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REVIEW

Current status on minimal access cavity preparations: a critical analysis and a proposal for a universal nomenclature

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Abstract

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In the last decade, several access cavity designs involving minimal removal of tooth tissue have been described for gaining entry to pulp chambers during root canal treatment. The premise behind this concept assumes that maximum preservation of as much of the pulp chamber roof as possible during access preparation would maintain the fracture resistance of teeth following root canal treatment. However, the smaller the access cavity, the more difficult it may be to visualize and debride the pulp chamber as well as locate, shape, clean and fill the canals. At the same time, a small access cavity may increase the risk of iatrogenic complications as a result of poor visibility, which may have an impact on treatment outcome. This study aimed to critically analyse the literature on minimal access cavity preparations, propose new nomenclature based on self-explanatory abbreviations and highlight the areas in which more research is required. The search was conducted without restrictions using specifics terms and descriptors in four databases. A complementary screening of the references within the selected studies, as well as a manual search in the highest impact journals in endodontics, namely International Endodontic Journal and Journal of Endodontics, was also performed. The initial search retrieved 1831 publications. The titles and abstracts of these papers were reviewed, and the full text of 94 studies was assessed. Finally, a total of 28 studies were identified as evaluating the influence of minimally invasive access cavity designs on the fracture resistance of teeth and on the different stages of root canal treatment (orifice location, canal shaping, canal cleaning, canal filling and retreatment). Overall, the studies had major methodological drawbacks and reported inadequate and/or inconclusive results on the utility of minimally invasive access preparations. Furthermore, they offered limited scientific evidence to support the use of minimally invasive access cavities to improve the outcome of root canal treatment and retreatment; they also provided little evidence that they preserved the fracture resistance of root filled teeth to a greater extent than traditional access cavity preparations. It was concluded that at present, there is a lack of supporting evidence for the introduction of minimally invasive access cavity preparation into routine clinical practice and/or training of undergraduate and postgraduate students.

Keywords: conservative endodontic cavity, endodontics, fracture resistance, minimal access cavity preparation, minimally invasive access cavity, root canal treatment.

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Introduction

The emerging concept of minimally invasive access cavity preparation aims to preserve sound dentine by maintaining as much of the pulp chamber roof as possible based on the assumption that retaining this structure will preserve the fracture resistance of teeth after root canal treatment (Clark & Khademi 2010a). However, making the access too small may compromise the subsequent stages of root canal treatment by preventing and/or complicating the location of canal orifices and the canal cleaning, shaping and filling procedures (Gluskin *et al.* 2014, Krishan *et al.* 2014, Rover *et al.* 2017, Silva *et al.* 2020). Concurrently, it may also increase the potential for iatrogenic complications including missed canals, deviations and/or instrument fracture (Gluskin *et al.* 2014, Rover *et al.* 2017, Silva *et al.* 2018, Pedullà *et al.* 2020). In addition, the residual roof of the pulp chamber may make it difficult to remove pulp remnants, dentinal debris, blood, filling materials and other residues, which may cause tooth discoloration, support microbial growth and have a negative impact on materials, particularly root canal sealers and composites (Lenherr *et al.* 2012, Marchesan *et al.* 2018, Neelakantan *et al.* 2018, Silva *et al.* 2020). Even though several articles have been published on this topic and there is substantial interest in such techniques on social media, there is a lack of scientific evidence to support the introduction of these new designs of access cavities into routine clinical practice and/or training of undergraduate and postgraduate students. Therefore, this study aimed to (a) review the current literature on minimal access cavity preparations during root canal treatment and retreatment, (b) propose a new nomenclature based on self-explanatory abbreviations and (c) highlight the areas in which more research is required.

Review

Literature search strategies

A literature search was performed without parameter restrictions up to June 2020 by two independent evaluators (K.P.P., C.M.F.) using specific Medical Subject Heading (MeSH) terms and free descriptors regarding minimally invasive access cavity in PubMed, Scopus, Web of Science and Science Direct databases. After applying a combination of descriptive terms [(conservative OR minimally OR minimally invasive OR contracted OR ultraconservative OR truss OR ninja) AND (cavity OR access) AND (endodontic)], studies that evaluated the influence of minimally invasive access preparations on all stages of root canal treatment or on fracture resistance of teeth were selected. A complementary screening of the references and a manual search in the highest impact journals in endodontics, namely the International Endodontic Journal and Journal of Endodontics, were also accomplished. The primary search retrieved 1831 articles. Their titles and abstracts were analysed, and 94 potentially relevant articles were read in full for eligibility. In cases of discordance, a third author made a final decision (E.J.N.L.S.). Articles that did not address the topic, studies about guided endodontic procedures, intracoronal bleaching, reviews and case reports were excluded. The final selection comprised 28 papers that compared various types of minimally invasive access cavity preparations in terms of fracture resistance of teeth, stress distributions through finite element models and their influence on different stages of root canal treatment.

Nomenclature of access cavity designs

Terminological consistency in science is important to communicate ideas, to explain concepts and to avoid ambiguity. The proposal for different designs of access cavity preparation is a relatively new trend in endodontics, and specific nomenclature has yet to be established. The numerous abbreviations proposed in the literature are characterized by mismatching and overlapping terms, leading to challenges around comprehension and readability. Hence, the new classification proposed in this study is based on the selected literature and is intended to condense 22 terms related to access cavity geometries (Table 1) into six main categories in order to provide a common language and self-explanatory abbreviations (Fig. 1):

- *Traditional Access Cavity* (TradAC): in posterior teeth, complete removal of the pulp chamber roof followed by achieving straight-line access to the canal orifices, with smoothly divergent axial walls, so that all orifices can be seen within the outline form (Fig. 1a). In anterior teeth, the straight-line access is obtained by removing the pulp chamber roof, the pulp horns, the lingual shoulder of dentine, and further extending the access cavity to the incisal edge (Fig. 2a; Levin 1967).
- *Conservative Access Cavity* (ConsAC): in posterior teeth, preparation usually starts at the central fossa of the occlusal surface and extends, with smoothly convergent axial walls to the occlusal surface, only

Table 1 Abbreviations and terms proposed in the literature to classify the different types of access cavity geometries in endodontics

Abbreviation	Meaning	References
CAC	Conservative access cavity	Sabeti *et al.* (2018), Freitas *et al.* (2020)[a], Mendes *et al.* (2020)
CEA	Contracted endodontic access	Bóveda & Kishen 2015
CEAC	Conservative endodontic access cavity	Saygili *et al.* (2018)
CEC	Conservative endodontic cavity	Alovisi *et al.* (2018), Chlup *et al.* (2017), Corsentino *et al.* (2018), Ivanoff *et al.* (2017), Krishan *et al.* (2014), Makati *et al.* (2018), Moore *et al.* (2016), Niemi *et al.* (2016), Plotino *et al.* (2017), Jiang *et al.* (2018), Özyürek *et al.* (2018), Roperto *et al.* (2019), Rover *et al.* (2017), Zhang *et al.* (2019), Tüfenkçi & Yilmaz (2020), Wang *et al.* (2020)
CECDW	CEC with divergent walls	Roperto *et al.* (2019)
DDC	Orifice-directed dentine conservation access	Neelakantan *et al.* (2018)
EEC	Extended endodontic cavity	Jiang *et al.* (2018)
MEC	Modified endodontic cavity	Zhang *et al.* (2019)
MI	Minimally invasive	Yuan *et al.* (2016), Eaton *et al.* (2015), Lin *et al.* (2020), Freitas *et al.* (2020)[a]
MS	Modified straight-line	Lin *et al.* (2020)
NEC	Ninja endodontic cavity	Plotino *et al.* (2017)
PEAC	Point endodontic access cavity	Saygili *et al.* (2018)
SL	Straight-line	Yuan *et al.* (2016)
SLF	Straight-line furcation	Eaton *et al.* (2015)
SLR	Straight-line radicular	Eaton *et al.* (2015)
TA	Truss access cavity	Abou-Elnaga *et al.* (2019)
TAC	Traditional access cavity	Abou-Elnaga *et al.* (2019), Sabeti *et al.* (2018), Mendes *et al.* (2020)
TEAC	Traditional endodontic access cavity	Saygili *et al.* (2018)
TEC	Traditional endodontic cavity	Alovisi *et al.* (2018), Chlup *et al.* (2017), Corsentino *et al.* (2018), Ivanoff *et al.* (2017), Krishan *et al.* (2014), Makati *et al.* (2018), Moore *et al.* (2016), Jiang *et al.* (2018), Neelakantan *et al.* (2018), Niemi *et al.* (2016), Plotino *et al.* (2017), Özyürek *et al.* (2018), Roperto *et al.* (2019), Rover *et al.* (2017), Silva *et al.* (2020), Zhang *et al.* (2019), Saberi *et al.* (2020), Tüfenkçi & Yilmaz (2020)
TREC	Truss endodontic cavity	Corsentino *et al.* (2018), Saberi *et al.* (2020)
TS	Traditional straight-line	Lin *et al.* (2020)
UEC	Ultra-conservative endodontic cavity	Silva *et al.* (2020)

[a]Freitas *et al.* (2020) did not use abbreviations.

as far as necessary to detect the canal orifices, preserving part of the pulp chamber roof (Clark & Khademi 2010b; Fig. 1b). This access type can be also performed with divergent walls (ConsAC.DW) (Roperto *et al.* 2019) (Fig. 1c). In anterior teeth, this access involves moving the entry point away from the cingulum towards the incisal edge, on the lingual or palatal surface, by creating a small triangular-shape or oval-shape cavity, conserving the pulp horns and the maximum pericervical dentine (Fig. 2b) (Vieira *et al.* 2020).

- *Ultra-Conservative Access Cavity* (UltraAC): known as 'ninja' access, such cavities start out as described in the ConsAC, but with no further extensions, maintaining as much of the pulp chamber roof as possible (Plotino *et al.* 2017) (Figs 1d and 2c). In anterior teeth, when there is attrition or a deep concavity in the lingual aspect of the crown, the access can be performed in the middle of the incisal edge, parallel to the long axis of the tooth (UltraAC.Inc) (Fig. 2d).
- *Truss Access Cavity* (TrussAC): aims to preserve the dentinal bridge between two or more small cavities prepared to access the canal orifice(s) in each root of multi-rooted teeth. In mandibular molars, for example, two or three individual cavities can be created to access the mesial and distal canals (Neelakantan *et al.* 2018; Fig. 1E).
- *Caries-Driven Access Cavity* (CariesAC): access to the pulp chamber is performed by removing caries and preserving all remaining tooth structures (Figs 1f and 2e), including the *soffit* structure,

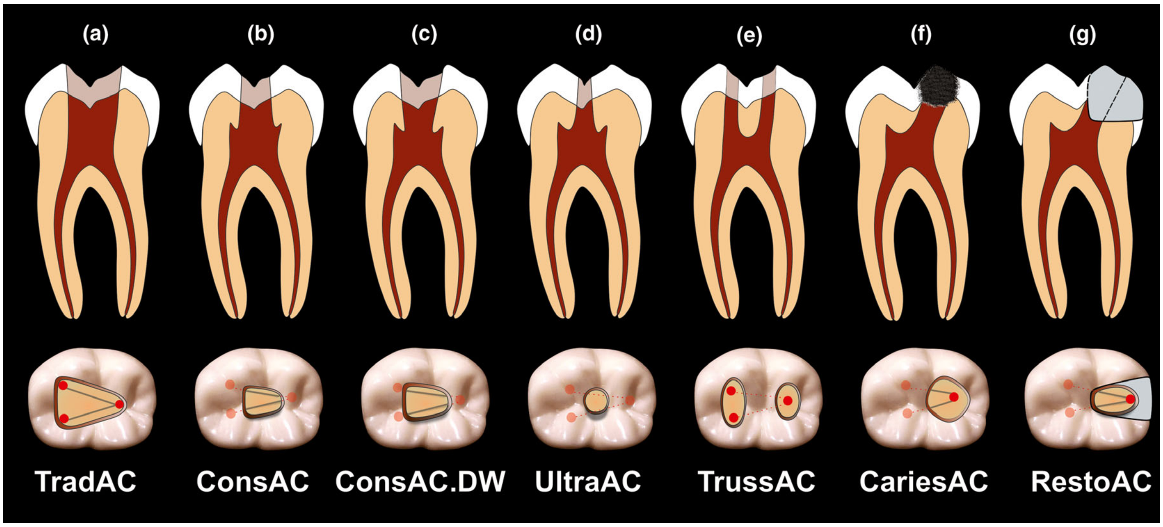

Figure 1 Classification of the access cavity designs in posterior teeth consolidating 20 out of 22 overlapping terms used in the selected literature. SLF and SLR do not fit in any category since the final shape of the access cavity obtained using these parameters is dependent on the position of the anatomical landmarks. (a) Traditional access cavity (TradAC); (b) conservative access cavity (ConsAC); (c) conservative access cavity with divergent walls (ConsAC.DW); (d) ultra-conservative access cavity (UltraAC); (e) truss access cavity (TrussAC); (f) caries-driven access cavity (CariesAC); (g) restorative-driven access cavity (RestoAC).

described as the underside of an architectural feature such as the ceiling, the corner of the ceiling and the wall (Clark *et al.* 2013).

- *Restorative-Driven Access Cavity* (RestoAC): in restored teeth with no caries, access to the pulp chamber is performed by totally or partially removing existing restorations and by preserving all possible remaining tooth structures (Figs 1g and 2f).

Amongst the 22 abbreviations reported in the literature (Table 1), two of them (SLF and SLR) differ from the others because their outlines are derived from pulp space landmarks projected onto the occlusal surface of the teeth. Whilst the straight-line furcation design (SLF) is based on the location of the centre of each canal at the furcation level, the reference for the straight-line radicular (SLR) access is associated with the position of the pulp horns (Eaton *et al.* 2015). Although SLF and SLR do not fit into the new proposal categories, they were applied recently in clinics using the concept of dynamic CT-guided endodontic access procedures (Gambarini *et al.* 2020).

Influence of minimal invasive access preparation on root canal treatment/retreatment

The overall description of the studies that evaluated the types of minimal access cavity preparations on various root canal procedures reported in the literature is summarized in Table 2.

Orifice location

One of the major inherent difficulties when using minimally invasive access cavities is the location of root canals as orifice location may be impaired by the limited view of the pulp chamber floor. Rover *et al.* (2017) demonstrated a greater detection of second mesiobuccal canals (MB2) in maxillary molars with TradAC compared to ConsAC, with or without magnification, but no difference was observed when troughing with an ultrasonic tip was associated with magnification. In another study, a greater MB2 detection rate was also observed in the TradAC group (60%) and ConsAC (53.3%) groups compared to UltraAC (31.6%) (Saygili *et al.* 2018). Additionally, a recent study using a simulated clinical environment reported that the type of access cavity (TradAC or ConsAC) did not influence the detection of middle mesial canals (MMC) in mandibular molars when performed by an experienced endodontist using an operating microscope and thin ultrasonic tips to remove the dentine overhanging the orifices (Mendes *et al.* 2020; Table 2).

Summary. Although the operators were blinded to the presence of the extra canals in these studies, their

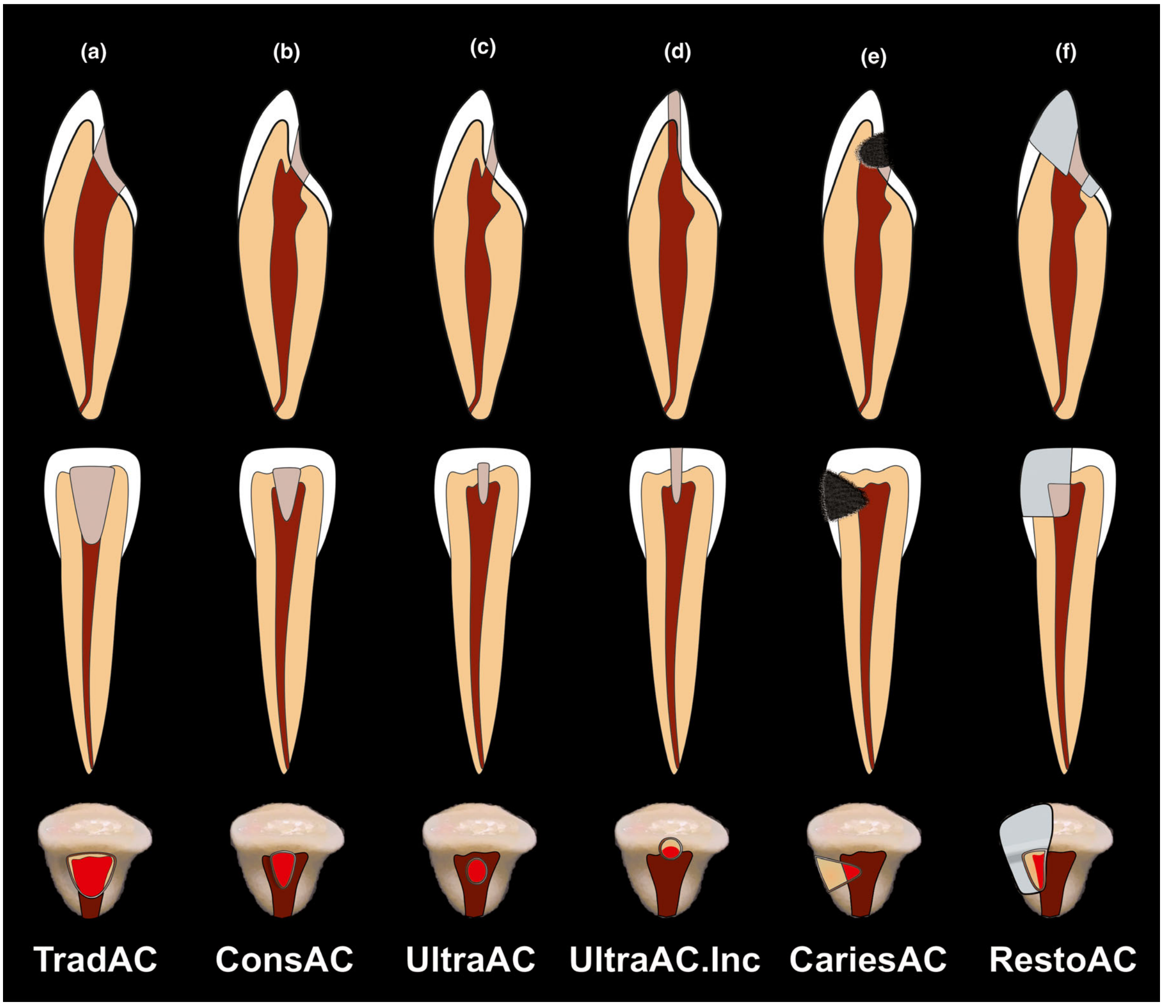

Figure 2 Classification of the access cavity designs in anterior teeth consolidating the 20 out of 22 overlapping terms used in the selected literature. SLF and SLR do not fit in any category since the final shape of the access cavity obtained using these parameters is dependent on the position of the anatomical landmarks. (a) Traditional access cavity (TradAC); (b) conservative access cavity (ConsAC); (c) ultra-conservative access cavity (UltraAC); (d) ultra-conservative access cavity performed in the incisal edge (UltraAC.Inc); (e) caries-driven access cavity (CariesAC); (f) restorative-driven access cavity (RestoAC).

detection was not influenced by TradAC or ConsAC types when associated with magnification/illumination and the use of thin ultrasonic tips. In contrast, detection of extra canals in teeth with UltraAC was impaired. Further studies are required to evaluate if the knowledge of the operator regarding the presence of extra canals would affect their detection rate in different groups of teeth with varying access designs.

Chemomechanical canal preparation

An adequately prepared access cavity is crucial for effective instrumentation and delivery of irrigants into the root canal system (Bóveda & Kishen 2015). In the present review, the influence of various access cavities on chemomechanical preparation procedures was assessed in 11 studies, including the evaluation of unprepared canal walls, canal curvature, canal transportation, accumulation of hard tissue debris, pulp tissue remnants and intracanal disinfection (Table 2).

Advances in image analysis using nondestructive micro-computed tomography (micro-CT) have revealed a large percentage of untouched areas in the main root canal after shaping procedures (Peters *et al.* 2001, Versiani *et al.* 2013). In teeth with necrotic pulps, these areas might be covered with pulp tissue remnants, bacteria and/or dentine chips (Siqueira *et al.* 2018) and may affect the long-term outcome of treatment (Chugal *et al.* 2017). This review included four studies that evaluated the influence of various access cavity designs on the untouched areas of the root canal walls after preparation, using micro-CT technology (Krishan *et al.* 2014, Rover *et al.* 2017, Silva *et al.* 2020, Vieira *et al.* 2020). Krishan *et al.* (2014) reported a greater percentage of untouched walls after preparation of distal canals of mandibular first molars with ConsAC compared to TradAC. The sample selection, however, was carried out using radiographic images, and the unknown cross-sectional morphology of the root canal may have acted as a confounding factor. In the other three studies, samples were pair-marched according to the canal configuration using micro-CT and no difference in the percentage of untouched walls after shaping the canal systems of maxillary molars (Rover *et al.* 2017), mandibular incisors (Vieira *et al.* 2020) and maxillary premolars (Silva *et al.* 2020) was observed by comparing the TradAC to ConsAC (Rover *et al.* 2017), UltraAC.Inc (Vieira *et al.* 2020) or UltraAC (Silva *et al.* 2020). Overall, these findings suggest that the percentage of untouched walls after the mechanical preparation of root canals in different groups of teeth may not be compromised by minimal access cavity preparations; however, further studies using micro-CT and contralateral pair-matched teeth (De-Deus *et al.* 2020) are recommended.

The influence of minimally invasive access cavities on canal curvature and transportation were investigated in five studies (Eaton *et al.* 2015, Rover *et al.* 2017, Alovisi *et al.* 2018, Zhang *et al.* 2019, Freitas *et al.* 2020). Overall, canal preparation using ConsAC resulted in a major deviation of the original anatomy at the apical level of the palatal canal of maxillary molars (Rover *et al.* 2017) and in the mesial canals of mandibular molars (Alovisi *et al.* 2018). Eaton *et al.* (2015) and Zhang *et al.* (2019) observed that the maximum angle of canal curvature was greater in teeth with ConsAC compared to TradAC. This would result in excessive pressure of the instrument against the outer aspect of the curvature (Alovisi *et al.* 2018), increasing the risk of transportation, which may explain these results. On the other hand, Freitas *et al.* (2020) reported no difference in the transportation of mesiobuccal canals in maxillary molars with ConsAC and TradAC. However, although using micro-CT, the major limitation of this study was the linear measurement of transportation at only two root levels, it is important to highlight that the stress level along the length of an instrument in curved canals may exceed its endurance limit, increasing the probability of fracture (Lopes *et al.* 2013, Özyürek *et al.* 2017). Once fractured, attempts to remove the fragment may be followed by unnecessary dentine removal, resulting not only in weakening the tooth structure, but also violating the basic concept of minimally invasive dentistry. To date, no study has attempted to assess the influence of different access cavity preparations on the incidence of instrument fracture.

During canal shaping, some areas may accumulate dentine debris generated and transported by endodontic instruments (Paqué *et al.* 2009, De-Deus *et al.* 2015). Debris may interfere with disinfection by both preventing irrigant flowing within the root canal system and by neutralizing its efficacy (Siqueira *et al.* 2013). Only two studies evaluated the influence of different access cavity designs on the amount of accumulated debris (Rover *et al.* 2017, Silva *et al.* 2020). Whilst no difference was observed by Rover *et al.* (2017) comparing maxillary molars with ConsAC or TradAC, Silva *et al.* (2020) reported that canal preparation of maxillary premolars with UltraAC was associated with a greater percentage of debris compared to TradAC. Therefore, it seems that the larger area of pulp chamber roof associated with small access cavities (UltraAC) might have affected the efficiency of irrigation (Neelakantan *et al.* 2018) and, consequently, resulted in more dentinal debris accumulated within the root canal system.

Disinfection procedures can be also impaired by contaminated pulp tissue remnants that may serve as a source for persistent infection and post-treatment disease (Siqueira & Rôças 2008). Neelakantan *et al.* (2018) reported a greater amount of remaining pulp tissue retained in the pulp chamber of mandibular molars with TrussAC compared to TradAC after chemomechanical preparation using rotary instruments and conventional syringe irrigation. According to the authors, the remaining pulp chamber roof interfered with the mechanical action of the instruments and compromised the flow of irrigants. More recently, it was reported that disinfection procedures using conventional syringe irrigation were compromised significantly after root canal preparation of teeth with conservative endodontic cavities (Vieira *et al.* 2020). Results from quantitative polymerase chain reaction revealed that the number of bacteria-positive samples was significantly greater in the ConsAC group (86%) than in the TradAC group (50%) after preparation. Even though this finding substantiates the potential negative influence of the access cavity type on root canal disinfection, bacterial sampling in this study was performed using paper points, a technique well known to overestimate the disinfection ability of chemomechanical procedures as it prevents the detection of bacterial biofilms on canal walls (Siqueira *et al.* 2013). In contrast, Tüfenkçi & Yilmaz (2020) reported no difference in bacterial reduction (*E. faecalis*) of mandibular molars with TradAC and ConsAC using XP-endo Finisher instruments (FKG Dentaire, La Chaux de Fonds, Switzerland) for one minute to activate the irrigant solution. In this study, however, bacterial detection was achieved using colony-forming units, a method in which clumps of bacterial cells can be miscounted as single colonies (Hazan *et al.* 2012). On the other hand, although this finding may support irrigant activation to enhance the effectiveness of root canal debridement and disinfection in teeth with minimal access cavities, it is also known that irrigating minimally enlarged canals may also pose additional disadvantages such as limited irrigant penetration, needle wedging, vapour lock effect and challenges associated with sonic/ultrasonic/apical negative pressure irrigation (Bóveda & Kishen 2015). Therefore, further research is required in this key area, as disinfection has a direct influence on the outcome of root canal treatment (Restrepo-Restrepo *et al.* 2019).

Summary. The data suggests there is no difference between the TradAC and ConsAC regarding untouched canal walls and accumulated hard tissue debris remaining after preparation, whilst greater canal transportation was observed in teeth with ConsAC. Additionally, the smallest access cavities, such as TrussAC and UltraAC, were associated with negative effects on irrigation efficiency as larger amounts of remaining pulp tissue and hard tissue debris remained after shaping procedures. On the other hand, the influence of access cavity design on bacterial reduction is still unclear and further studies are required.

Root canal filling and retreatment

This review identified only two studies that appraised the influence of access cavity design on root canal filling (Niemi *et al.* 2016, Silva *et al.* 2020) (Table 2). Niemi *et al.* (2016) assessed the quality of canal filling performed in oval-shaped canals of mandibular premolars after ConsAC or TradAC through radiographic analysis. The reduced dimensions of minimally invasive access hindered the adaptation of the gutta-percha cone when using a single-cone technique and hampered the accomplishment of the continuous wave of condensation method. For these reasons, it was concluded that warm lateral compaction would be the better option for filling canals in teeth with minimally invasive access preparations. Silva *et al.* (2020) compared UltraAC and TradAC regarding the percentage of voids created after filling root canals of two-rooted maxillary premolars with round cross-sectional shapes. The authors reported that canal filling was not impaired by access design, possibly because of the round root canal cross section; however, the operator was unable to remove remnants of filling materials from the pulp chamber prior to restoration of teeth with UltraAC, even with the aid of ultrasonic tips, magnification, and extra time to complete treatment. This extended operative period might lead to the fatigue of both patient and dentists, whilst the filling remnants can compromise aesthetics by causing tooth crown discoloration over time (Lenherr *et al.* 2012, Marchesan *et al.* 2018).

Only one study assessed the influence of different access designs on retreatment procedures. Niemi *et al.* (2016) used the sectioning method to evaluate the effectiveness of rotary systems on the removal of root filling materials from oval-shaped canals of single-rooted mandibular premolars (Table 2). Overall, teeth with ConsAC were associated with more filling remnants on root canal walls than TradAC. However, a possible access/instrument interaction was also demonstrated since the combination of ConsAC with ProFile Vortex Blue rotary system (Dentsply Sirona Endodontics, Tulsa, OK, USA) was associated with a significantly greater amount of filling remnants, whilst no difference was found comparing retreatment of teeth with TradAC or ConsAC using the TRUShape system (Dentsply Sirona Endodontics). On the other hand, more time was required for retreatment of teeth with the latter combination. In this study, however, no measurements regarding the percentage of filling remnants in relation to the original volume of the filling materials (baseline) were provided.

Summary. Evaluating the outcome of canal filling and retreatment procedures when using different types of

Table 2 Overall description of the *ex vivo* and *in vitro* studies that evaluated different types of minimally access cavity preparations converting most of abbreviation types used in the original studies into the new proposal classification system to allow proper comparisons

Authors	Year	Country	Teeth	*n*	Groups	Methods	Main results	Main findings
Abou-Elnaga *et al.*	2019	Egypt	Mandibular 1st molars	66	Control TradAC TrussAC	Fracture resistance	Control = TrussAC> TradAC	TrussAC improved the fracture resistance of endodontically treated molars with mesio-occluso-distal cavities.
Alovisi *et al.*	2018	Italy/ France	Mandibular molars	30	TradAC ConsAC	Micro-CT	TradAC> ConsAC	TradAC showed better preservation of the canal anatomy and less apical transportation than ConsAC.
Chlup *et al.*	2017	Czech Republic	Premolars	60	Control TradAC ConsAC	Fracture resistance	Control = TradAC = ConsAC	There was no difference in the fracture resistance between TradAC and ConsAC compared to the control group.
Corsentino *et al.*	2018	Italy	Mandibular molars	100	Control TradAC ConsAC TrussAC	Fracture resistance	Control> TradAC = ConsAC = TrussAC	TrussAC did not improve the fracture resistance of teeth. The loss of mesial and distal ridges significantly decreased the strength resistance, independent of the access cavity type.
Eaton *et al.*	2015	USA	Mandibular molars	30	ConsAC SLF SLR	Micro-CT	ConsAC> SLF> SLR	ConsAC showed the highest mean primary angle at the maximum curvature of mesial root canals.
Freitas *et al.*	2020	Brazil	Maxillary molars	20	TradAC ConsAC	Micro-CT	(1) Dentine removal: TradAC = ConsAC (2) Transport/ centering ability: TradAC = ConsAC	The type of endodontic access cavity did not influence the root canal preparation.
Ivanoff *et al.*	2017	USA	Mandibular premolars	45	Control TradAC ConsAC	Fracture resistance	Control = TradAC = ConsAC	ConsAC did not improve the fracture resistance of teeth with mesio-occlusal restored cavities compared to TradAC.
Jiang *et al.*	2018	China	Maxillary 1st molars	3	TradAC ConsAC ExtAC	FEA	(1) Occlusal stress: TradAC = ConsAC = ExtAC (2) Pericervical dentine stress: ConsAC < TradAC < ExtAC	The stress on the pericervical dentine increased with the enlargement of the access cavity.

Table 2 Continued

Authors	Year	Country	Teeth	*n*	Groups	Methods	Main results	Main findings
Krishan *et al.*	2014	Canada	Maxillary central incisors, mandibular 2nd premolars and mandibular 1st molars	90	Control TradAC ConsAC	Micro-CT Fracture resistance	(1) Untouched canal walls: distal canal (ConsAC> TradAC); mesial canal, incisor and premolar canals (ConsAC = TradAC); (2) Dentine removal: incisors (TradAC> ConsAC); premolars (TradAC> ConsAC); molars (TradAC> ConsAC); (3) Fracture resistance: incisors (Control = TradAC = ConsAC); premolars and molars (Control = ConsAC> TradAC)	ConsAC resulted in significantly less dentine removal, improved fracture resistance (mandibular premolars and molars), and high untouched dentine walls after preparation at the apical third of distal root canals, compared to TradAC.
Lin *et al.*	2020	Taiwan	Maxillary and mandibular molars	36	TradAC ConsAC UltraAC	CBCT	Cervical dentine removal: TradAC> ConsAC = UlraAC	Cervical dentine removal was higher with the TradAC.
Makati *et al.*	2018	India	Molars	60	TradAC ConsAC	CBCT/ Fracture resistance	(1) Dentine thickness: ConsAC> TradAC (2) Fracture resistance: ConsAC> TradAC	ConsAC doubled the fracture resistance of teeth compared to TradAC.
Mendes *et al.*	2020	Brazil	Mandibular 1st molars	60	TradAC ConsAC	Operating Microscope	Detection of middle mesial canals: TradAC = ConsAC	The detection of middle mesial canals in mandibular molars was not affected by the access cavity design.
Moore *et al.*	2016	Canada/ USA	Maxillary molars	57	Control TradAC ConsAC	Micro-CT Fracture resistance	(1) Modified canal walls: ConsAC = TradAC (2) Axial microstrain: ConsAC = TradAC (3) Fracture resistance: Control> TradAC = ConsAC	ConsAC performed similarly to TradAC regarding the mean proportion of modified canal walls, axial microstrain values and fracture resistance.
Neelakantan *et al.*	2018	China	Mandibular 1st molars	32	TradAC TrussAC	Histology	Remaining pulp tissue in the pulp chamber (TrussAC> TradAC) and mesial canal system (TrussAC = TradAC)	TrussAC showed higher amount of remaining pulp tissue in the pulp chamber compared with TradAC, but no difference within the mesial root canal system.

Table 2 Continued

Authors	Year	Country	Teeth	*n*	Groups	Methods	Main results	Main findings
Niemi *et al.*	2016	USA	Mandibular premolars	48	TradAC ConsAC	Root sectioning	Filling remnants after retreatment: ConsAC> TradAC	ConsAC resulted in more filling remnants than TradAC. Neither ProFile Vortex Blue nor TRUShape were able to remove all filling materials. ProFile Vortex Blue removed less filling material with the ConsAC mostly at the coronal and middle thirds. More time was required for retreatment of teeth with ConsAC using the TRUShape system.
Özyürek *et al.*	2018	Turkey	Mandibular 1st molars	100	Control TradAC ConsAC	Fracture resistance	Control> TradAC = ConsAC	ConsAC did not improve the fracture resistance of teeth with class II cavities compared to TradAC. More restorable fracture patterns were observed in teeth with ConsAC.
Plotino *et al.*	2017	Italy	Premolars and molars	160	Control TradAC ConsAC UltraAC	CBCT Fracture resistance	Control = ConsAC = UltraAC> TradAC	TradAC showed lower fracture resistance than ConsAC and UltraAC in noncarious teeth. Unrestorable fractures were more frequent in the experimental groups than in the control group.
Roperto *et al.*	2019	USA/ Brazil	Maxillary 1st premolars	32	Control TradAC ConsAC ConsAC.DW	Fracture resistance FEA	Control = TradAC = ConsAC = ConsAC.DW	ConsAC performed similarly to the TradAC and intact teeth in terms of fracture resistance strength. Stress level on the palatal cusps and proximal crests were slightly increased in the TradAC. In the restored teeth, the stress levels of the experimental groups were similar to the control group.
Rover *et al.*	2017	Brazil	Maxillary 1st molars	30	TradAC ConsAC	Micro-CT Fracture resistance	(1) Nonprepared areas: TradAC = ConsAC (2) Hard tissue debris accumulation: TradAC = ConsAC (3) Transportation: ConsAC> TradAC (4) Fracture resistance: TradAC = ConsAC	ConsAC and TradAC performed similar in terms of nonprepared areas, debris accumulation and fracture resistance. Transportation was higher at the palatal canal of ConsAC teeth. In the distobuccal canals, ConsAC maintained the preparation more centralized 5 mm from the apex. A higher detection of MB2 canal with or without magnification was observed in the TradAC teeth, but no difference was observed when ultrasonic tip was associated to magnification.

Table 2 Continued

Authors	Year	Country	Teeth	*n*	Groups	Methods	Main results	Main findings
Saberi *et al.*	2020	Iran	Mandibular molars	60	Control TradAC TrussAC	Fracture resistance	(1) Without thermocycling: Control = TrussAC> TradAC (2) With thermocycling: Control> TrussAC> TradAC	Under thermal stress, TrussAC increased the fracture strength of teeth compared with the TradAC.
Sabeti *et al.*	2018	USA/ Iran	Maxillary molars	48	Control TradAC ConsAC	Fracture resistance	Control> TradAC = ConsAC	ConsAC did not improved the fracture resistance of maxillary molars compared to TradAC.
Saygili *et al.*	2018	Turkey	Maxillary 1st molars	60	TradAC ConsAC UltraAC	CBCT	MB2 orifice location: TradAC = ConsAC> UltraAC	Detection of MB2 orifice was lower in UltraAC teeth compared to TradAC and ConsAC.
Silva *et al.*	2020	Brazil	Maxillary premolars	20	TradAC UltraAC	Micro-CT Fracture resistance	(1) Untouched areas: TradAC = UltraAC; (2) hard tissue debris accumulated: UltraAC> TradAC; (3) voids in root fillings: TradAC = UltraAC; (4) filling remnants in the pulp chamber: UltraAC> TradAC; (5) preparation time: UltraAC> TradAC; (6) fracture resistance: TradAC = UltraAC	UltraAC did not influence the quality of root canal filling or the fracture resistance of the teeth compared to TradAC, but resulted in more debris accumulation after preparation, more filling remnants at the pulp chamber after obturation, and increased time required to perform the endodontic treatment.
Tüfenkçi & Yilmaz	2020	Turkey	Mandibular 1st molars	80	TradAC ConsAC	Culture	Bacterial reduction: TradAC = ConsAC	No difference was observed between the access cavity designs regarding the reduction of *E. faecalis* after canal preparation.
Vieira *et al.*	2020	Brazil/ Norway	Mandibular incisors	62	TradAC ConsAC	qPCR Micro-CT	(1) Unprepared areas: ConsAC = TradAC (2) Number of positive samples for bacteria: ConsAC> TradAC	ConsAC performed similarly to TradAC in terms of unprepared canal areas but compromised the disinfection procedures. TradAC showed 82% lower bacteria counting than ConsAC.
Wang *et al.*	2020	China	Maxillary 1st molars	8	TradAC ConsAC	FEA	Stress concentration areas: TradAC> ConsAC	ConsAC reduced the failure probability and the maximum stress at the cervical region compared to TradAC.

Table 2 Continued

Authors	Year	Country	Teeth	*n*	Groups	Methods	Main results	Main findings
Yuan *et al.*	2016	China	Mandibular 1st molars	6	TradAC ConsAC	FEA	Stress concentration areas: TradAC> ConsAC	ConsAC reduced the stress distribution at the crown and the cervical level compared to TradAC. The highest stress concentration was observed at the margins of the cavities on the occlusal surface and was dependent on the enlargement of the canal orifices. ConsAC preserved almost 60% additional hard dental tissue compared to TradAC.
Zhang *et al.*	2019	China	Maxillary 1st molars	4	Control TradAC ConsAC UltraAC	Extended FEA	Stress concentration areas: ConsAC = TradAC> Control = UltraAC	Compared to TradAC, UltraAC increased the curvature of the endodontic instrument and the estimated fracture load of dentine, but reduced the stress concentration. Peaks of maximum stress at the cervical region were higher as the removal of hard dental tissue increased. UltraAC and ConsAC preserved 43.5% and 34.3% of coronal hard tissue, respectively, compared to TradAC.

CBCT, cone beam computed tomography; ConsAC, conservative access cavity; ConsAC.DW, ConsAC with divergent walls; Control, intact teeth; ExtAC, extended access cavity; FEA, finite element analysis; MB2, second root canal of the mesiobuccal root of maxillary molars; micro-CT, micro-computed tomography; q-PCR, quantitative real-time polymerase chain reaction; SLF, straight-line furcation; SLR, straight-line radicular; TradAC, traditional access cavity; TrussAC, truss access cavity; UltraAC, ultra-conservative access cavity.

Table 3 Methodological details of studies reporting the influence of minimally invasive access cavity preparation on the fracture resistance of teeth

Reference	Tooth type	Main results	Sample age	Freshly extracted teeth	Occlusal cavity	Control group	Canal shaping	Canal obturation	Tooth restoration	Selection method
Abou-Elnaga *et al.* (2019)	Mandibular 1st molars	Control = TrussAC> TradAC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	CBCT
Chlup *et al.* (2017)	Premolars	Control = TradAC = ConsAC	–	–	–	Yes	Yes	Yes	Yes	Not reported
Corsentino *et al.* (2018)	Mandibular Molars	Control> TradAC = ConsAC = TrussAC	–	Yes	Yes	Yes	Yes	Yes	Yes	Radiography and external measurement of teeth
Ivanoff *et al.* (2017)	Mandibular Premolars	Control = TradAC = ConsAC	–	–	Yes	Yes	Yes	–	Yes	External measurement of teeth
Krishan *et al.* (2014)	Premolars Molars Incisors	Control = ConsAC> TradAC Control = ConsAC> TradAC Control = TradAC = ConsAC	–	–	–	Yes	Yes	–	–	Radiography
Makati *et al.* (2018)	Molars	ConsAC> TradAC	–	–	–	–	Yes	Yes	Yes	Not reported
Moore *et al.* (2016)	Maxillary Molars	Control> TradAC = ConsAC	–	–	–	Yes	Yes	–	Yes	Radiography
Özyürek *et al.* (2018)	Mandibular Molars	Control> TradAC = ConsAC	Yes	–	Yes	Yes	Yes	Yes	Yes	External measurement of teeth
Plotino *et al.* (2017)	Premolars Molars	Control = ConsAC = UltraAC> TradAC	–	Yes	–	Yes	Yes	Yes	Yes	External measurement of teeth
Roperto *et al.* (2019)	Maxillary 1st premolars	Control = TradAC = ConsAC = ConsAC.DW	–	–	–	Yes	Yes	Yes	Yes	External measurement of teeth
Rover *et al.* (2017)	Maxillary Molars	TradAC = ConsAC	–	–	–	–	Yes	Yes	Yes	Micro-CT
Sabeti *et al.* (2018)	Maxillary Molars	Control> TradAC = ConsAC	–	–	–	Yes	–	–	–	External measurement of teeth
Saberi *et al.* (2020)	Mandibular Molars	Control> TrussAC> TradAC	–	Yes	–	Yes	Yes	Yes	Yes	External measurement of teeth
Silva *et al.* (2020)	Maxillary Premolars	TradAC = UltraAC	–	–	–	–	Yes	Yes	Yes	Micro-CT

Control, intact teeth; TradAC, traditional access cavity; ConsAC, conservative access cavity; TrussAC, truss access cavity; UltraAC, ultra-conservative access cavity; ConsAC.DW, ConsAC with divergent walls; CBCT, cone beam computed tomography; Micro-CT, micro-computed tomography.

access preparations remains a topic to be explored. Up to now, studies have suggested a possible influence of the cross-sectional canal shape on the outcome of filling procedures and difficulties in removing filling material from the pulp chamber in teeth with minimally invasive access cavities. Retreatment procedures in the presence of a ConsAC took more time, whilst instruments with asymmetric cutting motions seemed to be more effective as other rotary instruments for the removal of filling materials from oval-shaped canals of single-rooted teeth with TradAC.

Influence of minimally invasive access preparation on the fracture resistance of teeth

One of the most important conditions that contribute to the susceptibility of a tooth to fracture includes the removal of large amounts of sound dentine during the endodontic and restorative procedures (Tamse 2006, Khan *et al.* 2015, Kishen, 2015). In this way, the minimally invasive concept in endodontics was founded on the premise that dentine conservation during access cavity preparation was an essential measure to maintain optimal strength, fracture resistance and several other characteristics needed for the long-term function and survival of root filled teeth (Clark & Khademi 2010a). However, although it is being adopted clinically by some dentists, the influence of minimally invasive access cavity preparation on the fracture resistance of teeth has only limited supporting evidence. In the literature, fourteen studies evaluated the fracture resistance of extracted teeth with minimally invasive access preparations (Table 3). Whilst in five studies (Krishan *et al.* 2014, Plotino *et al.* 2017, Makati *et al.* 2018, Abou-Elnaga *et al.* 2019, Saberi *et al.* 2020), the fracture resistance of teeth with minimally invasive access preparations were greater than TradAC, no difference was observed in the other nine studies (Moore *et al.* 2016, Chlup *et al.* 2017, Ivanoff *et al.* 2017, Rover *et al.* 2017, Corsentino *et al.* 2018, Özyürek *et al.* 2018, Sabeti *et al.* 2018, Roperto *et al.* 2019, Silva *et al.* 2020). It is also possible that some methodological issues have confounded the reliability of the results and explain at least some of these variations.

Several risk factors may be involved in tooth fracture including the morphology of the crown and the root (Qian *et al.* 2013, Kang *et al.* 2016). Consequently, sample selection based on the external and internal anatomy of the teeth represents a critical step for the accomplishment of validity of the results of fracture resistance tests. Within the 14 selected studies, two did not report how specimen selection was performed (Chlup *et al.* 2017, Makati *et al.* 2018), whilst most of them used only the external measurement of the teeth and/or two-dimensional radiographs for sample selection and allocation to the experimental groups (Krishan *et al.* 2014, Moore *et al.* 2016, Ivanoff *et al.* 2017, Plotino *et al.* 2017, Corsentino *et al.* 2018, Özyürek *et al.* 2018, Sabeti *et al.* 2018, Roperto *et al.* 2019, Saberi *et al.* 2020). This lack of anatomical matching of the samples is likely to compromise the internal validity of these studies and raise questions regarding the trustworthiness of the results (De-Deus *et al.* 2020). Even though it is yet to be proven, it is likely that the volume of the pulp chamber and the thickness, height and/or volume of the remaining tooth tissue would affect the fracture resistance of teeth. These parameters can only be quantified using nondestructive three-dimensional imaging tools such as CBCT or micro-CT technologies. In this review, sample selection using these strict and more accurate tools was performed in only three studies (Rover *et al.* 2017, Abou-Elnaga *et al.* 2019, Silva *et al.* 2020).

Tooth age is another important aspect in sample selection; however, it is by far the most neglected requirement in experiments published on this topic (Versiani *et al.* 2015). Various studies agree that aging negatively impacts tooth toughness and ductility by reducing the endurance limit of dentine (Arola & Reprogel 2005, Kinney *et al.* 2005, Bajaj *et al.* 2006, Nazari *et al.* 2009, Ivancik *et al.* 2012); however, this parameter was not reported in most of the included articles (Table 3). Also to be noted are the extraction technique, conditions of storage and sample pre-treatment that followed immediately after tooth extraction. With the exception of Chlup *et al.* (2017) and Roperto *et al.* (2019), all other studies reported the time and medium used and storage conditions to prevent tooth dehydration. However, none of them reported the extraction technique used. Interestingly, one study simulated the aging of the teeth by thermocycling before the fracture resistance test (Saberi *et al.* 2020). Authors reported that without thermocycling, the fracture strength of teeth with TradAC and TrussAC was similar to control teeth, but when exposed to thermocycling, teeth with TradAC had the lowest fracture resistance strength.

After selection of teeth using strict criteria, sample preparation before the fracture test is another critical step that may affect the outcome of experimental procedures. In four studies (Ivanoff *et al.* 2017, Corsentino *et al.* 2018, Özyürek *et al.* 2018, Abou-Elnaga *et al.* 2019), various types of occlusal cavities were prepared prior to access cavity preparation (Table 3) aiming to simulate a common clinical scenario in teeth that require root canal treatment. However, in fact, this procedure introduced a confounding variable to the test considering that cavity preparation for restorations may reduce tooth stiffness by more than 60% (Reeh *et al.* 1989, Kishen, 2015). Unfortunately, experiments using real teeth do not allow the standardization of the total volume of dentine removal or the exact dimensions of a cavity amongst samples. In other studies, root canals were not prepared (Sabeti *et al.* 2018) or filled (Krishan *et al.* 2014, Moore *et al.* 2016, Ivanoff *et al.* 2017, Sabeti *et al.* 2018), and the crowns were not restored (Krishan *et al.* 2014, Sabeti *et al.* 2018) before the fracture test (Table 3). Even though the authors justified these approaches to avoid adding confounding factors related to these variables, it was not taken into consideration that the dentine removed by the root canal preparation would also affect the fracture resistance of teeth (Tang *et al.* 2010), the root canal filling might contribute to the re-establishment of the fracture resistance of teeth (Sandikci & Kaptan 2014), and the restoration of teeth can restore fracture resistance to root filled teeth by approximately 80% (Hamouda & Shehata 2011). As a result, conclusions on the influence of access cavity preparation on tooth strength drawn from these studies are at least questionable. One way to overcome most of the previously mentioned drawbacks is by using an approach based on a combination of virtual models and simulations, the so-called finite element analysis method (FEA). This method was used in four studies to evaluate the stress concentration areas on standardized models obtained from real teeth in which different types of access cavities were simulated (Yuan *et al.* 2016, Jiang *et al.* 2018, Zhang *et al.* 2019, Wang *et al.* 2020). Interestingly, all simulations showed larger stress concentration areas in the cervical region of teeth with TradAC compared to ConsAC.

Summary

Most laboratory studies reported unsatisfactory results with no scientific evidence demonstrating a real benefit of minimally invasive access for improving the fracture resistance of teeth. Future research must be focused in overcoming the methodological drawbacks of existing studies in an attempt to mimic as much as possible clinical conditions without adding confounding factors to the experiment by matching samples based on the age and 3D morphological dimensions of teeth and also simulating oral masticatory function and aging using mechanical and/or thermal cycling. Besides, it would be also of benefit to test fracture resistance by employing a combination of virtual 3D models of teeth and surrounding tissues (finite element analysis method) acquired by scanning real cadaver bone blocks with micro-CT. Finally, clinical trials would help to fill gaps on this knowledge since patient-related factors such as bruxism, trauma, periodontitis and antagonist teeth cannot be properly simulated in laboratory conditions. It is also essential that clinicians who advocate a shift from conventional access preparations should produce more than empiricisms or trends based on case reports or posts in social media, but real scientific-based clinical knowledge.

Conclusions

The numerous acronyms proposed to identify new minimally invasive access cavity preparations severely compromised the comprehension and readability of the articles, and new nomenclature based on self-explaining abbreviations is suggested. Considering the available scientific data, there is a lack of robust evidence to support the claim that minimally invasive endodontic access cavities preserve the fracture resistance of root filled teeth more than traditional access preparation. On the other hand, although the appraised studies had a wide range of methodological flaws or reported unsatisfactory and/or inconclusive results, performing ConsAC seemed not to affect several clinical procedures related to root canal treatment if performed under specific conditions, including the use of 3D imaging technology, operating microscope, high illumination, thin ultrasonic tips, irrigant activation and flexible instruments. However, more conservative access cavities, such as TrussAC and UltraAC, negatively affected canal transportation and irrigation procedures and are not recommended, particularly in teeth with necrotic pulps. Considering that additional research is needed to provide robust and conclusive evidence on all of these topics, it can be concluded that there is a lack of supporting evidence for the introduction of minimally invasive access cavity preparation into routine clinical practice and/or training of undergraduate and postgraduate students.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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