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Physicomechanical Properties of Tertiary Monoblock in Endodontics: A Systematic Review and Meta-analysis

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ABSTRACT

Introduction: A systematic review and meta-analysis were conducted to evaluate the physicomechanical properties of tertiary monoblock obturation with different obturation techniques. **Methods and Materials**: PubMed (MEDLINE), Web of Science, Scopus, the Cochrane Library, LILACS, IBECS, and BBO were searched time. PICO question was: "In extracted human teeth (Population), does tertiary monoblock obturation (Intervention) have superior physicomechanical properties (Outcome) compared to conventional obturation systems (Comparison)?". Statistical analyses for push-out bond strength were performed with RevMan software by comparing the mean differences of each study, with a 95% confidence interval. Inverse variance was used as statistical method, random-effects models as analysis model, and heterogeneity between studies was assessed by Cochran's Q test and I^2 statistic (P<0.05). **Results**: Of 2162 studies retrieved, 31 were included in this review for "Study Characteristics". Ten studies were included in the meta-analysis. Analysis demonstrated that conventional obturation had significantly higher push-out bond strength than tertiary monoblock obturation (P<0.01), with a mean difference of −1.00 (95% CI, −1.41 to −0.58; I^2=100%). Subgroups using single-cone and cold lateral condensation techniques showed significantly lower push-out bond strength for tertiary monoblock obturation (P<0.01), respectively with a mean difference of −0.09 (95% CI, −1.13 to −0.67; I^2=97%) and of −1.97 (95% CI, −3.19 to −0.75; I^2=100%). The warm vertical compaction subgroup showed no statistically significant difference between tertiary monoblock and conventional systems (P=0.13), with a mean difference of 0.49 (95% CI, −0.14 to 1.12; I^2=10%). **Conclusion:** Tertiary monoblock systems have a push-out bond strength similar to conventional systems when used with warm vertical compaction.

Keywords: Endodontics; Meta-analysis; Monoblock Obturation; Physiochemical Properties; Root Canal Obturation; Systematic Review

Introduction

Three-dimensional filling of the root canal system prevents infiltration of microorganisms from oral cavity into the periapical tissues, which is a parameter of successful endodontic treatment [1]. Failures can be related, among other factors, to the inability of the filling material to adhere to both dentinal walls of the root canal as a sealer, creating voids at this interface that may lead to leakage [2]. The incorporation of adhesive dentistry concepts into endodontics gave rise to the concept of monoblock obturation, in which a single cohesive unit is formed through adhesion of endodontic filling materials to the dentinal wall [3].

Monoblocks are defined according to the number of interfaces between the filling material and the dentinal wall [4]. Using only 1 filling material, such as mineral trioxide aggregate (MTA), creates a single interface between the dentin and the material; this is defined as a primary monoblock [4]. The use of a sealer associated with a solid filling material, such as gutta-percha, creates two interfaces, one between the dentin and the sealer, the other between the sealer and the filling cone, characterizing a secondary monoblock [4].

Tertiary monoblocks are those in which a third circumferential interface is created between the bonding substrate and the abutment material [4-7]. In this system, the use of a filling cone associated with a coating layer is recommended [4, 8].

Tertiary monoblock units can be created by using obturation systems such as EndoREZ (Ultradent Products Inc., South Jordan, UT, USA), EndoSequence BC (Brasseler, Savannah, GA, USA), and iRoot SP (Innovative BioCeramix Inc., Vancouver, Canada). EndoREZ is composed of a hydrophilic sealer based on urethane dimethacrylate and has been recommended for use in conjunction with polybutadiene-diisocyanate methacrylate resin-based gutta-percha for the formation of tertiary monoblock [9, 10]. EndoSequence BC, also known as iRoot SP, is a premixed, ready-to-use bioceramic sealer composed of calcium phosphate, calcium silicate, calcium hydroxide and zirconium oxide with hydrophilic characteristics, high biocompatibility, and antibacterial qualities due to its highly alkaline pH [11, 12]. Both EndoSequence BC and iRoot SP sealers, when associated with gutta-percha cones impregnated with bioceramic particles, are able to form tertiary monoblocks [2, 3].

Different methods are used to evaluate endodontic obturation, such as push-out bond strength [1], dye penetration [13], fluid filtration [14], bacterial leakage [15], and glucose leakage model [16]. Techniques such as digital radiography [17], stereomicroscopic examination [18], micro-computed tomography (CT) [19], and scanning electron microscopy (SEM) [20] have also been used to evaluate obturation quality. However, controversial results have been reported and attributed to methodological variations across studies. To date, there is no consensus regarding the optimal properties of materials and techniques applied to tertiary monoblock obturation. Previous studies have compared the performance of obturation techniques in different aspects, but with distinct results [18, 21]. Cold lateral condensation is simple and easy to perform, providing excellent clinical results [10]. However, this technique lacks homogeneity, thus failing to provide a hermetic seal, requiring high material consumption, and being time-consuming [21]. Warm vertical compaction shows satisfactory homogeneity, but the equipment required for this technique is considerably expensive compared to that for cold lateral condensation [21]. Single-cone obturation consists of a cone matching the size of the last endodontic instrument reaching the apex and is considered a simple and fast technique, being less stressful for patients and clinicians [2]. This technique has been made possible by the development of endodontic instrumentation systems that simulate the geometry of the main cones [1].

The aim of this systematic review and meta-analysis was to evaluate the physical-mechanical properties of tertiary monoblock obturation performed with single-cone, cold lateral condensation, and warm vertical compaction techniques. The null hypothesis was that there was no significant difference in the physical-mechanical properties of tertiary monoblock obturation compared to conventional obturation systems.

Materials and Methods

This systematic review was conducted according to the guidelines of the Cochrane Handbook for Systematic Reviews of Interventions [22], and it is reported according to the Preferred Report Items for Systematic Reviews and Meta-analyses (PRISMA). Although this systematic review is based on laboratory studies, the research PICO question was defined by adjusting the items to the "Population", "Intervention", "Comparison", "Outcome" format: "In extracted human teeth (Population), does tertiary monoblock obturation (Intervention) have superior physical-mechanical properties (Outcome) compared to conventional obturation systems (Comparison)?"

Eligibility criteria

Studies performed in extracted human teeth that reported comparisons between a tertiary monoblock and one or more conventional systems for root canal obturation were eligible for inclusion. Monoblocks created by using EndoREZ, EndoSequence BC, or iRoot SP were considered tertiary monoblocks because of the adhesion formed at the 3 circumferential interfaces (between the sealer and the root dentinal wall, between the sealer and the coating material, and between the coating material and the filling cone). All other types of obturation systems were considered conventional (control group). The outcome measure was push-out bond strength, and studies that did not present tests assessing both the cone and the sealer and those reporting the results of experimental filling materials were excluded.

Data sources and search strategy

The following electronic databases were searched for topic-related studies: PubMed (MEDLINE), Web of Science, Scopus, the Cochrane Library, Latin American and Caribbean Health Sciences Literature (LILACS), the Spanish Bibliographic Index of Health Sciences (IBECS), and the Brazilian Bibliography of Dentistry (BBO). The search terms were extracted from the MeSH metadata system. Indexed nomenclatures relevant to the search, entry terms, and common terms (such as brand names and terms commonly used but not indexed in MeSH) were selected. The search strategy developed for MEDLINE was adapted for use in all other databases (Table 1). The last search was run on April 12, 2021. Only studies published in English

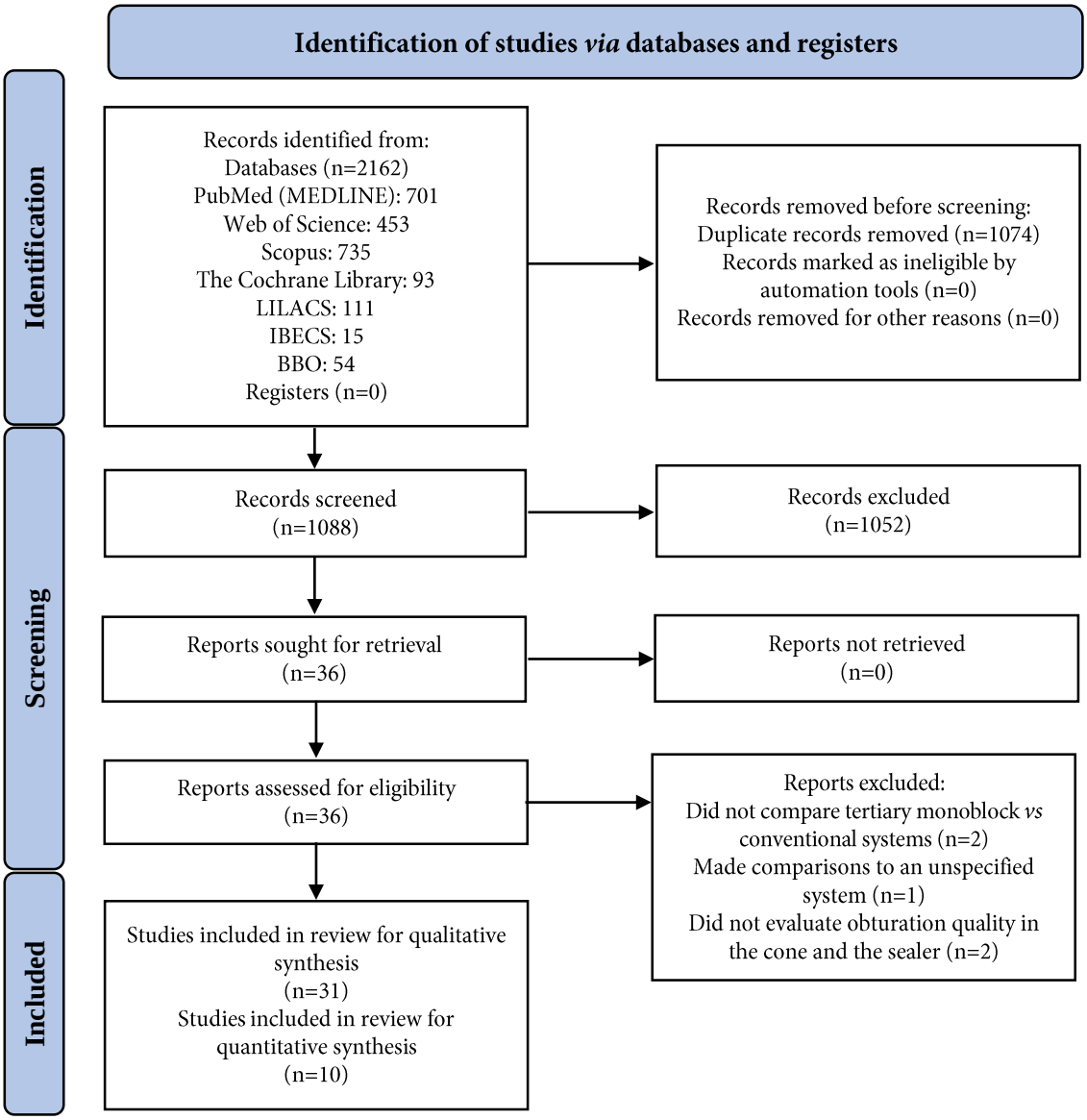

Figure 1. PRISMA 2020 flow diagram for systematic reviews which included searches of databases and registers

were included. No publication date restrictions were imposed. In addition, the reference lists of the retrieved articles were hand searched to detect other potentially eligible studies.

Study selection

The search results were compiled and duplicates were removed by using Mendeley Desktop (Elsevier Ltd, Amsterdam, Netherlands). Two independent reviewers (T.M.P. and K.P.) screened the titles and abstracts identified by the initial search. Full text was obtained for all potentially relevant articles to determine whether the study met the eligibility criteria. Disagreements between two reviewers were resolved by consulting a third reviewer (A.H.B.) for arbitration.

Data extraction

Two reviewers (T.M.P. and K.P.) independently extracted the following data from the selected articles using a standardized form: author, country and year of publication, tertiary monoblock group, conventional obturation group, methods, and main results.

The following properties were also extracted as they were considered of interest for this review: quality and adaptation of the filling material, sealing ability, percentage volume of filling materials, presence of voids, and bond strength. Disagreements between the 2 reviewers were resolved by consulting a third reviewer (A.H.B.) for arbitration.

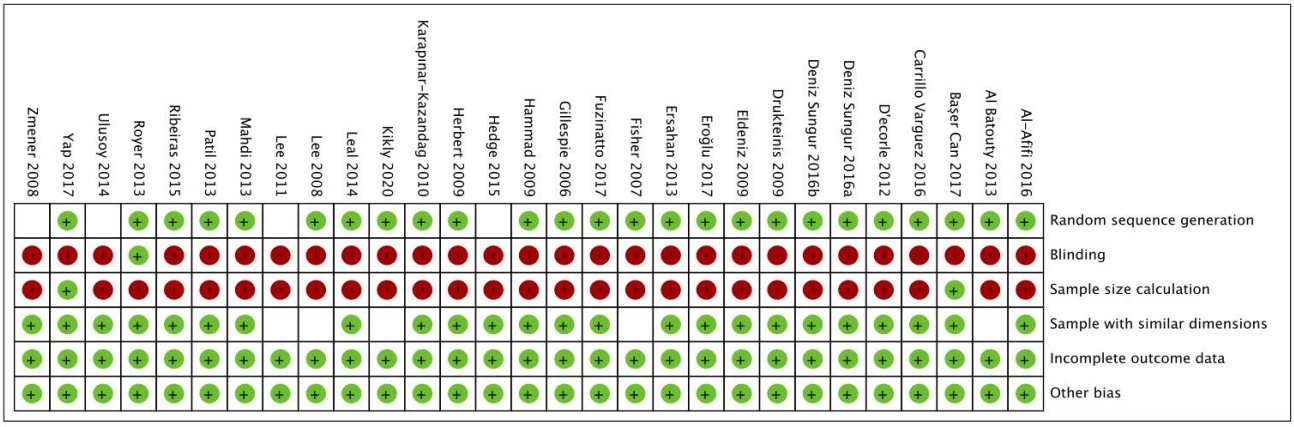

Figure 2. Review of authors' judgments about each risk of bias item for each included study; (+) Indicates low risk of bias; (-) Indicates high risk of bias

Assessment of quality and risk of bias

The methodological quality and risk of bias of each included study were independently assessed by two reviewers (T.M.P. and K.P.) and as adapted from previous systematic reviews of *in vitro* studies [22-24], according to the study's description of the following parameters: random sequence generation, blinding, sample size calculation, standardization of specimens with similar dimensions, incomplete outcome data, and other biases such as unexplained heterogeneity, inconsistency between trials, indirect comparisons, imprecision (few events), and risk of publication bias. Assessment of Quality and Risk of Bias was rated as "low", "unclear" and "High". Disagreements between the eviewers were resolved by consulting a third reviewer (A.H.B.) for arbitration.

Statistical analysis

All analyses were performed with Review Manager version 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark). The articles were selected for meta-analysis if they reported at least 1 comparison of push-out bond strength between endodontic obturation systems that support the concept of tertiary monoblock and conventional obturation systems (control group). Analysis was performed and pooled-effect estimates were obtained by comparing the mean differences of each study, with a 95% confidence interval (CI). A $P<0.05$ was considered statistically significant. Additionally, the studies were divided into subgroups according to the obturation technique used: single-cone, cold lateral condensation, and warm vertical compaction. Studies that compared conventional *vs* tertiary monoblock obturation using different techniques were excluded because of the risk of bias. Inverse variance was used as statistical method, random-effects models as analysis model, and heterogeneity between studies was assessed by Cochran's Q test and I^2 statistic. An I^2 value > 50% was indicative of substantial heterogeneity.

Results

The search strategy yielded a total of 2162 potentially relevant studies. Figure 1 provides an overview of the literature search and study selection. After removal of duplicates, 1088 remained for the screening of titles and abstracts. Of these, 36 studies met the inclusion criteria and were selected for full-text reading. Five of these studies were then excluded: 2 studies that did not compare tertiary monoblock *vs.* conventional systems [25, 26]; one study that made comparisons to an unspecified system [27]; and 2 studies performing tests that did not evaluate obturation quality in the cone and the sealer [28, 29]. The remaining 31 full-text publications were included in the present systematic review. Hand searches of reference lists yielded no additional studies. Ten studies were included for quantitative synthesis by meta-analysis.

Study characteristics

Thirty-one articles were included in this systemic review for descriptive analysis (Table 2). In the tertiary monoblock group, EndoREZ was the most commonly evaluated system (27 studies), followed by EndoSequence BC (5 studies).

The methods and main results of all 30 included studies are also shown in Table 2. In push-out bond strength tests, EndoREZ showed inferior bond strength compared to the combination of gutta-percha and AH-Plus (Dentsply Sirona, York, USA) [30-32]. In three studies [33-35], there was no significant difference between the tested materials. In other three studies [1, 2, 9], EndoREZ had significantly lower bond strength than all other test groups. The combination of RealSeal SE (SybronEndo, Glendora, USA) and Resilon (Pentron Clinical Technologies, Wallingford, UK) had higher bond strength values than EndoREZ [10]. EndoSequence BC showed greater bond strength values in all thirds of the root canal with promising results in 2 studies than AH-Plus [36, 37]. However, in 1 study [2] the EndoSequence system did not differ significantly from the conventional systems.

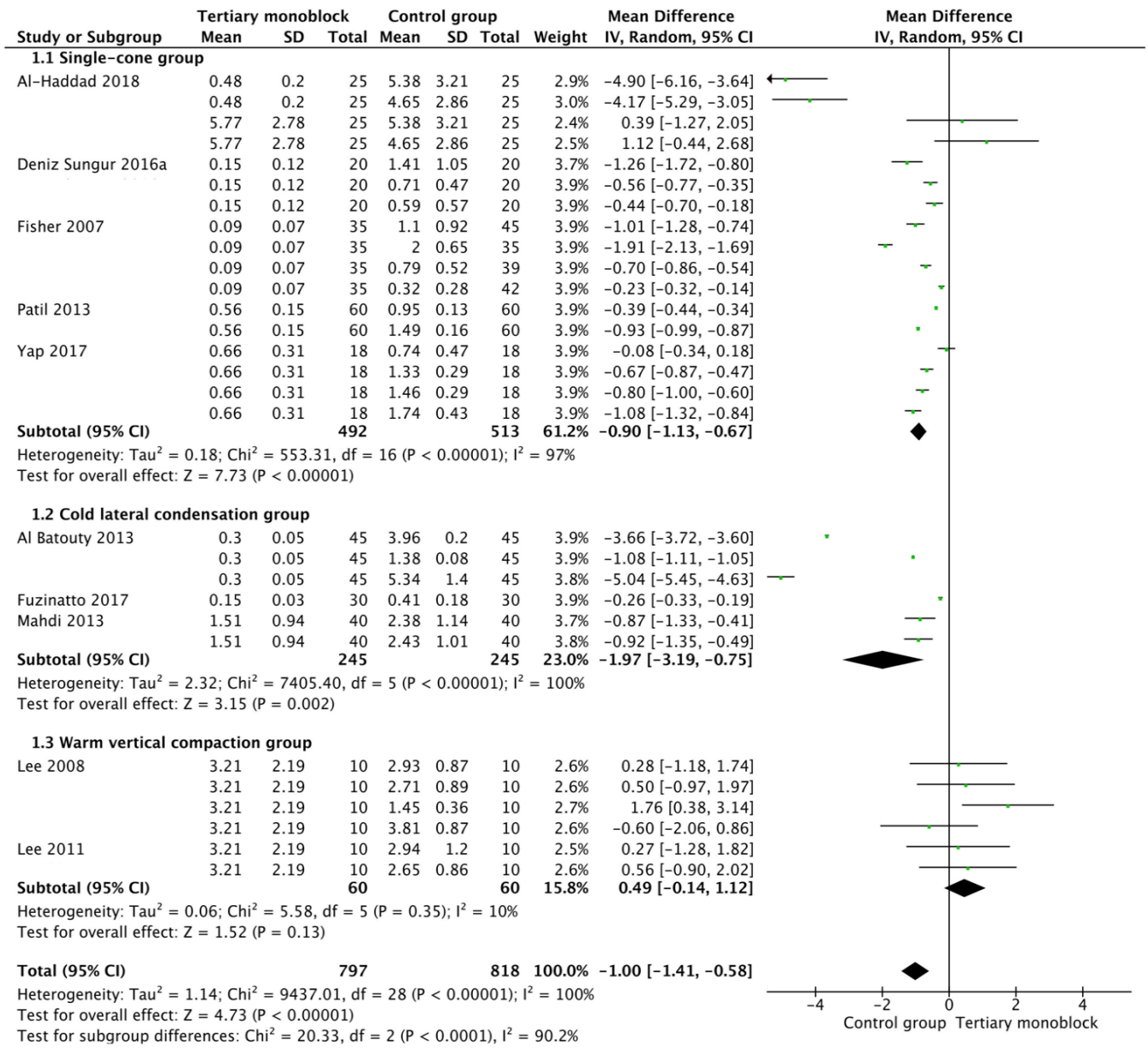

Figure 3. Meta-analysis considering the evaluation of push-out bond strength between Tertiary Monoblock and Conventional Obturation

Regarding leakage, although six studies [35, 38-42] found no significant differences between EndoREZ and the other test groups, 4 studies [13, 15, 43, 44] reported that EndoREZ exhibited significantly higher mean leakage than all other groups. However, three studies [14, 45, 46] demonstrated lower leakage values for EndoREZ than for all other groups. EndoSequence BC provided superior root canal system sealing ability compared to conventional systems [14, 45].

Regarding obturation quality, in two studies [18, 47] EndoREZ provided superior distribution between the cone and the sealer by stereomicroscopic examination than AH-Plus, but in another study [17] EndoREZ did not differ significantly from the other tested materials (Resilion/Epiphany SE, EndoREZ, and gutta-percha). None of the systems was associated with void-free obturation as assessed by micro-CT [19, 48] and SEM [13], but superior obturation quality was obtained using gutta-percha [13, 48]. EndoSequence BC produced superior obturation quality by scanning electron microscopy [20], while no statistically significant differences were found between the tested materials by radiographic evaluation [17].

Risk of bias

The included studies were rated as having a low risk of bias for random sequence generation, standardization of specimens with similar dimensions, incomplete outcome data, and other biases. For sample size calculation and blinding, the studies had a high risk of bias (Figure 2).

Meta-analysis

Ten studies were selected for meta-analysis considering the evaluation of push-out bond strength [1, 2, 9, 10, 30-35]. Conventional obturation (control group) had significantly higher push-out bond strength than tertiary monoblock obturation (P <0.01), with a mean difference of −1.00 (95% CI, −1.41 to −0.58; Heterogeneity: Tau^2=1.14, Chi^2=9437.01, df=28 (P<0.01), I^2=100%) (Figure 3). The subgroup analysis by obturation technique showed statistically significant differences between groups with lower push-out bond strength for tertiary monoblock obturation using single-cone and cold lateral condensation techniques, respectively with a mean difference of −0.09 (95% CI, −1.13 to −0.67 Heterogeneity: Tau^2=0.18, Chi^2=553.31, df=28 (P<0.01), I^2=97%) and of −1.97 [95% CI,−3.19 to −0.75 Heterogeneity: Tau^2=2.32, Chi^2=7405.40, df=5 (P<0.01), I^2=100%]. However, the subgroup using warm vertical compaction showed no statistically significant differences between tertiary monoblock and conventional systems (P =0.13), with a mean difference of 0.49 [95% CI, −0.14 to 1.12 Heterogeneity: Tau^2=0.06, Chi^2=5.58, df=5 (P=0.35), I^2=10%].

Discussion

Several materials and techniques have been tested in order to achieve the optimal properties for tertiary monoblock obturation, but a consensus is still lacking on the choice of material and technique [49]. The null hypothesis was rejected since there were differences in physical-mechanical properties between tertiary monoblock obturation and conventional obturation systems. Overall, the present findings indicate unsatisfactory results of bond strength with tertiary monoblock obturation. Conventional obturation systems showed better push-out bond strength than tertiary monoblock obturation; only when warm vertical compaction was used, no differences were observed between tertiary monoblock and conventional systems.

The push-out test is based on the shear stress produced at the interface between the dentinal wall and the filling material, which is comparable to the clinically observed stress [1]. Tertiary monoblock obturation showed inferior push-out bond strength compared to conventional obturation with the use of single-cone and cold lateral condensation techniques but not with the use of warm vertical compaction. A possible explanation for this may be that the use of warm vertical compaction results in a thinner film thickness of the sealer, leading to superior push-out bond strength [50]. However, this hypothesis cannot be confirmed by this meta-analysis. In a previous meta-analysis, without considering the concept of monoblock obturation, warm vertical compaction showed a higher rate of extrusion of the filling material than cold lateral condensation, which is a major sign of treatment failure [51]. Therefore, further adjustments in the formulation of these materials aiming to improve bond strength are justifiable.

All included studies evaluated not only bond strength but also leakage and obturation quality. Two studies [36, 37] compared EndoSequence BC using the single-cone technique to conventional obturation using the cold lateral condensation technique. The use of different techniques was considered a risk of bias, leading to the exclusion of these studies from the meta-analysis. However, the EndoSequence BC system showed higher adhesion values than those of conventional obturation. Concerning leakage evaluation, there was no standardization of the presented results. Discrepancies between the studies may be explained by differences in experimental designs, including variations in irrigating solutions and obturation techniques. Studies on sealing ability (leakage evaluation) have been shown to present a low level of evidence due to the lack of technique standardization, doubtful reliability, and consequently low impact [52]. The same can be argued for the evaluation of obturation quality. Although obturation quality testing lacks a standardized protocol, none of the systems was free of voids in the obturation, which represents a disadvantage for all tested systems. Therefore, the concept of creating homogeneous units within the root dentin is excellent in theory; however, monoblock obturation is challenging [4] because dentin adhesion is compromised by volumetric changes that occur in resin-based materials during polymerization, such as in EndoREZ, and also by the debris deposited on root canal walls [3].

Only EndoREZ, EndoSequence BC and iRoot SP were considered in the scope of this study for inclusion in the tertiary monoblock group because of the adhesion formed at the three circumferential interfaces (sealer/dentinal wall, sealer/coating material, and coating material/cone). Also, studies that did not evaluate the quality of endodontic obturation in the sealer and the cone were excluded. For the qualitative analysis using meta-analysis, of 10 studies evaluating EndoREZ, only 1 evaluated EndoSequence. A possible explanation for this difference may be that EndoREZ has entered the market long before the other tertiary monoblock systems. Despite the lack of studies assessing the physical properties of EndoSequence BC and iRoot SP, a systematic review of premixed calcium silicate-based sealers showed that these sealers have suitable physical, chemical and biological properties *in vitro* [52].

Table 1. Search strategy applied to Pubmed (Medline)

Search	Terms
#3	Search #1 AND #2
#2	((Root Canal Filling Materials) OR (Root Canal Sealants) OR (Canal Sealants, Root) OR (Sealants, Root Canal) OR (Gutta-Percha) OR (Gutta Percha) OR (Gutta-percha) OR (Ultrafil) OR (Thermafil) OR (Root Canal Obturation) OR (Canal Obturation, Root) OR (Canal Obturations, Root) OR (Obturation, Root Canal) OR (Obturations, Root Canal) OR (Root Canal Obturations) OR (Endodontic Obturation) OR (Endodontic Obturations) OR (Obturation, Endodontic) OR (Obturations, Endodontic) OR (Root Canal Therapy) OR (Canal Therapies, Root) OR (Canal Therapy, Root) OR (Root Canal Therapies) OR (Therapies, Root Canal) OR (Therapy, Root Canal))
#1	((EndoSequence root repair material) OR (active gp sealer) OR (iRoot SP) OR (EndRez) OR (real seal composite resin) OR (endodontic monoblocks) OR (endodontic monoblock) OR (single-cone) OR (tertiary monoblock) OR (coated gutta-percha))

Table 2. Presentation and description of selected studies for study characteristics

Authors	Country	Tertiary monoblock group	Conventional group	Methods	Results
Gillespie *et al.* [43]	Italy	EndoREZ system (*n*=15)	AH Plus and Gutta-percha; Adhesive-Modified EndoREZ System (*n*=15)	Fluid filtration model	EndoREZ showed a significantly greater leakage compared to the other groups
Fisher *et al.* [30]	United States of America	EndoREZ system (*n*=35)	Kerr EWT and Gutta-percha (*n*=39); AH Plus and Gutta-percha (*n*=35); Epiphany and Resilon (*n*=42); Activ GP system (*n*=45)	Push-out	Gutta-percha and AH-Plus presented significantly higher bond strength compared to all other groups
Lee *et al.* [33]	Taiwan	EndoREZ system (*n*=10)	Tubliseal and Gutta-percha; Tubliseal and Resilon; Epiphany and Gutta-percha; Epiphany e Resilon (*n*=10)	Push-out	There was no significant difference between groups
Zmener *et al.* [45]	Argentina	EndoREZ system (*n*=5)	Epiphany and Resilon; Grossman's Cement and Gutta-percha (*n*=5)	Dye Penetration	EndoREZ and Resilon/ Epiphany demonstrated significantly less leakage compared to other groups
Drukteinis *et al.* [38]	Lithuania	EndoREZ system (*n*=25)	AH-Plus and gutta-percha (*n*=25)	Bacterial leakage model	EndoREZ and AH-Plus/Gutta-Percha showed no significant difference
Eldeniz; Ørstavik [39]	Turkey	EndoREZ system (*n*=15)	AH Plus and Gutta-percha; Epiphany and Resilon; RC Sealer and Gutta-percha; Apexit and Gutta-percha; Acrosil and Gutta-percha; RoekoSeal and Gutta-percha; GuttaFlow applying a test primer and Gutta-percha (*n*=15)	Bacterial leakage model	AH-Plus, RC Sealer, RoekoSeal and EndoREZ did not resist bacterial infiltration after 40 days
Hammad *et al.* [48]	United Kingdom	EndoREZ system (n=12)	Tubliseal and gutta-percha; RealSeal and Resilon; GuttaFlow and gutta-percha (*n*=12)	Micro-computed tomography	Roots filled with gutta-percha showed less voids and gaps than roots filled with EndoREZ
Herbert *et al.* [17]	Germany	EndoREZ system (*n*=10)	Epiphany and Resilon; GuttaFlow and gutta-percha (*n*=10)	Stereomicroscope	All groups presented effective apical obturation
Herbert *et al.* [17]	Germany	EndoREZ system (*n*=10)	Epiphany and Resilon; GuttaFlow and gutta-percha (*n*=10)	Radiographic quality of obturation	There was no significant difference between groups
Karapınar-Kazandag *et al.* [40]	Turkey	EndoREZ system (*n*=20)	AH-Plus and gutta-percha; Epiphany and Resilon; AH-Plus and gutta-percha; Activ GP system (*n*=20)	Glucose leakage model	There was no significant difference between groups

Lee *et al.* [34]	Taiwan	EndoREZ system (*n*=10)	AH-Plus and gutta-percha; Epiphany e Resilon (*n*=10)	Push-out	There was no significant difference between groups
D'ecorle *et al.* [41]	Italy	EndoREZ system (*n*=25)	ZOE Sealer and gutta-percha; Pulp canal and Microseal technique gutta-percha (*n*=25)	Bacterial leakage model	There was no significant difference between EndoREZ and lateral-warm-vertical condensation of gutta-percha
Al Batouty; Hashem [31]	Egypt	EndoREZ system (*n*=45)	Epiphany and Resilon; AH-Plus and gutta-percha; MetaSeal and Glass Fiber (*n*=45)	Push-Oout	Gutta-percha and AH-Plus presented significantly higher bond strength compared to Resilon and EndoREZ
Ersahan; Aydin [44]	Turkey	EndoREZ system (*n*=18)	iRoot SP and Gutta-percha; Sealapex and gutta-percha; AH-Plus and Gutta-percha (*n*=18)	Fluid transport model	EndoREZ showed a significantly greater leakage compared to AH-Plus.
Mahdi *et al.* [35]	Spain	EndoREZ system (*n*=40)	AH-Plus and gutta-percha; RealSeal and Real Seal Point (*n*=40).	Push-out	There was no significant difference between AH-Plus/ gutta-Percha and EndoREZ
Mahdi *et al.* [35]	Spain	EndoREZ system (*n*=40)	AH-Plus and gutta-percha; RealSeal and Real Seal Point (*n*=40).	Fluid filtration model	There was no significant difference between groups
Patil *et al.* [32]	India	EndoREZ system (*n*=60)	AH-Plus and gutta-percha; Epiphany and Resilon (*n*=60).	Push-out	Gutta-percha and AH-Plus presented significantly higher bond strength compared to all other groups
Royer *et al.* [13]	United States of America	EndoREZ system (*n*=15)	Activ GP system; Kerr EWT and gutta-percha (*n*=15)	Dye penetration	EndoREZ presented inferior sealing ability compared to gutta-Percha/Pulp canal sealer and Activ GP system
Royer *et al.* [13]	United States of America	EndoREZ system (*n*=15)	Activ GP system; Kerr EWT and gutta-percha (*n*=15)	Scanning electron microscopy	EndoREZ showed more voids and root canal debris compared to guta-percha/ Pulp channel sealer and Activ GP system
Leal *et al.* [15]	Brazil	EndoREZ system (*n*=12)	Apexit Plus and Gutta-percha; AH-Plus and gutta-percha; EndoREZ and gutta-percha; Polifil and gutta-percha (*n*=12)	Bacterial leakage model	EndoREZ presented inferior sealing ability compared to Apexit Plus and AH-Plus
Ulusoy *et al.* [14]	Turkey	EndoREZ system (*n*=10)	Hybrid Root SEAL and gutta-percha; iRoot SP and gutta-percha; AH-Plus and gutta-percha (*n*=10)	Fluid filtration model	EndoREZ showed superior root canal system sealing ability when compared to IRoot SP and Hybrid Root SEAL
Hedge; Arora [16]	India	EndoSequence BC system (*n*=20)	AH-Plus and gutta-percha; Smart-paste bio-Sealer and C-points; RealSeal SE and Resilon (*n*=20)	Glucose leakage model	EndoSequence BC showed superior root canal system sealing ability when compared to other groups

Ribeiras *et al.* [20]	Portugal	EndoSequence BC system (*n*=7)	AH-Plus and Gutta-percha; EndoSequence BC Sealer and Gutta-percha (*n*=7)	Scanning electron microscopy	EndoSequence BC system resulted in enhanced marginal adaptation of obturation
Al-Afifi *et al.* [18]	Malaysia	EndoREZ system (*n*=15)	AH-Plus and gutta-percha; Lateral Compaction EndoREZ system; AH-Plus and Gutta-percha; Warm compaction EndoREZ system; AH-Plus and gutta-percha (*n*=15)	Stereomicroscope	EndoREZ is superior to the gutta-percha/AH-Plus in the percentage of core filling material
Carrillo Varguez *et al.* [37]	Mexico	EndoSequence BC system (*n*=18)	AH-Plus and Gutta-percha (*n*=18)	Push-out	EndoSequence BC presented better bond strength in all thirds of the root canal
Deniz Sungur *et al.* [39]	Turkey	EndoREZ system (*n*=20)	Activ GP system; Smartpaste and Smartpoint; AH-26 and gutta-percha (*n*=20)	Push-out	EndoREZ showed significantly lower bond strength compared to all other tested groups
Deniz Sungur *et al.* [39]	Turkey	EndoREZ system (*n*=20)	AH-26 and Gutta-percha; EndoSequence BC Sealer and gutta-percha; AH-26 and gutta-percha (*n*=20).	Fluid transport model	There was no significant difference between EndoREZ and Sealer 26/gutta-percha
Başer Can *et al.* [19]	Turkey	EndoREZ system (*n*=10)	Activ GP system; AH-Plus and gutta-percha (*n*=10).	Micro-computed tomography	No significant difference between the AH-Plus/gutta-percha and EndoREZ was observed with respect to percentage of filling materials and voids
Eroğlu; Bayırlı [47]	Turkey	Cimento e cone EndoREZ (*n*=20)	AH-Plus and gutta-percha; Epiphany and Resilon (*n*=20).	Stereomicroscope	EndoREZ presented superior percentage of core filling material and less presence of voids and debris at the apical third
Fuzinatto *et al.* [10]	Brazil	EndoREZ system (*n*=30)	RealSeal and Resilon (*n*=30)	Push-out	EndoREZ showed significantly lower bond strength compared to RealSeal SE
Yap *et al.* [1]	Malaysia	EndoREZ system (*n*=18)	AH-Plus and Gutta-percha; TotalFill BC System; TotalFill BC Sealer and gutta-percha; EndoREZ Sealer and gutta-percha (*n*=18)	Push-out	EndoREZ showed significantly lower bond strength compared to other groups
Carrillo Varguez *et al.* [36]	Mexico	EndoSequence BC system (n=15)	MTA Fillapex and gutta-percha; AH-Plus and Gutta-percha (*n*=15)	Push-out	EndoSequence BC presented better bond strength in all thirds of the root canal
Al-Haddad *et al.* [2]	Malaysia	EndoREZ system and EndoSequence BC system (n=25)	EndoSequence BC sealer and Active GP cone; EndoSequence BC sealer and gutta-percha (*n*=25)	Push-out	EndoREZ showed significantly lower bond strength compared to other groups
Kikly *et al.* [46]	Tunisia	EndoREZ system (n=20)	EndoREZ® sealer and gutta-percha; Acroseal sealer and gutta-percha (*n*=20)	Dye penetration	EndoREZ system showed the best sealing ability in the apical region

The number of laboratory studies far outweighs that of clinical studies, and the results of our review are limited to *in vitro* studies. It can be assumed that studies in extracted teeth provide a more feasible and objective approach to assessing root canal obturation for quality and adaptation of the filling material, bond strength, sealing ability, percentage volume of filling materials, and presence of voids than studies in patients. Moreover, laboratory studies have always been important in determining preliminary tests for the development of materials and concepts in endodontics. Clinical trials require rigorous projects, time and energy, in addition to being difficult to execute as they need long-term follow-up and requiring a more complicated evaluation [22]. Nonetheless, clinical trials provide useful information and practical suggestions, especially well-designed randomized clinical trials [22]. Another limitation of our review is the high heterogeneity observed in the global analysis, probably due to different materials and methods used in the included articles. In addition, the absence of sample size calculation and blinding accounted for a high risk of bias, which can limit the evidence provided by the included studies. Of 30 included studies, only one blinded the examiner and two [1, 19] presented the sample size calculation.

The development of new materials and techniques within the tertiary monoblock concept paves the way for future endodontic obturation applications. Our results provide evidence that tertiary monoblock systems only have a push-out bond strength similar to that of conventional systems when used with warm vertical compaction techniques although considering that this systematic review is based on laboratory studies. Further clinical trials are needed to confirm the efficacy of using tertiary monoblock systems.

Conclusion

This meta-analysis showed that only tertiary monoblock obturation performed with warm vertical condensation has a push-out bond strength similar to that of conventional obturation. When single-cone and cold lateral condensation techniques are used, conventional systems show better results. Considering the overall quality of the included studies and the level of evidence available, long-term clinical trials are still needed to generate sufficient evidence to support this conclusion.

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