The Effects of Clinical Procedures on Strength of Dental Zirconia: A Literature Review

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Abstract

Dental zirconia has been commonly used for all ceramic restorations as it has excellent mechanical properties and adequate optical properties. Dental zirconia has crystalline structure and transformation toughening mechanism which makes it one of the strongest dental ceramics available. Despite its high strength, fracture of restoration still occurs when dental zirconia is used. Multiple factors can influence zirconia's mechanical properties.

This present narrative review is focused on the procedures that may have influence on zirconia's mechanical properties. The clinical procedures include chairside grinding, surface treatment and the use of dental adhesive. All these factors may influence microstructural changes and phase transformation which, eventually, affect strength of zirconia.

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Introduction

All ceramic restoration has become part of routine dental treatments. To acquire good long-term outcomes, good clinical manipulation and laboratory procedure is mandatory for all ceramic restorations. One of the dental ceramics that has become widely used is dental zirconia. This is due to its good mechanical properties and acceptable optical properties. The strength of zirconia is owing to its polycrystalline structure and phase transformation properties. This phase transformation capability leads to transformation toughening mechanism which can inhibit crack propagation, therefore, increases its flexural strength compared to other polycrystalline ceramics. However, many factors may influence the strength of zirconia such as manufacturing, laboratory and clinical process.[1-3] Clinical procedures such as chairside adjustment, mechanical surface treatment, and dental adhesives utilization can also impact strength of zirconia.[4-6] These procedures induce a change in zirconia surface and will result in phase transformation and microstructural changes, therefore, affect mechanical properties of zirconia. Since clinical procedures are inevitable when zirconia is used in dental treatment, it is very important for practitioner to understand what procedures can have detrimental effect on zirconia and how to avoid those effects for good long-term outcome.

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Literature review

Transformation toughening and factors affecting strength of zirconia

Zirconia has three different phases, depending on the temperature. Monoclinic phase is the phase that is stable at room temperature. When temperature exceeds 1770^{O}C and 2370^{O}C, it will transform to tetragonal and cubic phase respectively. To manufacture zirconia, high temperature has to be used which changes monoclinic into tetragonal or cubic phase. However, the change from tetragonal back to monoclinic phase when temperature is reduced results in 3-4% volume change[7] and causes internal crack in the material. Thus, manufacturers tried to improve the mechanical properties by doping yttria into zirconia molecules. Adding yttria results in the stability of tetragonal phase called "metastable tetragonal phase" which has the ability to transform to monoclinic phase when stress is generated. Thus, it can inhibit crack propagation by increase of volume and close crack line along grain boundaries. This mechanism is known as "transformation toughening" (Figure 1).

Since phase transformation is a major

factor affecting strength of zirconia. Phase transformation occurs when zirconia encounters stress and thermal changes. Stress is generated when damage from mechanical surface treatments including burs, sandblast, and laser is introduced. Heat is generated from dental burs and sintering cycles may enhance phase transformation or reverse phase transformation. Moreover, grain size has been reported to affect phase transformation.[8] For example, when grain size is larger than 1 µm, tetragonal phase is susceptible to transform to monoclinic phase.[9] The reason is larger grains usually contain defect within grain resulted in lower nucleation barrier. In other words, the intrinsic phase stability of metastable tetragonal phase decreases when the grain size becomes larger.[10] Thus, the small grain size is less susceptible for phase transformation. However, if the grain size is too small, less than 0.2 µm, it results in lack of phase transformation. Thus, decrease fracture toughness.[11] Nevertheless, small grain size exhibits more translucency, better mechanical properties, and delayed the effect from low temperature degradation.[10, 12] Low temperature degradation is a spontaneous phase transformation slowly affected by the presence of moisture. The oxide ion in water molecules possibly fill up the oxygen vacancies present in yttria stabilized zirconia. Thus, water diffused into zirconia lattice and stress is generated, therefore, phase transformation occurs.[13] Nevertheless, the increase in volume resulted in surface uplifts, grain detachment, and microcracks. Promoting the diffusion of water into the deeper part of zirconia. Thus, increase the depth of transformation and depth of surface flaws. This process can continue and results in material fractures.[14] Phase transformation depends on the amount of yttria contents.[4] The studies showed that when stress is generated, the tetragonal phase of 3Y-TZP and 4Y-TZP transforms to monoclinic phase while 5Y-TZP is unable to transform due to its high amount of yttria. Thus, 5Y-TZP showed lower flexural strength under any test conditions. These may be due to the over-stabilized of tetragonal phase and the presence of cubic phase from the large amount of yttria. Thus, phase transformation rarely occurs.[3, 4]

When transformation toughening occurs, the flexural strength of zirconia is higher due to the formation of compressive stress layer. However, when the monoclinic phase was present more than 50% on zirconia, it had a negative effect on the flexural strength.[15]

Nevertheless, microstructural changes affect strength of zirconia. Since the grain growth, grain detached, porosities between grain boundaries or within grain, and flaws resulted in lower flexural strength. Clinical procedures can induce those changes and they are unavoidable in dental practice. These clinical procedures include chairside adjustment, surface treatment, and the use of dental adhesive.

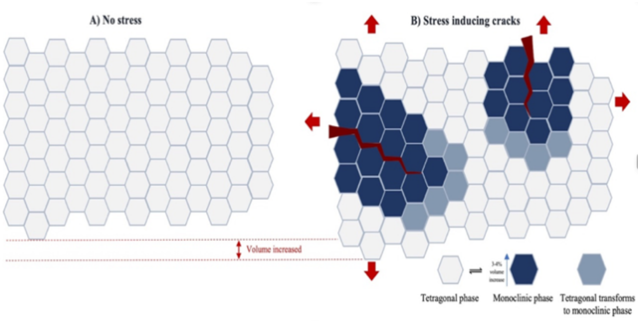

Figure 1. A) No stress concentration in zirconia surface. B) Stress inducing cracks and transformation layer.

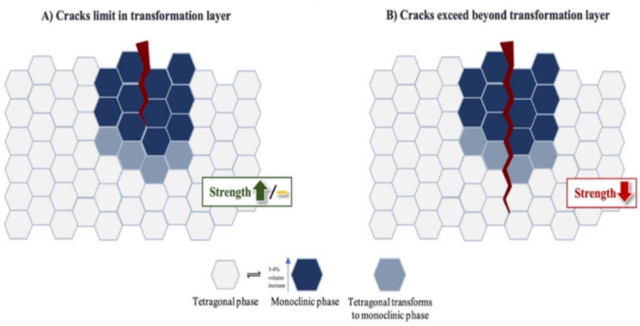

Figure 2. Stress can cause two countering effects on flexural strength of zirconia. A) If surface defects are within transformation layer, it results in no effect or increase flexural strength. B) If surface defects are deeper than transformation layer, flexural strength will be decrease.

Grinding

Before restorations can be cemented and function, internal fit and occlusion of restoration need to be adjusted by grinding. Grinding with diamond bur reported two countering effects on flexural strength. Some studies reported higher flexural strength after grinding because dental burs can create flaws on zirconia surface which induces phase transformation on the area.

However, if surface flaws exceed beyond transformed layer, it cannot inhibit crack propagation, thus, decrease flexural strength (Figure 2).[4, 5] In addition, the rough adjustment from diamond bur resulted in greater surface loss and deeper flaws.[16] One study reported adjusting zirconia with 25 µm particle size diamond bur resulted in higher flexural strength of zirconia compared to larger particle size. The coarser the particles size are, the lower flexural strength is.[17] Another study reported adjusting zirconia using 25, 160, and 200 µm particle size of diamond bur had higher flexural strength than no adjustment, but no significant differences were found among different particle size. However, SEM and XRD analysis found that the use of 25 µm had smoother surface and lower monoclinic phase than groups of 160 and 200 µm.[18] Therefore, it is recommended to use fine grit diamond bur for adjusting zirconia. Though some studies reported higher flexural strength from grinding with diamond bur, it resulted in more surface roughness which easily affected by low temperature degradation. Thus, decreasing flexural strength for long term period used.[19, 20]

Polishing after grinding resulted in removal of surface defects and compressive stress layer produced by grinding. Finishing and polishing affect flexural strength differently, since there are effects of particles size, load application, application time, operator factors, and the speed of bur rotation.[4,21] Some studies reported finishing and polishing causes flexural strength to decrease due to the presence of surface defects.[4] Though these studies found no significant differences on flexural strength between the effect of grinding and grinding followed by polishing. XRD analysis showed less phase transformation in polishing group associated with SEM result that showed smoother surface in polishing group.[4,16] On the other hand, some studies reported no effect on flexural strength due to the surface defects are limited in superficial layer after adjustment and polishing.[16,20] However, some studies reported higher flexural strength.[5,22] One study reported grinding and polishing resulted in higher flexural strength than grinding only. This is because grinding solely created larger surface flaws compared to grinding and polishing.[5] One study reported higher flexural strength when polishing by the diamond impregnated polyurethane rubber polishers alone.[(16)] The study reported that slight warming from rubber polishers alone induces tetragonal to monoclinic phase transformation. Moreover, polishing resulted in lower surface roughness than grinding and glazing and promoted more uniform surface of zirconia.[16] Furthermore, it is recommended to use the polishing system consist of diamonds which is appropriate for zirconia restoration due to its high surface hardness.[23, 24]

Rough surface and heat generation during grinding and polishing create stress on zirconia surface.[16] The low-speed handpieces produced more heat than high-speed handpieces.[21] However, when using with water-coolants, they reported no difference in heat generation from both low-speed and high-speed handpieces.[25] In addition, wet adjustment found no spark which indicated that temperature was low enough to prevent reverse phase transformation.[19] Reverse phase transformation is when the monoclinic transforms back to tetragonal phase, therefore, the increased volume is then decreased. This reverse phase transformation results in crack propagation. Another method to avoid heat is intermittent adjustment. One study found the prolong adjustment showed negative effect on zirconia's flexural strength.[21]

In the past the recommendation for zirconia was to glaze its surface after adjustment. However, glazing was reported to have two countering effects on flexural strength of zirconia.[16, 22, 26] One study reported higher flexural strength of zirconia because glazing has the effect of sealing surface flaws.[26] In facts, glazing cannot completely seal the surface flaws generated from dental burs. Supported by SEM and profilometer, glazed surface showed higher surface roughness than polished surface. Moreover, firing after glazing reported revere phase transformation from monoclinic to tetragonal phase. Thus, decrease the flexural strength.[16]

Surface treatment

Surface treatment is a step to improve bond strength between restoration and tooth substrate which are divided into two methods: mechanical and chemical treatments.[27] However, mechanical treatments seem to have more effect on the zirconia structure which affect strength of zirconia. The mechanical treatments include air abrasion, tribochemical silica coating, grinding with diamond burs, and laser.

Air abrasion was reported to have two countering effects on strength of zirconia since there are multiple factors from abrasion protocols which are particles size, pressure, and durations. Similar to grinding, air abrasion resulted in surface flaws and induced tetragonal to monoclinic phase transformation.[28] Most studies reported that air abrasion had higher flexural strength when the alumina particles size was between 25-150 µm under the pressure of 2-6 bar.[5, 28-32] The increased pressure reported more tetragonal to monoclinic phase transformation. Duration between 15 seconds to 2.5 minutes reported no effect on flexural strength.[28] On the other hand, sandblasted with coarse particles (250 µm) reported lower flexural strength.[5, 29] The use of fine particles created surface flaws sizes smaller than transformation depth which means transformation toughening can inhibit crack propagation. However, the use of coarse particles had surface flaws sizes bigger than transformation depth which means large particles size exhibited more aggressive abrasion. Thus, transformation toughening cannot inhibit crack propagation. Moreover, air abraded surface showed deeper transformation layer compared to grinding. Thus, air abraded zirconia exhibited higher flexural strength than ground ones.

Tribochemical silica coating can be accomplished in two methods: Cojet and Rocatec plus. Cojet can be done in clinical setting, while Rocatec plus is indicated for dental laboratory. Using Cojet which incorporated 30 µm particles reported higher flexural strength since it induced tetragonal to monoclinic phase transformation.[33] In other studies found no effect on flexural strength due to small, soft, and rounded shaped particle so it cannot lead to phase transformation.[29,32] While Rocatec plus with 120 µm alumina particles followed by 110 µm silica modified alumina particles reported higher flexural strength since it induced tetragonal to monoclinic phase transformation.[29,32]

Laser is used to create roughness on zirconia surface. It is reported to affect flexural strength differently since there are many types of lasers, intensity, wavelength, ablation rate, and pulse width.

Erbium lasers consist of Er:YAG and Er,Cr:YSGG. Both types of lasers have similar wavelength. Er:YAG laser irradiation with 0.75 W with 50, 100, 300, or 600 µs pulse width reported lower flexural strength due to excessive surface loss. Moreover, higher surface roughness and non-uniform surface were found. No phase transformation was found in XRD analysis.[33] Er,Cr:YSGG laser irradiation with 1.5 W with 74 µs found no effect on flexural strength. In accordance with SEM analysis that showed moderate roughness with the absence of microcracks nor discoloration, and XRD analysis reported no monoclinic phase transformation. The study concluded that the higher the power causes more surface damage.[(31)] One study also reported similar effect of Er,Cr:YSGG laser irradiation. This study used laser intensities between 2 to 6 W and no effect on flexural strength under 4 W, however, the power exceeded 5 W resulted in lower flexural strength. The higher flexural strength was speculated to be from transformation toughening. However, the higher intensity results in heat generation, therefore, reverse phase transformation can occur and surface damages are shown. However, SEM analysis showed microcracks and surface flaws in all intensities.[34] In conclusion, it is not recommended to use Er,Cr:YSGG laser with high power.

Another type of laser used is ultra-short pulsed laser, which is $Nd:YVO_4$ laser with 12 picosecond pulse width. This ultra-short pulsed laser (USPL) also known as picosecond laser. They reported that USPL randomly emitted in four different paths reported no effect on flexural strength and surface roughness. In addition, XRD analysis reported less monoclinic phase and higher Weibull moduli than non-laser zirconia. It may conclude that laser removes both defects and compressive stress layer from manufacturing process results in no effect on flexural strength.[35]

Adhesives

Dental cements can be easily grouped into two main types. First is conventional type, such as glass ionomer cement, zinc phosphate cement. Second is adhesive type commonly known as resin cement. Many studies reported improved strength of glass ceramic when resin cement is used with dental adhesive, however, the effect of using adhesive on zirconia ceramic is still controversial.

For zirconia restorations, most studies showed no influence of using different cements on the strength of zirconia.[36-38] Studies showed different cements had no effect on zirconia strength due to high strength of zirconia. However, one study showed contradicting result.

The study found that zirconia restoration cemented with zinc phosphate cement led to lower fracture resistance than resin cement (Panavia F). Finite element showed that the resin cement led to more uniform stress distribution.[6] However, this study has different design of specimen from other studies. The specimens were prepared as substructure which limited their thickness to 0.5 mm, unlike other studies that the specimens were fabricated as crowns resulted in more thickness. Nevertheless, there are limitations in those studies which cannot mimic clinical situations due to the abutment substates were not human teeth, but they were prepared from cobalt-chromium alloy[37], hybrid polymer resin-based[36], and glass fiber-filled epoxy resin[6]. The reasons used were to reduce the confounding factors from the tooth variations and the two latter materials have similar flexural strength and elastic modulus to tooth dentin.

Conclusions

Grinding with fine diamond bur (25 μm), followed by polishing with polishing system specified for zirconia restoration is recommended. Water-coolants and periodic adjustment are recommended to reduce heat on zirconia surface.

Recommended mechanical surface treatments are sandblasted with fine grit (50 μm) and tribochemical silica coating with fine grit. (30 μm)

Both type of cements, conventional and adhesive cements, can be used for zirconia except when the restoration thickness is less than 0.5 mm, the adhesive type is recommended for this situation.

Declaration of Interest

The authors report no conflict of interest.

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