Diametral Tensile and Compressive Strengths of Several Types of Core Materials

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Abstract

Purpose: Compressive and diametral tensile strengths (DTSs) of core materials are thought to be important, because cores usually replace a large bulk of tooth structure and should provide sufficient strength to resist intraoral tensile and compressive forces. This study was undertaken to compare the mechanical properties of materials used for direct core foundations.
Material and Methods: The differences between the compressive and DTSs of six core materials, including Duralloy (high-copper amalgam), Grandio (visible light-cured nanohybrid resin composite), Admira (organically modified ceramic), Filtek P60 (packable composite resin), Rebilda DC (dual-cure adhesive core material), and Argion Molar (silver-reinforced glass ionomer cement), were tested. A total of 120 specimens, half for the compressive strength (CS) test (6 mm in height, 4 mm in diameter) and the other half for the DTS test (6 mm in diameter, 3 mm in thickness), were prepared. The specimens were stored at room temperature in distilled water for 7 days. The Lloyd testing machine was used to load the specimens at a crosshead speed 0.5 cm/min, and the strength values were determined in MPa.
Results: The compressive and DTS test values (in MPa), respectively, of the materials were: Admira (361, 44); Filtek P60 (331, 55); Grandio (294, 53); Rebilda DC (279, 42); Duralloy (184, 40); and Argion Molar (107, 9). Kruskal–Wallis test was computed, and multiple comparisons test discerned many differences among materials ($p < 0.05$).
Conclusion: Packable composite resin (Filtek P60), visible light cured nanohybrid resin composite (Grandio), and organically-modified ceramic (Admira) had higher compressive and DTS values than the other materials.

A core foundation is a restoration in a badly broken-down tooth to restore the bulk of the coronal portion in such a way as to facilitate the subsequent restoration by means of an indirect extracoronal restoration.[1–8] A core restoration should provide satisfactory strength and resistance to crown preparation and impression procedures and therefore initially contribute to the retention and support of a temporary crown, and in the long-term, the definitive extracoronal restoration.[2] It should provide sufficient tensile and compressive strength (CS) in order to resist multidirectional masticatory forces for many years.[3,4] Several dental materials were not specifically developed for this purpose, but as a consequence of their properties, have found application in core foundation procedures.[1] Newer materials have many different useful attributes, such as fluoride release, pleasing colors, adhesion to tooth structure, fast setting rate, choice of curing mechanism, and handling properties.[4,5,9–12]

The mechanical properties of amalgam, when used as a core material, are satisfactory; however, its relatively high coefficient of thermal expansion, the need for matrix bands during condensation, the unesthetic dark color, and the inability to complete a crown preparation in the same session may restrict its use.[3,5] The CS value recommended by the British Standard Specification for dental amalgam is a minimum of 50 MPa.[13]

Improvements in composites and development of enamel–dentin bonding systems have stimulated trends toward more conservative techniques.[6,14] Although resinous materials may be less stable physically and dimensionally than amalgam, apart from esthetics, resin composite cores have a number of advantages. Due to the immediate hardening, teeth can be prepared for a crown restoration at the same appointment. Resin composites can also bond to dowel and crowns when appropriate bonding techniques are used;[4,7] however, their disadvantages include their higher coefficient of thermal expansion relative to that of enamel and the possible contamination by eugenol-containing provisional cements.[3] A large of amount of research is being devoted to the development of nanocomposites with the objective of achieving a composite dental material that could be used in all areas of the mouth with excellent mechanical properties suitable for high stress-bearing areas.[15] In contrast to composites, glass ionomer and glass cement core materials exhibit such advantageous properties as a coefficient of thermal expansion similar to natural tooth structure; a physicochemical bond to enamel, dentin, and cementum; biocompatibility; and release of fluoride.[1,8,16–18] Strength is only one criterion for selection of a core material, but it is crucial. Stronger core materials better resist deformation and fracture and provide more equitable stress distributions, reduced probability of tensile or compressive failure, greater stability, and greater probability of clinical success. In view of the above, it is suggested that the clinician may have uncertainty as to which material to select as a core material to achieve the desired results. If the other parameters, such as fast setting rate, adhesion to tooth structure, color, and shrinkage properties, are considered to be equal, the strongest core material is recommended. In the present study, the objective was to determine the CS and diametral tensile strength (DTS) of different types of core foundation materials, as representing one aspect in the selection of materials for clinical application.

Material and methods

Six core materials (Table 1) were evaluated with two mechanical tests: CS and DTS. CS is compressive stress within a compression test specimen at the point of fracture. DTS is the tensile strength of brittle materials generally determined by subjecting a rod, wire, or dumbbell-shaped specimen to tensile loading.[19] Sixty specimens for CS test, ten of each brand, 6 mm in height and 4 mm in width, as determined by American Dental Association (ADA) specification No. 27[20] for direct filling resins, were made using custom-made Plexiglas molds.

Argion Molar was manipulated according to manufacturer's instructions for weighing powder and liquid (4.6 powder/1 liquid). The material was mixed with a plastic instrument on a glass plate, which was refrigerated and dried. After the mixed cement had a solid condensable consistency, the mixture was condensed directly into the molds. The capsulated material (Grandio) was mixed using a proprietary capsules mixer (Capmix, 3M ESPE, Seefeld, Germany). After mixing, Grandio was injected by a syringe into the molds. Admira, Rebilda DC, and Filtek P60 were packed into the mold using proprietary syringes.

Molds that were previously coated with a nonreactant lubricant (solid Vaseline) were filled and then closed between glass plates firmly clamped against the molds, to eliminate entrapped air bubbles. The light-cured materials were cured using a light-curing unit (Translux CL, Heraus Kulzer, Mainz, Germany). Photopolymerization was initiated by illuminating two surfaces of the specimens for 40 seconds. The tip of the light source was held within 3 to 4 mm of the surface to cure the material to a depth of 2 to 2.5 mm. The specimens were then ejected from the mold and inspected for voids, and the ones with voids or other defects were discarded. As their height was greater than 3 mm, the specimens were taken out of the molds and illuminated for 40 additional seconds to ensure a good polymerization depth. The encapsulated Duralloy was admixed in an amalgam triturator (Capmix). After trituration the capsules were removed from the clip, and then mixed amalgam was condensed promptly into the mold. The increments of alloy were carried to and inserted in the cavity by means of an amalgam carrier and were condensed with sufficient pressure to remove voids and to adapt to the walls of the cavity in the molds. The condenser point was forced into the amalgam mass under hand pressure. The procedure of adding an increment, condensing it, adding another increment, and so forth was continued until the molds were overfilled. Relatively small increments of amalgam were used throughout the condensation procedure to reduce void formation and obtain maximum adaptation to the mold cavity. The Duralloy specimens were then removed from the molds 24 hours after condensing. Afterwards, cylinder ends were flattened at right angles to the long axes using wet 240 grit silicone carbide paper. The DTS specimens were measured twice for their diameter and once for their thickness, and CS specimens were measured twice for their diameter.

The specimens were stored in distilled water (pH 7). The water was changed daily, and the specimens were stored together in lightproof containers at room temperature ($23 \pm 10^{\circ}$C) for 7 days.

The CS test was conducted on a mechanical testing machine (Lloyd Instruments, Segenswath West, Fareham, UK) with 50 N load cell at a crosshead speed of 0.5 cm/min. The results were recorded in megapascals (MPa).

DTS was determined in a manner similar to the compressive test. For this procedure, 60 specimens (6 mm in diameter, 3-mm thick) were prepared according to ADA specification No. 27[20] and stored in the same manner as the CS specimens. The DTS test was conducted on a mechanical testing machine (Lloyd Instruments) at a crosshead speed of 0.5 cm/min. An apparatus made of hard steel platens was designed for the test. The horizontal fracturing section mounted at the end of a 1-cm diameter

Table 1 Materials used

Material	Classification	Manufacturer	Batch no.	Shade
Filtek P60	Packable composite resin	3M Dental Products, St Paul, MN	20030917	A3
Duralloy	High-copper admixed silver amalgam	Degussa, Cheshire, UK	010507101	–
Rebilda DC	Dual cure adhesive core material	Voco, Cuxhaven, Germany	401364	Dentine
Admira	Organically modified ceramic	Voco, Cuxhaven, Germany	331112	A3, 5
Grandio	Visible light cured nanohybrid resin composite	Voco, Cuxhaven, Germany	600697	A3, 5
Argion Molar	Silver-reinforced glass ionomer cement	Voco,Cuxhaven, Germany	371539	–

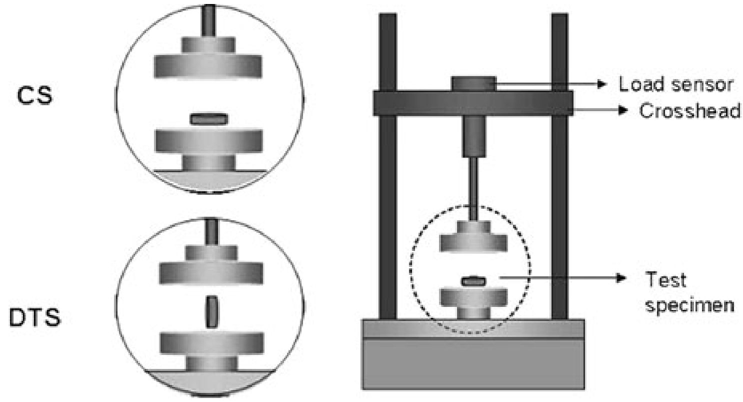

Figure 1 Testing machine.

vertical rod clenched between the upper jaws of the mechanical testing machine was 6 cm long, 1 cm thick, and 4 cm wide. In this method, a compressive load was placed on the curved surface of the cylindrical specimen (Fig 1). The compressive force recorded on the digital display at the moment of fracture was subsequently used to calculate the DTS. Thin pads of soft, wet blotting paper were placed on the steel platens to ensure that diametral forces were applied to the specimens without undue stress concentration. Then, the DTS was computed according to the following formula:[21,22]

$$\text{Diametral tensile strength } = \frac{2P}{\pi \, dt}$$

where P = load, d = diameter, and t = thickness.

Kruskal–Wallis test was conducted on the data for each material. Multiple Comparison post-hoc analysis was used to evaluate the difference among materials with a significance level of $p < 0.05$.

Results

The results of the CS and DTS tests are presented in Table 2. According to the results of Kruskal–Wallis test for CS ($H = 26.93$, $p = 0.000$) and DTS ($H = 21.09$, $p = 0.001$) among the six products tested, intergroup differences among the materials were statistically significant.

Multiple Comparison post-hoc analysis revealed that the CS values for the materials were found to be statistically significant ($p < 0.05$). The CS values for Admira were found to be higher than those of the other materials tested (361 MPa). According to the CS values, the weakest material was Argion Molar (107 MPa) (Fig 2).

Filtek P60 possessed significantly higher DTS (55 MPa) than that for all other materials except Grandio (53 MPa). For DTS test, Argion Molar exhibited the lowest strength values (9 MPa) (Fig 3).

Table 2 Means and standard deviations of the results of compressive strength and diametral tensile strength test (MPa)

Materials	Compressive strength test, mean ± SD	Diameteral tensile test, mean ± SD
Filtek P60	331 ± 32	55 ± 7
Duralloy	184 ± 55	40 ± 9
Rebilda DC	279 ± 46	42 ± 4
Admira	361 ± 74	44 ± 8
Grandio	294 ± 27	53 ± 10
Argion Molar	107 ± 31	9 ± 3

Discussion

The selection of an appropriate core build-up material requires the evaluation of many factors. Commonly used amalgams,[23] composites,[24] and glass ionomer cements[25] all have advantages and disadvantages. This study assessed the CS and DTS of six materials that were considered as core foundation materials.

Considerable differences in CS and DTS were found among core materials. CS is considered to be the critical indicator of success, because a high CS is necessary to resist masticatory and parafunctional forces.[3,4,6]

It is therefore suggested that teeth restored with Admira were significantly stronger than the other core materials except Filtek P60 ($p < 0.05$). The CS of Filtek P60 was slightly stronger than that of Grandio, which is formulated to use as a core material. According to Mitra et al,[15] the DTS and CS test values of nanocomposites are superior to hybrid or microhybrid composites and significantly higher than those of the microfill materials. The CS value for amalgam was found to be lower than that of other materials tested except Argion Molar. Amalgam cores are certainly to be preferred over silver-reinforced glass ionomer cement (GIS) cores. This result is in accordance with the results of the study by Cho et al.[4] On the other hand, the results of the studies by Saygılı and Şahmalı[6] and Combe et al[1] show that in terms of CS, amalgam cores could be the most appropriate materials with values of 217 to 435 MPa and 221 to 486 MPa for 1-hour, 24-hour, 1-month, and 3-month results, which are inconsistent with the present study. The dark color of amalgam may not be esthetically pleasing, but it is easy to differentiate from tooth structure during preparation. Unfortunately, the relatively slow set of amalgam delays rotary preparation of amalgam cores, which therefore limits their use.

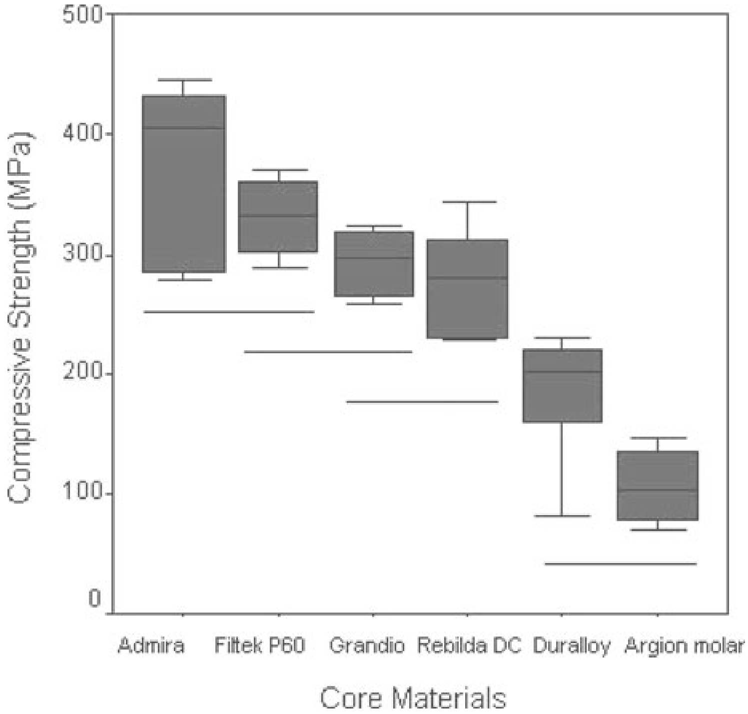

Figure 2 Box-plots of compressive strength test according to core materials. Lines on the boxes signify the mean and standard deviation. Horizontal lines below the boxes indicate nonsignificance among core materials ($p > 0.05$).

Glass ionomer-based materials were markedly weaker than the other materials in CS and DTS tests used in the study (Table 2), which is in accordance with the results of other studies on physical and mechanical properties of core build-up materials.[1,4,6] In a study by Levartovsky et al,[3] DTS, CS, and flexural strength values of silver-reinforced GIS, light-cured GIS, and dual-cure composite resin were compared, and the results were comparable with the present study in that DTS and CS values of dual-cure composite resin were higher than that of GIS core materials. Silver reinforcement did not improve the strength of

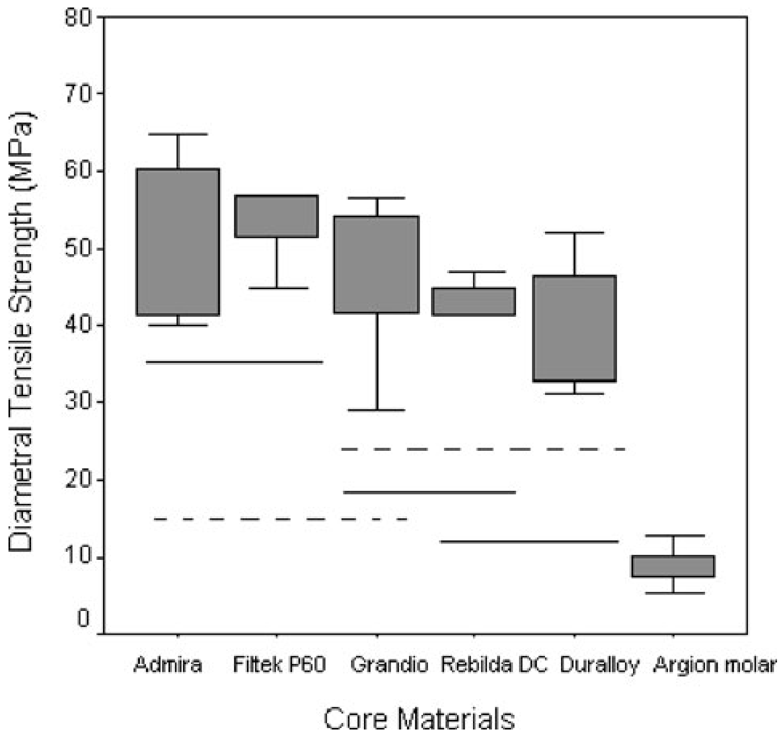

Figure 3 Box-plots of diametral tensile strength test according to core materials. Lines on the boxes signify the mean and standard deviation. Horizontal lines (solid and dashed) indicate nonsignificance among core materials ($p > 0.05$).

Argion Molar. Although some mechanical properties of glass ionomer materials only deteriorate slowly over time, the dimensional stability of these materials can be poor.[4,17,18] Thus, the role of glass ionomers and glass ionomer-based materials as cores must be questioned; however, composites have presented better scores than glass ionomer materials. Consequently, in terms of CS, Admira, which is an organically-modified ceramic, and Filtek P60, which is a packable composite resin having zirconia/silica filler particles in its chemical composition, could be considered the most appropriate materials for core foundations.

Packable composites are highly-filled composite resins, and the filler distribution gives them a different consistency compared to hybrid composites. They are mainly characterized by less stickiness or stiffer viscosity than conventional composites and are therefore claimed for stress-bearing posterior restoration as an alternative to amalgam, based on an application technique that somewhat resembles amalgam placement.[15] Cobb et al[11] stated that while packable composites had certain advantages over conventional composite resins in ease of handling, their physical properties, such as DTS and CS values, were not superior to those of the conventional hybrid composites tested. On the other hand, the results of the study on physical properties of packable resin composites by Kelsey et al[14] indicate that the condensable composite products showed higher DTS values than those of conventional hybrid resin composites. Instead of traditional monomer systems containing Bis-GMA, UDMA, and TEGDMA, multifunctional urethane and thioether (-meth) acrylate alkoxysilanes as sol-gel precursors have been developed as a synthesis of inorganic–organic copolymer organically-modified ceramic composites as dental restorative materials. After incorporation of filler particles, organically modified ceramic composite can be manipulated like hybrid composites. Organically modified ceramics are characterized by this novel inorganic–organic copolymer in the formulation, which allows the modification of mechanical parameters in a wide range.[10–12]

All six materials tested were found to have mean CS values (>100 MPa) greater than the minimum value (50 MPa) recommended for dental amalgam.

CS may not be a very useful parameter for describing brittle behavior, as it varies with specimen size, geometry, and lateral pressure.[16] Loads that stretch or elongate cause tensile stresses.[13] Tensile strength is lower than that CS and is considered to be more relevant. As it is not possible to measure the tensile strength of brittle materials directly, DTS was adopted by the British Standards Institution.[16] For dental materials undergoing brittle fracture, the DTS test is often carried out because of its relative simplicity and reproducibility of results.[1,3,14,18,22] It is an indirect tensile test in which a disk of the material is compressed diametrically until fracture occurs. The tensile stress is directly proportional to the load applied in compression. A limitation of the test is that if the specimen deforms significantly before failure, the data may not be valid.[14,16,18]

Filtek P60 and Grandio may be considered the most appropriate as core foundation materials. Strength is only one criterion for selection of a core material, but it is crucial. Stronger materials resist deformation and fracture better, provide equal stress distribution and reduced risk of tensile or compressive failure, and have greater stability and probability of clinical success. Other properties, such as shear bond strength to dentin, coefficient of thermal expansion, and fluoride release, should be considered in their selection as core foundation materials; however, these criteria were not the scope of our study. No current material is ideal. For clinical success, dentists must be aware of the properties of materials, choose materials accordingly, and manipulate them properly.

The results of this study indicate that on the basis of strength alone, resin composites may be used as alternatives to amalgam cores; however, other physical qualities should also be considered, and long-term clinical experiences must be studied for correlation with the in vitro laboratory results.

Conclusions

Within the limitations of this study it can be concluded that:

1. Admira had CS values significantly higher than the other materials tested in this study ($p < 0.05$).
2. Filtek P60 had DTS values stronger than the materials tested in this study.
3. The strength of Argion Molar was substantially lower than that of resin composites or Duralloy. Argion Molar exhibited the lowest strength values and cannot be considered particularly suitable materials for large core foundation procedures ($p < 0.05$).

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