KEY WORDS
Ceramic, porcelain, lithium disilicate, zirconia

LEARNING OBJECTIVES
- To provide an overview of the various types of contemporary ceramic restorations
- To outline the benefits and limitations of contemporary ceramic restorative materials
- To provide information on the potential survival of ceramic dental restorations in different clinical situations

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DEMYSTIFYING MODERN DENTAL CERAMICS

ABSTRACT
With increasing patient expectation for aesthetic dental restorations, there has been a drive towards developing ceramic materials to meet this expectation. Multiple ceramic systems have been introduced over the past four decades with considerable advances in material properties. Survival rates of all-ceramic crowns differ by type of ceramic used, fabrication method and clinical indication. Zirconia and lithium disilicate are the most commonly used contemporary ceramic materials in dentistry. Survival data for these types of restorations appears to be promising; however, there is a lack of high-quality long-term clinical data on the success of these restorations. In the absence of robust longitudinal clinical research, laboratory studies have provided some useful information on the performance of ceramic restorations. Further high quality long-term clinical studies are needed to inform us of modes of failure of these restorations and the range of clinical circumstances in which each type of ceramic restoration may be used.

Introduction
Materials for indirect dental restorations can be broadly divided into three main categories: metal alloys (all-metal and metal-ceramic), all ceramic and resin-based composites. Of these restorative materials, it is widely accepted that cast gold alloy restorations provide extremely predictable long-term clinical service, with reported survival rates of 94.1% at 40 years.[1] Metal-ceramic restorations offer the advantage of combining good clinical longevity with reasonable aesthetic outcomes.[2,3] Over-time however, there has been an increasing patient expectation for higher aesthetic outcomes and metal-free restorations. This has led to a drive towards engineering and developing ceramic materials to meet this demand. Multiple ceramic systems have been introduced over the past four decades[4] with considerable advances in material properties. Survival rates of all-ceramic crowns differ by the type of ceramic used, fabrication method and clinical indication.[5,6]

Each type of ceramic material has its own advantages and limitations, and it is the clinician's responsibility to guide the patient as to which material will meet their functional and aesthetic needs. The aim of this paper is to provide an overview of the most common contemporary ceramics used in dentistry and outline their benefits and limitations.

Porcelain jacket crowns and metal ceramic crowns

Dental ceramics are broadly defined as 'inorganic, non-metallic materials which are specifically formulated for use when processed according to the manufacturers' instructions to form the whole or part of a dental restoration or prosthesis.'[7] Feldspathic porcelain was previously the only ceramic available for making 'porcelain jacket crowns'. It contains three minerals: feldspar (potassium and sodium aluminosilicate), kaolin (hydrated alumina silicate) and quartz (silica).[8] When the porcelain powder is sintered in a porcelain furnace, the feldspar forms leucite crystals (<5% mass) within the alumina-silicate glass matrix.[9] Feldspathic porcelain crowns, although aesthetically pleasing, are brittle and crack sensitive. They are vulnerable to crack propagation following cyclic occlusal loading which can lead to catastrophic failure.[10] The limited physical properties of feldspathic porcelain are associated with low leucite concentration and the flaws found in a sintered material.[11]

Metal-ceramic restorations with a metal coping or framework completely or partially veneered in feldspathic porcelain (see Figure 1) were developed as a way of strengthening the feldspathic porcelain crowns.[12] These restorations allow a reduced tooth preparation in areas where there is no veneering feldspathic porcelain. In cases where a patient is a bruxist, a metal occlusal surface of the metal-ceramic crown provides the added advantage of a more conservative tooth preparation and a reduced risk of porcelain fracture. In addition, a metal occlusal surface is considerably less abrasive to the opposing tooth than a ceramic occlusal surface .[13]

Figures 1, 2, 3a, 3b, 4, 5a, 5b, 7a, 7b and 7c are reproduced by kind permission of George Bourne

Figure 1: *Metal-ceramic crown with a partially veneered metal coping in feldspathic porcelain*

Classification of dental ceramics

Dental ceramics can be broadly divided into two main categories based on their composition:[9]

1. Glass ceramics: These have a crystalline phase within a glass matrix and can be etched with hydrofluoric acid (see Figures 2 and 3). Silane is then applied to the etched surface for 60 seconds followed by an adhesive resin cement to allow bonding to enamel.
2. Polycrystalline ceramics: These do not contain a glass matrix and therefore cannot be etched with hydrofluoric acid for bonding to enamel. They are densely sintered polycrystalline structures containing aluminium oxide or zirconium oxide and are usually cemented with a conventional luting cement.

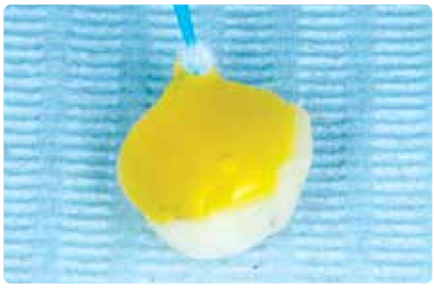


Figure 2: *5% hydrofluoric acid placed on the fit surface of a glass ceramics matrix lithium disilicate crown*

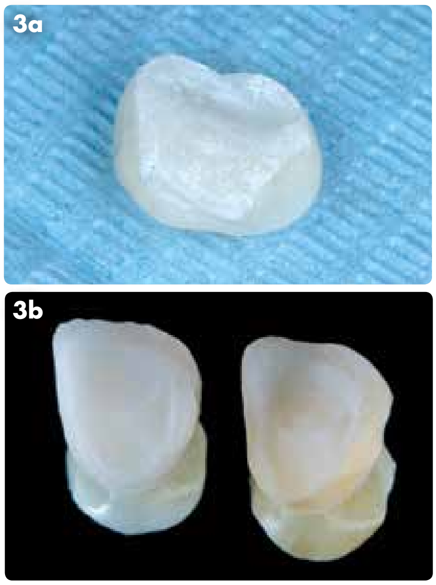
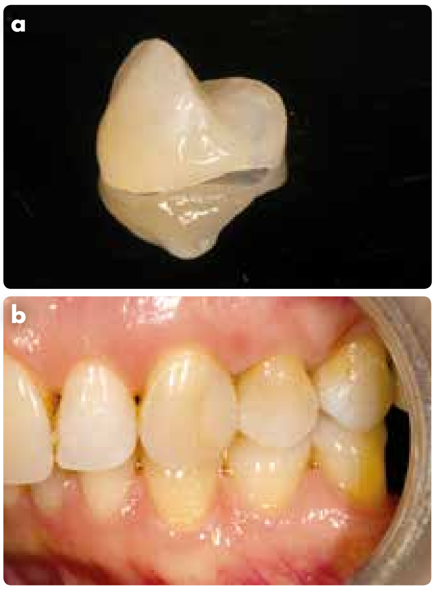


Figure 3: *Etched fit surface of glass ceramics lithium disilicate crowns prior to cementation*

Figure 4: *Monolithic lithium disilicate restoration with surface staining*

Figure 5a: *Lithium disilicate restoration UL4 with 'layered' veneering buccal feldspathic porcelain*

Figure 5b: *Layered lithium disilicate restoration UL4 following cementation. Note the enhanced aesthetics mimicking the patient's natural dentition surface features*



Glass ceramics matrix

Glass ceramics are reinforced by fillers which are polycrystals or crystalline structures. This strengthening can extend all the way through the material to give a monolithic restoration (Figure 4). Alternatively, it can be a strengthened core veneered with an aesthetic but weaker ceramic (e.g. feldspathic porcelain), commonly called a 'layered' ceramic restoration (Figure 5). Examples of polycrystals used to strengthen glass matrix ceramics include leucite, lithium disilicate and alumina.

High concentration leucite

These restorations contain an increased concentration of leucite (40-55% by mass) compared to feldspathic porcelain (<5% leucite by mass). Leucite ceramics have a flexural strength of 160MPa[4] and therefore are not strong materials. They do, however, remain a popular restoration by dentists for use as resin-bonded veneers. The leucite polycrystals and the surrounding glass matrix have a similar refractive index, giving this restoration excellent aesthetics.[14] An example of a high concentration leucite restoration is Ivoclar Porcelain System (IPS) Empress (Ivoclar Vivadent, Liechtenstein).

Lithium disilicate

IPS Empress II (Ivoclar Vivadent, Liechtenstein) was the first dental ceramic to incorporate lithium disilicate (70% volume) as a polycrystal to strengthen the glass matrix. This produced a restoration with three times greater flexural strength than the high concentration leucite ceramic Empress (Ivoclar Vivadent, Liechtenstein).

IPS e.max® ceramic (Ivoclar Vivadent, Liechtenstein) replaced Empress II in 2006.[15] IPS e.max® is a lithium disilicate based dental ceramic which can be formed by either machining with CAD/CAM, or by pressing the ceramic ingot (Figure 6). IPS e.max® can be used for both anterior and posterior single tooth restorations.

In common with feldspathic porcelain and high concentration leucite ceramic, the glassy matrix can be etched with hydrofluoric acid. Restorations are then silanized using Monobond Plus (Ivoclar Vivadent, Liechtenstein) for 60 seconds, followed by the application of an adhesive resin cement to allow bonding to enamel. The resin bond may enhance the strength of the restoration[16], and provided the restoration is finished in enamel, the need for conventional retention and resistance form may be reduced. This allows for a more minimally invasive and conservative tooth preparation for veneers and onlay restorations.

The manufacturers indicate that this type of ceramic is strong enough for three-unit bridges using the second premolars as the distal abutment. A systematic review however showed that lithium disilicate bridgework has five and ten-year survival rates of 78.1% and 70.9% respectively.[17]

Alumina

Alumina can be used to strengthen a glass ceramics matrix through infusing lanthanum glass into a porous core made of partly sintered polycrystals consisting of alumina.[11] This produces a core material which then requires a sintered veneer for aesthetics. A popular brand of glass-infiltrated alumina is In-Ceram Alumina (VITA Zahnfabrik, Bad Säckingen, Germany). In-Ceram Alumina cores (VITA Zahnfabrik, Bad Säckingen, Germany) are popular with some dentists when a high strength core is required. Alternatively, some dentists prefer a densely sintered zirconia polycrystalline ceramic core in these circumstances.

Polycrystalline dental ceramics

Polycrystalline dental ceramics do not have any glassy components. They are generally much tougher and stronger than glass ceramics. Well-fitting polycrystalline ceramic restorations were not achievable prior to the availability of computer-aided manufacturing.[14] Zirconia and alumina are the principal

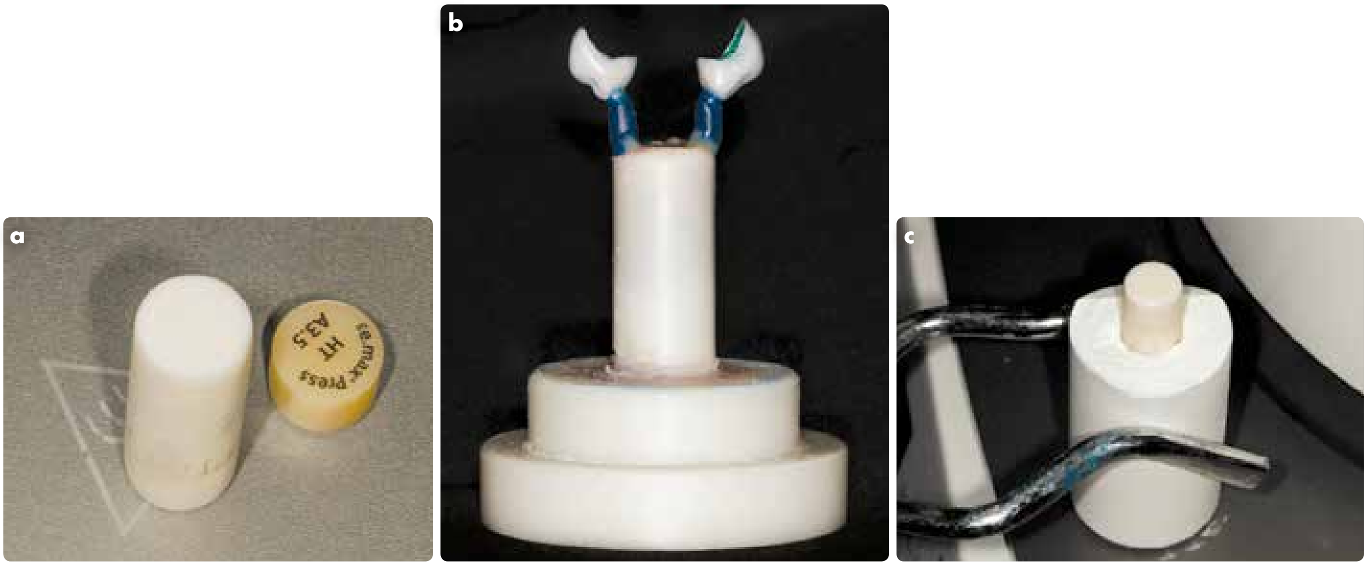


Figure 6a: *IPS e.max® (Ivoclar Vivadent, Liechtenstein) Ingot*

Figure 6b: *Waxed up IPS e.max® (Ivoclar Vivadent, Liechtenstein) crowns ready for pressing*

Figure 6c: *IPS e.max® (Ivoclar Vivadent, Liechtenstein) crowns invested and ready to be pressed*

compounds used to create polycrystalline dental ceramics. Procera® (Nobel Biocare, Sweden) is one such example. First described in 1993, it is described as 'a densely-sintered, high purity alumina coping with porcelain'.[18] Alumina based polycrystalline ceramics are now used much less given the increased popularity of the stronger zirconia-based restorations.

Early monolithic zirconia materials had flexural strengths as high as 1400 MPa but lacked the translucency essential for excellent aesthetic outcomes.[19] Their use was primarily limited to posterior teeth. Layered zirconia restorations (Figure 7) on the other hand have enhanced aesthetics but a high rate of chipping of the veneering ceramic.[20,21] New generations of zirconia with the addition of more yttria (yttrium oxide) and cubic phase zirconia have modest improvements in translucency, but are less than half the flexural strength of the original yttria-stabilised tetragonal zirconia polycrystal ceramic.[22] The flexural strength of commonly used all-ceramic restorations can be seen in Table 1.

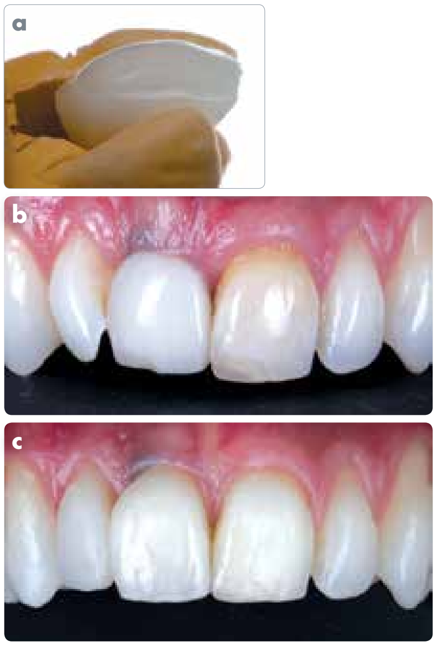


Figure 7a: *Layered zirconia crown restoration with buccal feldspathic porcelain for an implant retained prosthesis*

Figure 7b: *Pre-operative UR1*

Figure 7c: *Post-operative UR1, layered zirconia crown restoration with buccal feldspathic porcelain in situ*

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TABLE 1
THE FLEXURAL STRENGTH OF COMMONLY USED ALL CERAMIC CROWNS[4]

Type of all ceramic restoration	Flexural Strength (MPa)
Feldspathic porcelain	90
IPS Empress	140
IPS e.max®	400
High-Yttria Zirconia	600
Low-Yttria Zirconia	1400

Wear of opposing enamel or restorative material was a concern with feldspathic porcelain jacket crowns. Studies have demonstrated polished zirconia is kinder to the opposing tooth enamel.[23,24] It is therefore advised that the laboratory polish zirconia crowns prior to glazing. The advantage of this approach is that when the glaze eventually wears away during function, a polished surface remains.[25,26] The authors would advise the clinician to indicate this on the laboratory prescription to the dental technician.

It has been reported that zirconia crowns fail commonly due to loss of retention.[27] This may be due to an un-retentive tooth preparation, or a misplaced faith in a resin adhesive bond to zirconia. Numerous protocols have been described to bond to zirconia. These all involve a combination of light air-particle abrasion (15 seconds using 50 micron alumina particles at 0.25 MPa), 10-Methacryloyloxydecyl dihydrogen phosphate (10 MDP) containing primer and resin cement.[28,29,30] Studies related to the effectiveness of these protocols have used shear bond testing which is limited in its ability to predict clinical performance.[31] Bonding to zirconia restorations is not currently predictable, therefore these restorations should be prescribed with a traditional tooth preparation to maximise resistance and retention form.

Survival rates

Five year survival rates for different types of ceramic restorations are shown in Table 2.[27]

The main reported complication associated with all-ceramic crowns is framework fracture. This is most common in feldspathic/silica-based ceramics.[27]

A systematic review on lithium disilicate restorations has reported the survival rate of lithium disilicate single crowns as favourable, with survival rates of 97.8% at five years.[17] The survival rate of fixed bridge prostheses on the other hand was low at 78.1%.[17] Five of the 12 studies included in this review received support from the manufacturer of lithium disilicate (Ivoclar Vivadent, Liechtenstein) and four of the 12 studies did not specify their study design. The data was also heterogenous. Given these limitations, the usefulness of the results that can be drawn from this review are limited, and high-quality studies are needed to provide more robust evidence on lithium disilicate restoration survival.

A retrospective study of 21,337 indirect restorations in situ for up to 45 months showed a failure rate of 0.91% for monolithic lithium disilicate single crowns, and almost double at 1.83% for layered lithium disilicate crowns.[32] Failure rate of bonded ceramic onlays was low at 1.01%, indicating that these restorations have good survival rates whilst maintaining greater tooth structure than a conventional crown restoration.[32]

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TABLE 2

FIVE-YEAR SURVIVAL RATES FOR DIFFERENT TYPES OF CERAMIC RESTORATIONS

Type of all ceramic restoration	Number of studies included in meta-analysis	Estimated five-year survival
Feldspathic or silica-based ceramics	10	90.7%
Leucite/Lithium disilicate reinforced glass ceramics	10	96.6%
Glass-infiltrated alumina	15	94.6%
Densely sintered alumina	8	96.0%
Densely sintered zirconia	8	93.8%

Failure rate of lithium disilicate bridgework was approximately five times greater at 4.55%, echoing the systematic review results.[17]

Two retrospective studies on survival of monolithic and layered zirconia restorations reported a failure rate of 0.71% at five years for monolithic zirconia crowns, and 3.25% for layered zirconia crowns.[33,34] Monolithic zirconia bridgework had a failure rate of 2.62% at five years.[34]

Although zirconia and lithium disilicate are the most commonly used contemporary ceramic materials,[32,33,34] there is a lack of high-quality evidence on the survival of these restorations. Further high-quality evidence is needed on the long-term success and survival of these restorations to provide robust guidelines on clinical indications. When selecting what type of restorative material is to be used to restore a tooth, a balance must be made between the need to achieve a successful aesthetic result and providing a long-term functional restoration. Ultimately, it is the clinician's responsibility to provide patients with the appropriate information so that they can make an informed decision.

Conclusion

Advances in material science and production methods means that increasingly aesthetic and functional ceramic restorations are used in dental practice. However, further clinical studies are required to inform us of modes of failure of these restorations and of the clinical indications each type of restoration may be used in.

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