courtesy of the ADA Tripartite Grassroots Initiative.*

**Table 2. Buyers' Summary for NiTi Rotary Endodontic Instruments.**

(No. of clinical survey respondents*)		324 Niti Medidenta International, Inc.	EndoSequence Brasseler USA (62)	K3 SybronEndo (38)	Liberator Miltex, Inc. (11)*	LightSpeed Lightspeed Endodontics (12)*	ProFile Series 29 DENTSPLY Tulsa Dental (203)	ProTaper DENTSPLY Tulsa Dental (187)	V-Taper Guidance Endodontics (10)*
Laboratory Performance	<b>Dimensions</b>	pass	pass	pass	pass	pass	pass	pass	pass
	<b>Lab Score † %</b>	91	65	73	69	NA ‡	NA ‡	NA ‡	NA ‡
Clinical Impressions*	<b>Excellent %</b>	Insufficient # of survey responses.	33	24	9	23	23	23	20
	<b>Very Good %</b>		37	52	39	32	42	46	48
	<b>Good %</b>		20	18	40	30	26	23	24
	<b>Fair %</b>		7	6	12	13	7	6	8
	<b>Poor %</b>		3	0	0	2	2	2	0
	<b>DN** %</b>		0	0	0	0	0	0	0
<b>Single or Multi Use</b>	multi	single	multi	multi	multi	single	single	multi	
<b>Price ¥ (per file)</b>	\$5.00	\$10.20	\$5.50 - \$7.50	\$6.99	\$7.00	\$7.08	\$8.65	\$7.65	

†Lab score reflects the values obtained for torsional strength, angular deflection and stiffness and is an overall average of all percentages normalized to the best performer for each of these three tests for file sizes 20, 30 and 40.

‡Not applicable. An overall score could not be calculated for LightSpeed, ProFile Series 29, ProTaper and V Taper because the tapers were not comparable to the other brands.

\*Via a web-based survey. Indicates percentage of time a rating was selected for a product. Less than twenty survey responses were received for Liberator, LightSpeed and V-Taper. When considering the clinical data, keep in mind that ratings are more reliable when based on the opinions of more respondents.

¥ MSRP as of June 2006.

\*\*Indicates percentage of time "does not meet clinical expectations" was selected for a product.



**Corrections**

There was an error in Table 2 of the Digital Radiography Systems report in the Summer 2006 issue of the ADA Professional Product Review (PPR 2006;1(1):12). The average scores reported for the digital radiography systems as ranked by dentist evaluators according to image quality all should be reduced by 1.0.

**ADA.org Offers More Product Information**

The ADA's Web site now hosts a special section for the Professional Product Review at [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). Our online space offers background on the program and features extra information to supplement our product review and letters to the editor. You can also sign up to be an ADA Clinical Evaluator.

# The Back Page *The Editor's Bottom Line*

**LED lights:** Prices and features vary greatly in the curing lights we evaluated. At under \$400, FLASH-lite 1401 rated well in the laboratory tests and was highly rated by dentists; however the battery cannot be replaced. The Radii Plus provides a ramped cure mode and replaceable battery at under \$800, and scored well in the laboratory tests, but was rated middle-of-the-road by dentists. The blue phase at under \$1500 offers three curing modes, a replaceable battery, and was highly rated by dentists. Smartlite iQ, at under \$1300, has a replaceable battery and two curing modes; however it showed the lowest depth of cure in laboratory testing and was rated middle-of-the-road by dentists.

**Resin-based cements:** All brands performed well on working time, setting time, radiopacity, and film thickness. All brands, except Maxcem, had acceptable levels of water sorption and solubility. According to the manufacturer, Maxcem could not be tested for water sorption because it contains water. DUO-LINK (a total-etch system) and PANAVIA F2.0 (a

self-etch system) showed the highest strength and resistance to flexure, respectively. The self-adhesive systems Maxcem and Rely X Unicem, and the total-etch system Ultra-Bond Plus were rated highest by surveyed dentists.

**NiTi rotary endodontic instruments:** Comparing different brands of rotary endodontic instruments is like comparing apples and oranges, because each system is unique in terms of design of tip sizes and tapers. All brands passed the basic evaluations of dimensions and corrosion and should be expected to prepare canals to the desired size and taper, and withstand sterilization. For the systems that could be compared, the 324 Niti files scored 91% on the overall Lab Score and K3 ranked second with 73%. V-Taper, ProFile Series 29, 324 Niti, K3, and Lightspeed, when run at manufacturer recommended RPM, showed the longest resistance to fatigue failure in a simulated curved canal. Endosequence, K3, ProFile, ProTaper, and V-Taper were the highest rated systems by surveyed dentists. Cost per file ranges from \$5.00 for 324 Niti to \$10.20 for Endosequence.

## *Your Views:*

PPR welcomes letters from readers on articles and other information that has appeared in PPR or been posted on [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). PPR reserves the right to edit all letters and requires that they be signed. The views expressed are those of the letter writer and do not necessarily reflect the opinion or official policy of the ADA or its subsidiaries. Statements that are libelous or might otherwise expose the ADA to legal liability will not be published. Brevity is encouraged. Due to space limitations, we may not be able to publish every letter in its entirety in the newsletter. The complete versions along with other letters that have been submitted will be posted online at [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr). You may submit letters by e-mail to [ppreditor@ada.org](mailto:ppreditor@ada.org), by fax to 312-440-2536, or by mail to ADA Professional Product Review, 211 E. Chicago Ave, 4th floor, Chicago, IL 60611-3528.

### **ADA Leadership**

A pleasure to find the ADA in a leadership role again. This is the type of dental involvement that adds to the position of the organization, which is devoted to the dental profession.

Paul C. Belvedere, DDS Edina, MN

### **Digital Radiography Systems**

I was pleased to receive and read the first issue of this publication. I think it is a great idea, and most useful. One comment—I wish the digital x-ray evaluation had included a comparison of a film x-ray for quality comparison.

Don Smith, D.D.S. Oklahoma City, OK

I read the Digital Radiography evaluation with great interest, but was greatly disappointed by the lack of "control" in your evaluation. Rather than simply comparing existing systems, what some of us who have not yet purchased a digital radiography might be interested in — what I am certainly interested in — why not compare how the digital resolution, as defined by specificity, accuracy and sensitivity compares with Insight (Kodak) and D speed film?

Please differentiate yourselves by providing useful information that is in our, and not the corporate, best interest.

Grant T. Chyz, D.D.S. Seattle, WA

*Excerpt, complete letter posted on [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr)*

*Editor's comment: We have received several inquiries about why conventional x-ray film was not*

*included as a control in the digital radiography device evaluation. There are a number of published studies already comparing conventional x-ray film to digital radiographic images from specific manufacturers. These studies (References 11-14 in Van der Stelt, JADA Oct 2005;136(10);1378-1387) generally find that digital images performed at least as well as conventional radiographs in their diagnostic ability. However, it might be interesting for readers to have another look, and we'll consider this for a future issue.*

Where is the science, the evidence-based decision making process, in asking for dentists' experiences?

Th. 'Pat' Collins, D.D.S. Greenbrae, CA

*Excerpt, complete letter posted on [www.ada.org/goto/ppr](http://www.ada.org/goto/ppr)*

*Editor's comment: We decided to gather clinical data via practitioner surveys for several reasons. First, ADA access to a very large percentage of practicing dentists is one of the unique things PPR has to offer its readers. We've been delighted with our members' willingness to get involved in the ADA ACE panels. The number of participants is over 1,500 and still growing.*

*Also important to our decision are the rules governing the ethical conduct of clinical research. We aren't willing to ask our members to conduct clinical research in their offices without the protection of these rules for dentists and their patients. The practice-based research networks that are being formed around the country with federal funding will apply these protections to office-based clinical research. We hope to be able to use these kinds of*

*networks to expand our clinical research in the future. In the meantime, our readers told us they want to know about the experiences of their colleagues with dental products, and that's what we'll deliver.*

*Dr. Collins raises a good point about the low number of respondents for certain products. We gave a lot of thought to whether to report these results. The decision could have gone either way. Finally, we decided in favor of giving our readers more information, and using disclaimers to put it in context. In this issue of PPR, we did not report survey results based on five or fewer dentists. We would be pleased to hear from more readers about whether they found this information useful.*

I wanted to take this opportunity to congratulate you on the introduction of the PPR. I received the first one with my July 2006 copy of JADA.

During this haze of heavy commercial endorsement and sponsorship, your objective and independent publication is a breath of fresh air. On behalf of dental students everywhere, thank you.

I was particularly impressed by the review of the digital X-ray sensors. I purchased the Schick CDR system for my father's practice a number of years ago, and had been curious to see how it measured up to the competitors. I'm happy to say that I made the right decision.

Toby M Cohen, D.D.S.

Columbia University College of Dental Medicine, Class of 2009

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