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# The clinical success of all-ceramic restorations

Alvaro Della Bona, DDS, MMedSci, PhD, FADM; J. Robert Kelly, DDS, MS, DMedSc

**S**ome basic concepts are useful in understanding all-ceramic systems.<sup>1,2</sup> It is universally true that the stronger (and tougher) ceramics are more opaque (thus, less translucent) than esthetic porcelains.<sup>3</sup> Therefore, in patients whose tooth restoration involves esthetic demands without much structural need, the clinician can use single (that is, monolithic) layers of tooth-colored porcelains. When structural demands require stronger materials, the clinician uses copings and frameworks made of less esthetic ceramic materials that are veneered (that is, layered) with tooth-colored porcelains. The dentist also uses layered ceramics to mask discolored preparations.

Clinical data strongly suggest that clinicians achieve higher success rates when they can bond ceramics to teeth (for example, resin-based cement versus glass ionomer or zinc phosphate).<sup>3</sup> Bonding requires that the ceramic contain filler particles that can be removed selectively via etching to create micromechanical adherence features. Manufacturers routinely provide cementation directions that should be followed.

In this review, we emphasize restorations rather than the ceramic

## ABSTRACT

**Background.** The authors conducted a comprehensive literature review to compile and compare clinical evidence for the treatment of teeth using all-ceramic restorations.

**Types of Studies Reviewed.** The authors searched the English-language peer-reviewed literature using MEDLINE and PubMed with a focus on research published between 1993 and 2008. They also conducted a hand search of relevant dental journals. They reviewed randomized controlled trials, nonrandomized controlled studies, longitudinal experimental clinical studies, longitudinal prospective studies and longitudinal retrospective studies.

**Results.** Evidence suggests that for veneers, intracoronal restorations and complete-coverage restorations for single-rooted anterior teeth, clinicians may choose from any all-ceramic system on the basis of esthetic needs (many systems have had greater than 90 percent success at six years). Well-studied molar restorations include those made of alumina and, increasingly, zirconia and bonded lithium disilicate. Reasonable evidence has shown the effectiveness of anterior three-unit fixed partial dentures made of lithium disilicate, alumina and zirconia. For three-unit restorations involving a molar, expert consensus suggests that only zirconia-based systems are indicated.

**Clinical Implications.** Available evidence indicates the effectiveness of many all-ceramic systems for numerous clinical applications. Bonding has been shown to increase clinical success. Studies of zirconia prostheses indicate problems with porcelain cracking.

**Key Words.** Literature review; zirconia; alumina; survival rate. *JADA 2008;139(9 suppl):8S-13S.*

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systems. We begin with the most well-studied and successful restorations (that is, veneers bonded to enamel and inlays/onlays) and end with the least well-studied restorations (that is, multiunit posterior prostheses). We have kept this review brief to make it accessible to the widest possible clinical audience.

### **VENEER RESTORATIONS**

Ceramics are particularly well-suited for veneer restorations, which have failure rates, including loss of retention or fracture, of less than 5 percent at five years.<sup>4,5</sup> In one of the earliest clinical studies, which examined 83 veneers (IPS Empress, Ivoclar Vivadent, Amherst, N.Y. [now IPS Empress Esthetic Veneer]), the authors reported a success rate of 98.8 percent after six years.<sup>6</sup> Two recent reports on feldspathic porcelain veneers ( $n = 3,047$  and  $n = 1,828$ ) showed similar long-term survival rates (according to Kaplan-Meier statistics): 96 percent at five to six years, 93 percent at 10 to 11 years and 91 percent at 12 to 13 years in one study<sup>7</sup> and 94.4 percent at 12 years in the second study.<sup>8</sup> Mechanical and biological complications that did occur were associated with esthetics (31 percent), mechanical complications (31 percent), periodontal support (12.5 percent), loss of retention (12.5 percent), caries (6 percent) and tooth fracture (6 percent).<sup>7</sup> We should point out that both periodontal support and secondary caries are biological responses that likely are not related to the materials used in fixed prostheses.

### **INLAY AND ONLAY RESTORATIONS**

Some of the most extensively studied ceramics in dentistry are used for inlay and onlay restorations; they are made of feldspathic ceramic (Vitablocs Mark I and II, Vita Zahnfabrik, Bad Säckingen, Germany) or mica-filled glass-ceramic (Dicor, Dentsply, York, Pa. [no longer on the market]) by using the CEREC computer-aided design/computer-aided manufacturing (CAD/CAM) system (Sirona Dental Systems GmbH, Bensheim, Germany).<sup>9-14</sup> Another widely studied ceramic is the hot-pressed leucite-reinforced ceramic from Ivoclar Vivadent (formally IPS Empress, now IPS Empress Esthetic).<sup>15-18</sup>

Within a private practice setting, Otto and De Nisco<sup>12</sup> reported a survival rate (using Kaplan-Meier statistics) of 90.4 percent at 10 years for 200 restorations. Reported failures were related

to ceramic fracture (53 percent), tooth fracture (20 percent) and endodontic problems (7 percent). A literature review of six clinical trials that used IPS Empress (Ivoclar Vivadent) for inlay/onlay restorations reported survival rates ranging from 96 percent at 4.5 years to 91 percent at 7 years<sup>15</sup>; these results are consistent with those of a prospective controlled clinical trial (92 percent at eight years; Kaplan-Meier statistics)<sup>16</sup> and a recent evaluation<sup>17</sup> of 1,588 IPS Empress inlay/onlay restorations placed on vital teeth (97 percent at 10 years; Kaplan-Meier statistics).

A systematic review of 22 clinical studies that used the CEREC system to produce inlay and onlay restorations and crowns from Vitablocs Mark I and II and Dicor ceramics reported a survival probability of approximately 97 percent at five years and 90 percent at 10 years.<sup>13</sup> One of these studies<sup>14</sup> reported data about 66 CAD/CAM inlays that had an estimated survival rate of 89 percent after 10 years—77 percent for the inlays luted with a dual-cured resin-based composite and 100 percent for those luted with a chemically cured resin-based composite. This difference in performance on the basis of the cement used was statistically significant.

### **SINGLE-UNIT CROWNS**

As expected, the first all-ceramic systems to appear on the market have received the most attention in the peer-reviewed literature. These systems are leucite-reinforced glass-ceramic (IPS Empress), glass-infiltrated ceramics (In-Ceram Alumina and In-Ceram Spinell, Vita Zahnfabrik) and polycrystalline alumina (Procera Alumina, Nobel Biocare, Göteborg, Sweden). Despite the differences in their microstructure, composition, processing methods and intraoral area (anterior or posterior), most clinical trials have reported survival rates of greater than 90 percent, irrespective of the time in service; the one exception is a glass-ceramic introduced in the 1980s (Dicor), but it is no longer on the market (Table 1<sup>19-43</sup>).

In general, fracture rates appear to be lower for anterior crowns than for molar crowns, and the two alumina-based systems are proving to be comparable (that is, In-Ceram Alumina and Procera Alumina). Greater success for anterior teeth also has been the trend for IPS Empress crowns.

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**ABBREVIATION KEY.** CAD/CAM: Computer-aided design/computer-aided manufacturing. FPDs: Fixed partial dentures.

TABLE 1

## Peer-reviewed studies of survival rate of all-ceramic single-unit crowns.

ALL-CERAMIC MATERIAL	NO. OF CROWNS		FABRICATION METHOD	OBSERVATION PERIOD IN MONTHS (MEAN)	SURVIVAL RATE IN PERCENT (PERIOD)
	Anterior	Posterior			
In-Ceram Alumina (Vita Zahnfabrik)*	21	40	Slip cast <sup>19</sup>	4-35 (20.8)	100 (30 months) <sup>††</sup>
	35	— <sup>¶</sup>	Slip cast <sup>20</sup>	2.5-21 (NI <sup>**</sup> )	91.5 <sup>‡‡</sup>
	28	68	Slip cast <sup>21</sup>	1.3-55.9 (24.4)	100 (56 months) <sup>††</sup>
	25	38	Slip cast <sup>22</sup>	24-44 (37.6)	98.4 <sup>‡‡</sup>
	223		Slip cast <sup>23</sup>	36 (36)	96 <sup>‡‡</sup>
	45	23	Slip cast <sup>24</sup>	NI-60 (NI)	92 (5 years) <sup>††</sup>
	177	369	Slip cast <sup>25</sup>	12-72 (33.4)	99.1 <sup>‡‡</sup>
In-Ceram Spinell (Vita Zahnfabrik)*	—	19	CAD/CAM <sup>#26</sup>	14-58 (40.6)	92 (5 years) <sup>††</sup>
	40	—	Slip cast <sup>27</sup>	28-56 (36.3)	100 (5 years) <sup>††</sup>
	18	—	Slip cast <sup>27</sup>	22-60 (50)	97.5 (5 years) <sup>††</sup>
Procera (Nobel Biocare) <sup>†</sup>	17	83	CAD/CAM <sup>28</sup>	33-57 (44.7)	91.7 (5 years) <sup>††</sup>
	23	64	CAD/CAM <sup>29</sup>	60 (60)	94 (5 years) <sup>††</sup>
	50	155	CAD/CAM <sup>30</sup>	1-120 (NI)	93 (10 years) <sup>††</sup>
	61	46	CAD/CAM <sup>31</sup>	6-60 (23.5)	96.7 (5 years) <sup>††</sup>
	32	103	CAD/CAM <sup>32</sup>	72 (72)	94.3 (6 years) <sup>††</sup>
IPS Empress (Ivoclar Vivadent) <sup>‡</sup>	41	37	CAD/CAM <sup>33</sup>	1-92 (55)	99 (5 years) <sup>††</sup>
	41	37	Hot pressed <sup>34</sup>	1-24 (20)	95 (2 years) <sup>††</sup>
	101	43	Hot pressed <sup>35</sup>	6-68 (37)	95 (3 years) <sup>††</sup>
	47	28	Hot pressed <sup>36</sup>	14-42 (NI)	99 (3 years) <sup>††</sup>
	43	67	Hot pressed <sup>37</sup>	1-42 (3.6)	92 (3.5 years) <sup>††</sup>
IPS Empress 2 (Ivoclar Vivadent) <sup>‡</sup>	93	32	Hot pressed <sup>38</sup>	48-132 (NI)	95.2 (11 years) <sup>††</sup>
	56	23	Hot pressed <sup>39</sup>	12-60 (58)	95 (5 years) <sup>††</sup>
	—	27	Hot pressed <sup>40</sup>	6-60 (NI)	100 (5 years) <sup>††</sup>
	12	8	Hot pressed <sup>41</sup>	24 (24)	100 (2 years) <sup>††</sup>
Dicor (Dentsply) <sup>§</sup>	—	30	Hot pressed <sup>42</sup>	12 (12)	100 (1 year) <sup>††</sup>
	98		Lost wax <sup>43</sup>	15-130 (74)	82 <sup>‡‡</sup>
	30		Lost wax <sup>24</sup>	84 (84)	86 (7 years) <sup>††</sup>

\* In-Ceram Alumina and In-Ceram Spinell are manufactured by Vita Zahnfabrik, Bad Säckingen, Germany.  
† Procera is manufactured by Nobel Biocare, Göteborg, Sweden.  
‡ IPS Empress is now IPS Empress Esthetic; IPS Empress 2 is now reformulated as IPS e.max Press. They are manufactured by Ivoclar Vivadent, Amherst, N.Y.  
§ Dicor was manufactured by Dentsply, York, Pa. It is no longer on the market.  
¶ Dash indicates none.  
# CAD/CAM: Computer-aided design/computer-aided manufacturing.  
\*\* NI: Not included.  
†† Kaplan-Meier survival rate was calculated for the endpoint listed.  
‡‡ No period indicated.

Fradeani and Redemagni<sup>38</sup> reported an overall survival rate of 95.2 percent at 11 years for 125 IPS Empress crowns, which represents 98.9 percent survival in the anterior segment and 84.4 percent survival in the posterior segment.

The main causes of failure reported in all studies were catastrophic fractures (that is, the crown broke into two pieces), chipping of the veneer ceramic and secondary caries. Again, we

should point out that secondary caries is a host response likely unrelated to the particular materials used in fixed prostheses. In a four-year study of 80 In-Ceram Alumina crowns (58 anterior [72 percent] and 22 posterior [28 percent]), Haselton and colleagues<sup>44</sup> reported that only one molar crown had fractured and the marginal ridge of one premolar crown had chipped. However, another four-year study did not report any

bulk fractures for 28 anterior and 68 posterior crowns (In-Ceram Alumina).<sup>21</sup>

McLaren and White<sup>23</sup> conducted a study in a private practice setting and reported that 223 crowns (In-Ceram Alumina) had a survival rate of 96 percent after three years, with anterior crowns trending toward a higher survival rate (98 percent) than premolars or molars (94 percent). A retrospective study<sup>25</sup> of 546 In-Ceram Alumina restorations (177 anterior and 369 posterior crowns) reported a survival rate of 99.1 percent for both anterior and posterior crowns after six years of service. Furthermore, a recent study of 135 restorations (Procera Alumina) reported a cumulative survival rate of 100 percent in the anterior region and 98.8 percent in the posterior region (one crown fracture) after five and seven years regardless of the cement used (resin-based composite or glass-ionomer cement).<sup>33</sup>

Restorations composed of lithium disilicate-based glass-ceramic (IPS Empress 2 [now reformulated and optimized as IPS e.max Press], Ivoclar Vivadent) also have had high survival rates. Two recent reports on IPS Empress 2 crowns showed survival rates of 95 percent<sup>39</sup> and 100 percent<sup>40</sup> after five years.

### MULTIUNIT PROSTHESES

Two manufacturers have recommended their all-ceramic systems for anterior three-unit prostheses: a glass-infiltrated alumina (In-Ceram Alumina) and a lithium disilicate-based glass-ceramic (IPS Empress 2 [now IPS e.max Press]).<sup>3</sup> Some clinical studies also reported using In-Ceram Alumina for fixed partial dentures (FPDs) involving posterior teeth (Table 2<sup>19,20,40,41,45-51</sup>). In a three-year study of 61 three-unit FPDs (In-Ceram

**TABLE 2**

## Peer-reviewed studies of survival rate of all-ceramic three-unit fixed partial dentures (two conventional retainers).

ALL-CERAMIC MATERIAL	NO. OF FIXED PARTIAL DENTURES		FABRICATION METHOD	OBSERVATION PERIOD IN MONTHS (MEAN)	SURVIVAL RATE IN PERCENT (PERIOD)
	Anterior	Posterior			
In-Ceram Alumina (Vita Zahnfabrik)*	7	8	Slip cast <sup>19</sup>	2-35 (16.3)	93.3 (1 year)**
	7	—	Slip cast <sup>20</sup>	4.5-21 (NI#)	100 <sup>††</sup>
	21	40	Slip cast <sup>45</sup>	36 (36)	88.5 <sup>††</sup>
	— <sup>§</sup>	20	Slip cast <sup>46</sup>	60 (60)	90 <sup>††</sup>
	8	7	Slip cast <sup>47</sup>	2-110 (76)	88 (10 years)**
	16	—	Slip cast <sup>48</sup>	3-146 (76)	67.3 (5 years)**
In-Ceram Zirconia (Vita Zahnfabrik)*	—	18	Slip cast <sup>49</sup>	32-36 (NI)	94.5 (3 years)**
IPS Empress 2 (Ivoclar Vivadent)†	31	—	Hot pressed <sup>40</sup>	6-60 (NI)	70 (5 years)**
	12	8	Hot pressed <sup>41</sup>	24 (24)	50 (2 years)**
	—	30	Hot pressed <sup>50</sup>	24 (24)	93 <sup>††</sup>
Cercon Zirconia (Dentsply Ceramco)‡	—	33	CAD/CAM <sup>¶51</sup>	1-60 (53.4)	74 (5 years)**

\* In-Ceram Alumina and In-Ceram Zirconia are manufactured by Vita Zahnfabrik, Bad Säckingen, Germany.  
† IPS Empress 2 is now reformulated as IPS e.max Press. It is manufactured by Ivoclar Vivadent, Amherst, N.Y.  
‡ Cercon Zirconia is manufactured by Dentsply Ceramco, York, Pa.  
§ Dash indicates none.  
¶ CAD/CAM: Computer-aided design/computer-aided manufacturing.  
# NI: Not included.  
\*\* Kaplan-Meier survival rate was calculated for the endpoint listed.  
†† No period indicated.

Alumina), Sorensen and colleagues<sup>45</sup> reported survival rates of 100 percent for anterior teeth and 83 percent for posterior teeth. Seven of the FPDs fractured through the connector area. All FPDs had been cemented with glass-ionomer cement.<sup>45</sup>

In another study of 42 FPDs (64 percent were cantilevered two-unit FPDs and 36 percent were three-unit FPDs), 62 percent of which involved a posterior tooth, Olsson and colleagues<sup>47</sup> reported an overall survival rate of 93 percent at five years and 83 percent at 10 years; however, for the three-unit FPDs only, the survival rate was 88 percent at 10 years. Kern<sup>48</sup> also examined cantilevered two-unit (n = 21) and conventional three-unit (n = 16) anterior FPDs (In-Ceram Alumina) in a study that reported a five-year survival rate of 73.9 percent for the three-unit FPDs and 92.3 percent for the two-unit FPDs. The results of this study also showed that when one connector fractured, the other was quite stable when left as a cantilevered unit.<sup>48</sup>

Three clinical studies reported survival rates for FPDs (IPS Empress 2).<sup>40,41,50</sup> A two-year study<sup>41</sup> reported that 10 (50 percent) of 20 FPDs experienced catastrophic failures, with five failures (25 percent) occurring within the first year and the other five failures (25 percent) occurring within the second year. However, the other two studies reported survival rates of 70 percent after five years<sup>40</sup> and 93 percent after two years of follow-up.<sup>50</sup> In the study conducted by Esquivel-Upshaw and colleagues,<sup>50</sup> two fractures occurred; one was associated with a short connector height (2.9 millimeters, instead of the recommended 4 mm) and the other was associated with an unusually high occlusal force (1,031 newtons).

Manufacturers recommended two other all-ceramic systems for posterior three-unit prostheses: a glass-infiltrated alumina/zirconia (In-Ceram Zirconia, Vita Zahnfabrik) and a transformation-toughened polycrystalline zirconia (such as Cercon Zirconia, Dentsply Ceramco, York, Pa.; Lava, 3M ESPE, St. Paul, Minn.; In-Ceram YZ, Vita Zahnfabrik).<sup>3</sup> Suárez and colleagues<sup>49</sup> evaluated the clinical performance of posterior FPDs (In-Ceram Zirconia) (n = 18) after three years of service. They reported only one failure, the result of root fracture, resulting in a survival rate of 94.5 percent. The success rate for the 33 posterior zirconia FPDs (Cercon) was 97.8 percent.<sup>51</sup> However, the overall survival rate was 73.9 percent because of other complications, such as secondary caries (21.7 percent) and chipping of the veneering ceramic (15.2 percent).<sup>51</sup> These two clinical studies (n = 51) reported only one fracture of the zirconia-based framework, which suggests a promising future for all-ceramic FPDs.

## CONCLUSIONS

In this review, we presented current evidence suggesting that all-ceramic restorations have an acceptable clinical longevity that accompanies their long-lasting esthetic advantages. Evidence from many clinical studies suggests that clinicians may choose from any all-ceramic system on the basis of patients' esthetic needs for veneers, intracoronal restorations and full-coverage restorations for single-rooted anterior teeth. Only a few systems have been successful for the restoration of molars, and additional clinical factors such as adequate preparation depth and cementation can outweigh materials considerations.

In the future, transformation-toughened zirconia may stand out as the most successful all-

ceramic system, irrespective of the clinical indication. Nevertheless, chipping of the veneering ceramic on zirconia restorations continues to be a problem. The evidence provided here should enable clinicians to enter into informed-consent decisions with their patients who desire all-ceramic restorations. ■

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