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TRUENESS OF MILLED ZIRCONIA VERSUS MILLED HYBRID CERAMIC CROWNS DESIGNED FOR PRIMARY TEETH RESTORATION COMPARED TO THE DIGITALLY DESIGNED FILR: AN IN VITRO STUDY

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Introduction: Stainless Steel Crowns (SSC) are not easily replaced by Zirconia Prefabricated Crowns (ZPC) because of their adaptation problem and risk of fracture and loosening.

Objectives: To assess and compare the trueness of milled zirconia and milled hybrid ceramic crowns designed for primary teeth restoration to a digitally designed file.

Methods: The fourteen extracted primary molars were scanned using an intraoral scanner to obtain digital files of the teeth. The digital files were imported into the Design dental software (TDS) and used to design and mill zirconia and hybrid ceramic crowns using a 4-axis milling machine: 14 zirconia crowns and 14 hybrid ceramic crowns were milled. The milled crowns were fitted onto their corresponding primary molars and evaluated for trueness using Geomagic Control X Software (Control X®, Geomagic, Morrisville, NC, USA). The results were recorded in millimeters.

Results: No significant difference was observed in terms of trueness between the milled zirconia crowns and the milled hybrid ceramic crowns ($p>0.05$).

Conclusions: Computer Aided Design/Computer Aided Manufacture (CAD/CAM) technology and zirconia/ hybrid ceramic materials can be used effectively in the restoration of primary teeth. The use of the hybrid composite material in this technique provides a highly accurate, quick and esthetic solution for pediatric patients, which can improve their oral health and quality of life.

Keywords: CAD-CAM crown, Deciduous molars, Milled Hybrid ceramic crown, Milled zirconia crown, Trueness

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The authors declare no conflicts of interest.

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JUSTESSE DE LA ZIRCONE FRAISÉE COMPARÉE AUX COURONNES COMPOSITES HYBRIDES FRAISÉES CONÇUES POUR LA RESTAURATION DES DENTS PRIMAIRES PAR RAPPORT AU FILR CONÇU NUMÉRIQUEMENT : UNE ÉTUDE IN VITRO

Introduction: Les couronnes pédodontiques préformées (CPP) ne sont pas facilement remplacées par les couronnes préfabriquées en zircone (CPZ) en raison de problèmes d'adaptation et du risque de fracture et de descellement.

Objectifs: Évaluer et comparer la précision des couronnes personnalisées en zircone et des couronnes personnalisées en céramique hybride conçues pour la restauration des dents temporaires à un fichier conçu numériquement.

Méthodes: Quatorze molaires temporaires extraites ont été scannées à l'aide d'un scanner intra-oral pour obtenir des fichiers numériques de ces dents. Ces fichiers ont été importés dans le logiciel de conception dentaire (TDS) et utilisés pour concevoir et confectionner digitalement des couronnes en zircone et en céramique hybride à l'aide d'une fraiseuse à 4 axes : 14 couronnes en zircone et 14 couronnes en céramique hybride ont été confectionnées. Ces couronnes ont été évaluées pour leur précision à l›aide du logiciel Geomagic Control X (Control X®, Geomagic, Morrisville, NC, États-Unis). Les résultats ont été enregistrés en millimètres.

Résultats: Aucune différence significative n'a été observée en termes de précision entre les couronnes en zircone CAD-CAM et les couronnes en céramique hybride CAD-CAM ($p>0,05$).

Conclusions: La technologie CFAO ou CAD-CAM et les matériaux en zircone/ceéramique hybride peuvent être utilisés efficacement dans la restauration des dents temporaires. L'utilisation du matériau céramique hybride dans cette technique offre une solution précise, rapide et esthétique pour les patients pédiatriques, ce qui peut améliorer leur santé buccale et leur qualité de vie.

Mots-clés: CAD-CAM, Couronne CFAO, Molaires temporaires, Couronne en éramique hybride, Couronne en zircone, Précision

Introduction

Recently, there has been rapid development in the field of dentistry in the area of esthetic dentistry [1]. Researchers and clinicians have directed their interest towards aesthetic solutions in the restorative process to provide naturally colored, durable, and long-lasting restorations that society currently demands. This aesthetic direction seems to afford the child a sense of health, safety, and self-esteem as well. Crowns are the preferred final restoration for primary teeth as they outperform direct restorations and increase the success rate of endodontic treatments due to their better sealing abilities [2]. The use of stainless-steel crowns (SSCs) for primary molars in pediatric dentistry has been a common practice in the management of heavily decayed and deformed primary teeth [3], These SSCs provide a cost-effective solution for a restoration with the highest success rate without causing secondary caries [4]. The metallic color appearance of SSCs, the possible damage to gingival tissues, and the possibility of cytotoxic and allergenic phenomena due to the release of nickel and chromium ions into the saliva may promote biocompatibility issues [5].

Prefabricated zirconia crowns (PZCs) for primary teeth were introduced in 2010 as an alternative and more aesthetic option compared to SSCs [6]. Manufacturers offer a significant range of zirconia crown sizes, along with specific preparation and cementation protocol [7]. These ready-made commercially available zirconia crowns are offered for the treatment of anterior and posterior primary teeth. They are functional, feature high resistance and long durability, and can be used within a short working time. Ready-made zirconia crowns provide satisfaction to the child's parents as a restoration in the primary maxillary anterior dentition since they improve their children's appearance and oral health [8]. Even though PZCs provide acceptable tooth color, they cannot be modified in any way like SSCs, in addition to having a limited selection of shades and contours, while some of the marketed brands require over two millimeters of tooth reduction [6]. Moreover, PZCs require feather-edged subgingival preparation, thus, potentially extending the operatory time due to the gingival injuries that may occur [8].

Digital workflow in dentistry has evolved in recent years due to the headway made in technologies such as intraoral scanners and software programs. This evolution has impacted various specialties, including prosthodontics, orthodontics, oral surgery, and pediatric dentistry [9]. The materials used for the Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM) technique include lithium disilicate, zirconia, hybrid ceramics, and polymethyl methacrylate. The superior mechanical properties of these materials support the use of CAD-CAM as a trustworthy method for dental patients resulting in a high survival rate of the restorations with a low rate of restoration fracture and long-term clinical survivability [10].

Milled zirconia crown (MZC) could be another alternative for the restoration of deciduous teeth. It is an all-ceramic CAD-CAM fabricated crown milled directly from solid blocks of zirconia. It might present a better adaptation to the prepared tooth and might reduce the chairside working time. Its shape and size could be adjusted easily mainly in areas of crowding or space loss. It can be assumed that this new procedure may lead to an increase in mechanical strength. In addition, it was proved that the fracture strength of MZC is significantly higher compared to the PZC resulting in a better longevity since longevity of a crown material is strongly related to its mechanical properties [11]. This newly introduced perception was based on the concept of monolithic restorations which are manufactured by means of subtractive methods. Results of this study showed that milled zirconia crowns for primary dentition could overcome the problems encountered with preformed crowns specifically in terms of insertion and fracture resistance [11].

In recent years, hybrid ceramics have been used in prosthetic dentistry due to their high biocompatibility [12]. These materials, which feature the positive characteristics of both composites and ceramics, reduce abrasion from the opposite arch. The structure of hybrid ceramics is formed by an interpenetration of ceramic and composite polymer networks, called a hybrid double network, and it mimics the interlocking of prism bands in natural teeth. Hybrid ceramics exhibit a double-phase network structure that not only enhances their fracture resistance but also guarantees stable edges and excellent marginal fitting with oral tissues.

According to ISO 5725, "trueness" refers to the closeness of agreement between the arithmetic [13]. In terms of measurement, accuracy refers to the degree of agreement or closeness between the value of a measured quantity and the true value of the quantity being measured, also known as the measurand and when it comes to crowns, it is the combination of trueness and precision. Trueness, which refers to the degree of agreement between the arithmetic mean of numerous test results and the true or accepted reference value, is a critical factor in measurement accuracy. Trueness reflects the extent to which the average of multiple measurements approximates the actual value of the object, and a measurement is considered more accurate the closer it is to the true value. To evaluate trueness in the case of dental models, a reference is necessary, such as an acquisition made with a machine that has certified accuracy (possibly $\leq 5\mu$m), like a coordinate measuring machine (CMM), or an industrial optical or desktop scanner like Geomagic Control X software (Control X®, Geomagic, Morrisville, NC, USA) [13].

Several studies have addressed the trueness of MZC and MHCC (Milled Hybrid Ceramic Crown) [14] but to the best of our knowledge, no previous study has compared the trueness of MZC and MHCC in pediatric CAD-CAM crowns. The purpose of this *in vitro* study was to compare the trueness of MZC and MHCC designed for primary teeth restoration to a digitally designed file using Geomagic Control X software.

Materials and Methods

Sample size

A power analysis for paired Student's *t* test was conducted using G*Power software 3.1.9.7 for Windows (Heinrich Heine, Universitat Düsseldorf, Düsseldorf, Germany) to determine the sample size. A power of 0.95 and an alpha level of 0.05 were considered, and an effect size of 1.17 was calculated based on a previous study [15]. The minimum sample size required was 12 primary molars. An attrition rate of 15% was added resulting in a sample size of 14.

Sample collection and preparation

The study was approved by the Ethical Committee of the Saint Joseph University of Beirut in January 20th 2020 (USJ-2020-24). In the care center of the Saint Joseph University of Beirut, freshly first and second primary molars extracted for reasons independent from this study were collected (FMD205). Clinical extractions took place due to ectopic eruption of the permanent underlying tooth, acute infection that can no longer be treated by pulpotomy or tooth with negative prognosis. The inclusion criteria were primary molars with caries located on the proximo-occlusal surface, molars with caries affecting the dentin and not affecting the pulp, and molars that required pulpotomy-type pulp treatment with pedodontics crown indication. The exclusion criteria were molars with pathological or physiological resorption

Fourteen dry teeth were collected and preserved in thymol (0.1%) in an incubator for a period of 30 days and then fixed in scannable plaster work bases leaving the whole crown visible up to the cervical margin. After that, decay was eliminated completely by one experimented pediatric dentist (J.H) using a diamond bur pear mounted on a high-speed dental handpiece and a round steel bur mounted on a contra-angled handpiece. This was followed by the opening of the pulp cavity and the placement of IRM® filling (Reinforced Zinc Oxide Cement, Dentsply®) followed by restorative glass ionomer filling (GC Fuji II®, GC). Subsequently, molars were prepared using a diamond tapered chamfer bur (Diamond Bur KOMET #5856-014, HENRY SCHEIN®) by an experienced prosthodontist. Afterwards, each tooth received two types of milled crowns: Zirconia (AIDITE 3D PRO ML®, Shade A1, Size: 20*15*19) and hybrid ceramic (VITA ENAMIC®, Shade 1 M2-HT) materials.

Each tooth was scanned using an intraoral scanner (Trios 3, 3shape) and files were then sent by 3shape Communicate to a CAD software (Dental System, 3shape, Copenhagen). In addition, upper (U-STL) and lower arch (L-STL) scans of a 6-year-old child having intact primary molars were previously performed using an intraoral scanner (Trios 3, 3shape) and exported in Standard Tessellation Language (STL) format to help in designing the monolithic primary crowns. The software was used to design monolithic primary crowns using a conventional workflow. Instead of utilizing a pre-designed crown from the library, the anatomy of the primary molar was duplicated from the previously saved scanned arches (Figure 1). Then, for each molar, two types of crowns were milled: Zirconia and Hybrid Ceramic (Figure 2, 3). Each crown of each group was then seated on a silicone index and the internal surface was captured using an industrial optical scanner. The desktop Scanner used was 3Shape E3 (Figure 4).

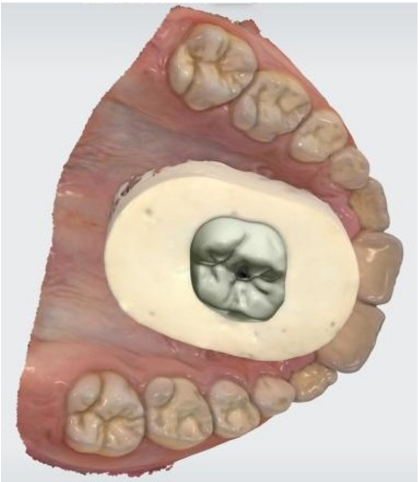

Figure 1. Tooth scanned and designed in the TDS software.

Figure 2. Tooth fixed in scannable plaster with the milled zirconia crown.

Figure 3. Tooth fixed in scannable plaster with the milled hybrid ceramic crown.

Outcome measurements

Using reverse engineering software (Control X®, Geomagic, Morrisville, NC, USA), the STL files (14 per group) generated from these

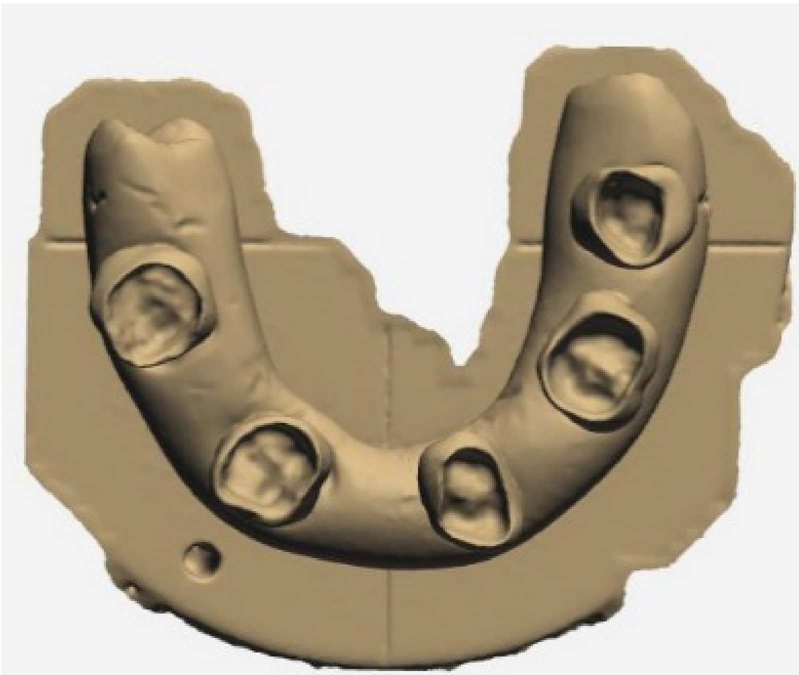

Figure 4. Teeth placed on the silicone index to be captured by 3Shape E3.

optical scans were then compared with the reference CAD modeling file ("reference crown") to assess trueness, resulting in Root Mean Square Deviation (RMSD) measured in millimeters and then converted into micrometers during data analysis. Three superimposition sequences were carried out. Prior to evaluating the overall accuracy of the crown intaglio surface, the CAD file of the modeled crown used as a reference was superimposed on each scan of the zirconia and hybrid composite crowns [2]. The reference CAD file was then sliced with specialized tools to isolate and select only the internal intaglio surface and surface margin. The scans of each individual group were then overlaid with these parts as references in order to evaluate the marginal and fitting trueness, respectively. The aforementioned program is where colorimetric maps were created and where all superimpositions were carried out (Figure 5).

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows (Version 26.0. Armonk, NY: IBM Corp.). Descriptive statistics of the main outcome variable among groups were presented as medians (interquartile ranges), means ± standard deviations, and minimum and maximum values. After evaluating the normality of distribution using the Shapiro-Wilk test, root mean square (RMS) values were compared between groups using the non-parametric Wilcoxon signed-rank test. The test was two-tailed and the level of significance was set at 5%.

Results

Results of the trueness measurements and comparison between groups are summarized and displayed in Table 1 and Figure 6. While the Hybrid ceramic (92.33 ± 47.64 μm) showed a slightly better trueness than the Zirconia (97.74 ± 45.85 μm), the difference in root mean square distances between both groups was not statistically significant (5.41 ± 15.80; $p = 0.972$).

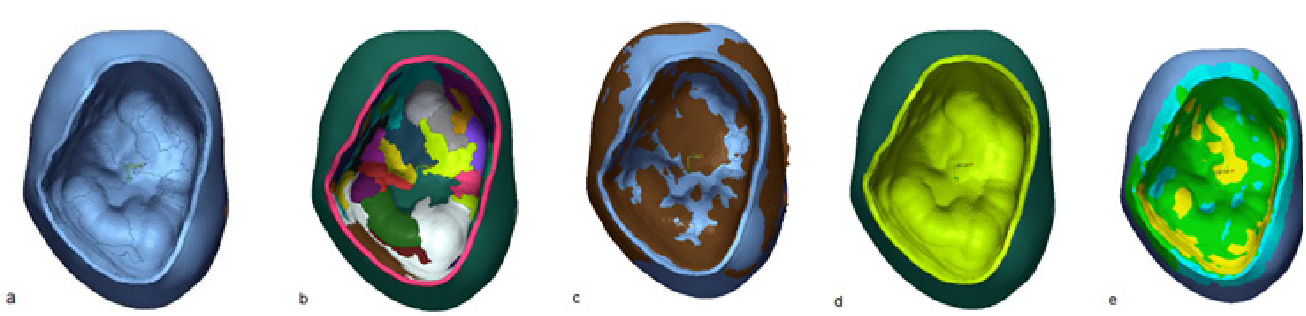

Figure 5. Using Geomagic Control X: a. Reference Standard Tessellation Language File; b. Regions delineated on the reference file; c. Best fit Algorithm between the reference and measured file; d. Fitting surface selected as a separate region; e. 3D deviation analysis.

Table 1: Comparison of root mean square distances (µm) between groups.

Groups	RMS (µm) Median (Q1 – Q3)	RMS (µm) Mean ± SD	Minimum RMS value (µm)	Maximum RMS value (µm)	Difference (µm) Mean ± SD	p-value
Zirconia (N=14)	80.20 (65.37 – 117.22)	97.74 ± 45.85	49.60	216.60	5.41 ± 15.80	0.972[a]
Hybrid ceramic (N=14)	74.75 (61.50 – 112.50)	92.33 ± 47.64	42.30	216.60		

SD = standard deviation; a: Wilcoxon signed-rank test. Significance if $p<0.05$

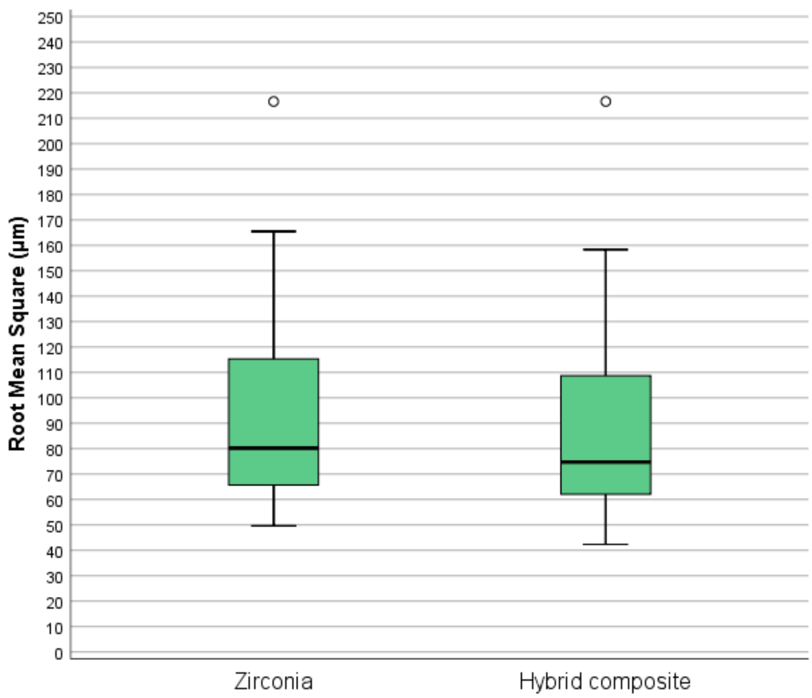

Figure 6. Box-plots of the root mean square values among groups

Discussion

The aim of this *in vitro* study was to compare the trueness of MZC and MHCC designed for primary teeth restoration to a digitally designed file using Geomagic Control X software. It was shown that for primary teeth restoration, MZC and MHCC had similar trueness. These findings are consistent with those of previous studies in this field [15].

The marginal fit is a determining factor for the survival success of prosthetic restorations and is measured by the trueness and precision of the crown [16]. If a prosthetic crown does not close properly, the marginal discrepancy between the dental structure and the restoration can lead to dissolution of the cement, microleakage, risk of pulp inflammation, and formation of secondary caries, as well as inflammation of the periodontal tissues [17]. Even though there have been many scientific studies on the topic, there is still a lack of consensus regarding the definition of a marginally acceptable level of gaps in a clinical context; a range between 50 and 120 microns is considered tolerable [18]. In the current study, and for both groups, the mean 3D deviations were 97 and 92 micrometers (µm), which are considered to fall in the range of clinical acceptability. MZC are widely used and several studies have reported a marginal discrepancy between 15 and 120 µm (Laumbacher et al. 2021). A recent systematic review that was based on 54 articles reported a marginal gap for milled monolithic crowns between 7.6 and 206.3 µm [18]. In addition, and in a recent study, Lerner and coll [2], assessed the trueness and precision of MZC, the authors reported high trueness for this material in permanent dentition which is compatible with the clinical use.

MHCC materials are increasingly being used for the restoration of teeth due to their favorable properties, including improved marginal fit. Studies have shown that hybrid materials, such as Vita Enamic, demonstrate superior marginal and internal fit compared to conventional CAD-CAM materials [15]. The improved marginal fit of MHCC makes them a promising option for minimally invasive restorations that require high precision and accuracy [15]. This is attributed to the polymer component in the hybrid material, which allows for better adaptation to the tooth structure and reduces the risk of avulsion. A study by Möhn et al. [19], evaluated the marginal quality of hybrid ceramic crowns and zirconia crowns in primary teeth. The study found that both materials had acceptable marginal fit, with hybrid crowns showing better results in terms of marginal discrepancy.

Milled monolithic restorations represent a reliable treatment option in modern digital dentistry. However, milling has some limitations, such as the considerable amount of raw material wasted (the material used for the supports and remnants of milled discs, which cannot be reused). During milling, the reproduction of surface geometry is dictated by the size of the milling burs, and the number of working axes of the computer numerical control (CNC) machine; therefore, in some applications (such as the milling of individual zirconia abutments), milling suffers from a limited ability to access smaller hollow areas and/or bypass undercuts [20]. Moreover, the burs are subject to abrasive wear, particularly when fully sintered ceramic material blocks are milled [21]. These blocks are dimensionally stable, but their milling can generate microcracks on the surface of the ceramic, which can compromise the longevity of the restoration. In pediatric dentistry, CAD-CAM technique does not need blocks with longevity more than four years approximately, that will bring a plus for the hybrid ceramic blocks to be preferred. Additionally, the high hardness of zirconia may cause excessive wear on milling burs and require frequent replacement, further adding to the overall cost of fabrication [22]. Furthermore, the accuracy of restorations made with zirconia blocks may be partially impacted by dimensional changes that occur after the sintering process [20].

In the current study, the fabrication time for each MHCC consisted of 7 to 20 minutes in total without any step further; however, the time required for the fabrication of each MZC has reached 11 hours (30 minutes for the milling process, 10 hours for sintering, and around 15 minutes for the layering). Therefore, MHCC offers several advantages, including a lower cost and faster fabrication time compared to MZC [23].

Limitations and strengths

The results of the current study indicated that the two materials had similar trueness to the reference design. Despite the promising findings, the study had some limitations. One of the limitations was the use of an in vitro study design, which may not fully replicate the clinical conditions of restoring primary teeth [24]. As a result, the findings of the study may not be directly applicable to clinical situations. Another limitation of the study was the relatively small sample size, which could affect the generalizability of the results. Nonetheless, the study had a significant strength, which was the use of Geomagic software Control X to assess trueness [25]. The latter being a reliable and accurate tool for assessing the accuracy of dental restorations. In addition, all the steps in the current study were fully digitized and performed in the same digital setting, which had definitely lessened the risk of distortion and errors. Another strength was the fabrication of two crowns using the two different materials for every primary molar which allowed a robust comparison of trueness between the two materials. Although the study's findings suggest that both materials can provide similar fit, larger studies with larger sample sizes and clinical trials are necessary to confirm these results and determine the long-term clinical success of these materials in restoring primary teeth [26].

Conclusion

Our findings support the use of milled hybrid ceramic material when it comes to trueness, and consequently internal and marginal fit, compared to the conventional CAD-CAM material for the restoration of primary teeth, which can provide a minimally invasive and durable solution for children with extensive caries or structural damage in their primary teeth. Overall, the choice between milled hybrid ceramic crowns and zirconia crowns for the restoration of primary teeth depends on various factors, including the clinical situation, esthetic requirements, and cost considerations. The durability of the material may not be an issue when restoring primary teeth due to their short longevity.

However, long-term clinical studies are needed to evaluate the clinical performance and longevity of milled hybrid ceramic materials in primary teeth and to introduce printed materials in primary dentition.

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