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Benoit Ballester, Thomas Giraud, Hany Mohamed Aly Ahmed, Mohamed Shady Nabhan, Frédéric Bukiet, et al.. Current strategies for conservative endodontic access cavity preparation techniques-systematic review, meta-analysis, and decision-making protocol. *Clinical Oral Investigations*, 2021, 25 (11), pp.6027-6044. 10.1007/s00784-021-04080-7. hal-03464008

HAL Id: hal-03464008

<https://hal.science/hal-03464008>

Submitted on 15 Apr 2022

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Current strategies for conservative endodontic access cavity preparation techniques—systematic review, meta-analysis, and decision-making protocol

Benoit Ballester^{1,2} · Thomas Giraud^{1,3} · Hany Mohamed Aly Ahmed⁴ · Mohamed Shady Nabhan⁵ · Frédéric Bukiet^{1,3}  · Maud Guivarc'h^{1,6}

Received: 30 March 2021 / Accepted: 13 July 2021 / Published online: 8 October 2021

Abstract

Objectives To assess related studies and discuss the clinical implications of endodontic access cavity (AC) designs.

Materials and methods A systematic review of studies comparing the fracture resistance and/or endodontic outcomes between different AC designs was conducted in two electronic search databases (PubMed and Web of Science) following the PRISMA guidelines. Study selection, data extraction, and quality assessment were performed. Meta-analyses were undertaken for fracture resistance and root canal detection, with the level of significance set at 0.05 ($P = 0.05$).

Results A total of 33 articles were included in this systematic review. The global evaluation of the risk of bias in the included studies was assessed as moderate, and the level of evidence was rated as low. Four types of AC designs were categorized: traditional (TradAC), conservative (ConsAC), ultraconservative (UltraAC), and truss (TrussAC). Their impact on fracture resistance, cleaning/disinfection, procedural errors, root canal detection, treatment time, apical debris extrusion, and root canal filling was discussed. Meta-analysis showed that compared to TradAC, (i) there is a significant higher fracture resistance of teeth with ConsAC, TrussAC, or ConsAC/TrussAC when all marginal ridges are preserved ($P < 0.05$), (ii) there is no significant effect of the type of AC on the fracture resistance of teeth when one or two marginal ridges are lost ($P > 0.05$), and (iii) there is a significantly higher risk of undetected canals with ConsAC if not assisted by dental operating microscope and ultrasonic troughing ($P < 0.05$).

Conclusions Decreasing the AC extent does not necessarily present mechanical and biological advantages especially when one or more surfaces of the tooth structure are lost. To date, the evidence available does not support the application of TrussAC. UltraAC might be applied in limited occasions.

Clinical relevance Maintaining the extent of AC design as small as practical without jeopardizing the root canal treatment quality remains a pragmatic recommendation. Different criteria can guide the practitioner for the optimal extent of AC outline form which varies from case to case.

Keywords Endodontic access cavity · Conservative access cavity · Minimally invasive access cavity · Root canal treatment

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Introduction

Endodontic access cavity (AC) preparation is an essential prerequisite for effective instrumentation and filling of the root canal space (1). For decades, the outline form of the endodontic AC was standardized for every tooth type and its design followed the principles of “convenience form” and “extension for prevention”. The main purpose of this endodontic approach was to achieve complete deroofing of the pulp chamber for adequate access and visibility to the root canal orifice(s) while limiting the risk of procedural errors (1–3); however, little consideration was given to the dental tissue preservation.

The last decade has witnessed considerable evolutions for minimal intervention and many of the traditional principles taught in the past were critically revised (4,5). “Minimally invasive dentistry” is a modern approach aiming to prevent or treat diseases with a maximal preservation of the dental tissues (6). Technological advances in optics (magnification and illumination), diagnostic procedures (3D diagnostic modalities such as cone beam computed tomography), software programs as well as root canal instrumentation (nickel titanium metallurgy, kinematics, file design) resulted in new strategies based on minimal invasive concepts in the different phases of root canal treatment procedures including AC designs. In the past few years, a growing interest on more conservative AC designs has emerged. This trend was mainly based on the assumption that preservation of tooth structure during endodontic AC preparation would improve the fracture resistance of teeth (7).

Literature shows that the terminology used to characterize the different conservative AC designs is inconsistent and confusing which may lead to misleading interpretations of related research studies. Recently, a new nomenclature was proposed that considered 4 main geometric types of AC designs: traditional access cavity (TradAC), conservative access cavity (ConsAC), ultraconservative access cavity (UltraAC), and truss access cavity (TrussAC) (8).

The impact of different AC designs on fracture resistance and other properties has been extensively investigated. Therefore, a systematic review of related studies and meta-analysis are needed to provide a careful synthesis of results. Based on the available knowledge on AC, this work aims to assess and discuss the clinical implications of conservative endodontic cavity designs. In addition, decision-making criteria are proposed in this systematic review to help clinicians for proper planning of AC designs.

Material and methods

A systematic review of publications related to minimal endodontic access cavity was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses

(PRISMA) guidelines (9). The protocol has been registered with the International Prospective Register of Systematic Reviews (PROSPERO number CRD42020159657).

Research question

The following research question for the current systematic review was designed based on the Problem, Intervention, Comparison, Outcome, Study design (PICOS) framework:

Is there an improvement in the fracture resistance and other properties related to mechanical instrumentation (O) when performing TrussAC, ConsAC and UltraAC (I) on human mature teeth (P) compared to TradAC (C) in experimental and clinical studies (S)?

Literature search methodology

Electronic search strategy

In December 2020, an electronic search was conducted in PubMed database (2000 to present) and the Web of Science database (2000 to present) using the following search keywords:

((Conservative access cavity) OR (Contracted access Cavity) OR (Minimal invasive access) OR (Truss access cavity) OR (Ninja Cavity) OR (Orifice directed access cavity) OR (Modern access cavity)) AND (Endodontics OR Endodontic) AND (“01/01/2000”[Date—Publication]: “3000”[Date—Publication]).

Selection criteria

Inclusion criteria

- Studies comparing fracture resistance and/or endodontic outcomes between different endodontic cavity designs (TradAC and/or ConsAC and/or UltraAC and/or TrussAC)
- Ex vivo and clinical studies performed in human permanent teeth
- Finite element analysis studies
- Peer-reviewed studies published in English

Exclusion criteria

- Studies performed in training simulated resin teeth or animal teeth
- Studies investigating guided endodontic cavities
- Editorial and commentary publications
- Case reports or series publications

Study selection

After the removal of duplicate publications, selection of studies was undertaken by screening the title and abstract and the full-text assessment was independently performed by two reviewers (BB, MG). Any disagreement was resolved by a third reviewer (FB). The references listed in the retrieved full-text articles were also reviewed to identify additional eligible publications.

Data extraction

After the study selection process, two reviewers (BB, MG) independently identified and categorized the available information in the selected publications. The type of AC evaluated in the studies was categorized between TradAC, ConsAC, UltraAC, and TrussAC following the criteria previously described by Silva et al. (8) (Fig. 1). An evaluation of the parameters assessed in each study with different AC designs was conducted (Table 1).

Quality assessment

Before quality assessment, the 2 reviewers (BB, MG) discussed each item in the appraisal instrument for each study included in this review taking into consideration the specific characteristics of eligible studies. Each included study was evaluated for methodological risk of bias independently by two authors (TG, MG). A quality appraisal was performed according to a methodology used in previous systematic reviews (10,11). The following parameters were taken into

consideration for each study quality assessment: (i) sample size calculation, (ii) samples with similar dimensions, (iii) control group, (iv) standardization of procedures, (v) statistical analysis, and (vi) other risk of bias. Using the robvis visualization tool, the risk of bias was assigned as “low” (green dot), “high” (red dot), or “some concerns” (yellow dot) (12). Then, the overall risk of bias was judged for each included publication taking into consideration the previous analysis:

- Low risk of bias (studies that met at least five of the six quality criteria)
- Moderate risk of bias (studies that met three or four of the quality criteria)
- High risk of bias (studies that met only one or two of the quality criteria)

The presence of at least one red dot led to moderate or high risk of bias depending on the evaluation of the other parameters. Any disagreement between two authors was resolved through discussion with a third reviewer (FB).

Meta-analyses

Two authors designed the meta-analysis of this systematic review (HA, MN). The analysis was undertaken for the fracture resistance of teeth for AC class I (occlusal endodontic access with no loss of marginal ridges) and AC class II (endodontic access with loss of one or two marginal ridges), which were divided into the following subgroups:

Fig. 1 Illustration of 4 different access cavity designs (TradAC, ConsAC, UltraAC, and TrussAC) on maxillary premolars, maxillary molars, and mandibular molars. TrussAC has been mainly described on mandibular molars

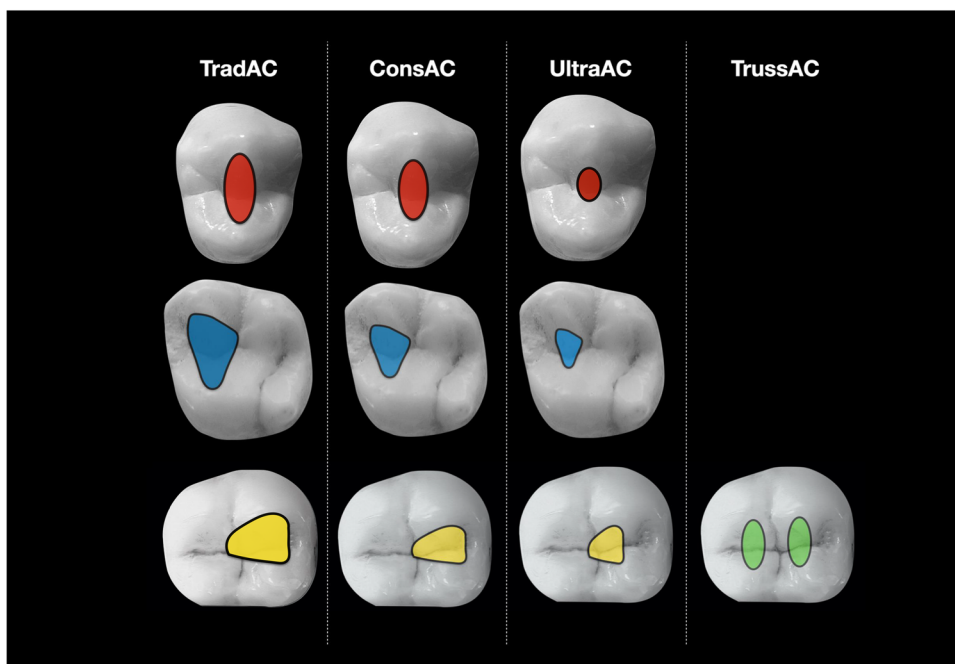


Table 1 Parameters evaluated in the studies

Authors, year	Study design	Tooth type	Type of access cavity (AC)				Parameters evaluated								
			Trad AC	Cons AC	Ultra AC	Truss AC	Fracture resistance	Cleaning ability	Procedural errors	Treatment time	Instrumentation	Canal detection	Obturation	Apical debris extrusion	
Abou-Elnaga et al. 2019 ^[19]	EV	Post	X			X									
Allen et al. 2018 ^[18]	FEA	Post	X		X*		SD								
Alovisi et al. 2018 ^[20]	EV	Post	X	X					CT		FS				
Barbosa et al. 2020 ^[31]	EV	Post	X	X		X		BL/UCW	CA/CT		FS				
Chlup et al. 2017 ^[32]	EV	Post	X	X											
Corsentino et al. 2018 ^[33]	EV	Post	X	X		X									
Freitas et al. 2020 ^[21]	EV	Post	X		X				CT						
Ivanoff et al. 2017 ^[43]	EV	Post	X	X											
Jiang et al. 2018 ^[22]	FEA	Post	X	X			SD								
Kainath et al. 2018 ^[34]	EV	Post	X	X				GPR							
Krishan et al. 2014 ^[35]	EV	Ant/Post	X	X				UCW			FS				
Makati et al. 2018 ^[44]	EV	Post	X	X											
Marchesan et al. 2018 ^[36]	EV	Post	X	X					CT		FS				
Maske et al. 2020 ^[14]	EV	Post	X		X*										
Mendes et al. 2020 ^[23]	EV	Post	X	X								MMC			
Moore et al. 2016 ^[24]	EV	Post	X	X				MCW			FS				
Neelakantan et al. 2018 ^[37]	EV	Post	X	X		X		RPT							
Niemi et al. 2016 ^[38]	EV	Post	X	X				GPR							
Özyürek et al. 2018 ^[7]	EV	Post	X			X*									
Plotino et al. 2017 ^[39]	EV	Post	X	X	X										
Rover et al. 2017 ^[40]	EV	Post	X	X				UCW/AHTD	CT		FS	MB2			
Saber et al. 2020 ^[25]	FEA	Post	X	X		X	SD								
Saberi et al. 2020 ^[26]	EV	Post	X			X									
Sabeti et al. 2018 ^[45]	EV	Post	X	X											
Saygili et al. 2018 ^[41]	EV	Post	X	X	X							MB2			
Silva et al. 2020 ^[42]	EV	Post	X		X			UCW/AHTD							
Silva et al. 2020 ^[27]	EV	Post	X		X						Cyclic fatigue				
Tüfenkçi et al. 2020 ^[28]	EV	Post	X	X				BL							
Tüfenkçi et al. 2020 ^[29]	EV	Post	X	X											
Vieira et al. 2020 ^[30]	EV	Ant	X	X				BL/UCW							
Wang et al. 2020 ^[17]	FEA	Post	X		X*		SD								
Yuan et al. 2016 ^[15]	FEA	Post	X		X*		SD								
Zhang et al. 2019 ^[16]	FEA	Post	X	X*	X*		SD								

EV: ex vivo studies / FEA: Finite element analysis studies

Ant: Anterior / AHTD: Accumulation of hard Tissues Debris / BL: Bacteria load / CA: Centering Ability/ CT: Canal Transportation / FS: File Separation / GPR: Gutta-Percha removal / MB2: Second Mesio Buccal Canal / MCW: Modified Canal Walls / MMC: Middle Mesial Canal / Post: Posterior / RPT: Remaining pulp tissue / SD: Stress distribution / UCW: Untouched Canal Walls

Grey boxes represent the parameters evaluated in the included studies.

*Recategorized

- TradAC compared to ConsAC
- TradAC compared to TrussAC
- TradAC compared to ConsAC and TrussAC as one group

Another meta-analysis was undertaken for detection of canals (TradAC compared to ConsAC) under the following different conditions:

- No magnification
- Operative microscope only
- Operative microscope combined with ultrasonic troughing

The statistical analysis was carried out using the Review Manager software (Revman 5.4). For continuous

data (fracture resistance), the mean difference with 95% confidence interval was used. For categorical data (canal detection), the risk ratio with 95% confidence interval was used. The statistical heterogeneity was assessed in each meta-analysis by examining the forest plot and using the I^2 and Chi^2 statistics. The authors interpreted I^2 based on the guidelines given in the Cochrane Handbook such that an 0 to 40% might not be important; 30 to 60% may represent moderate heterogeneity; 50 to 90% may represent substantial heterogeneity; 75 to 100% considerable heterogeneity. Chi^2 test was considered statistically significant with a P value less than 0.1. The authors used the formula described in Cochrane Handbook for combining groups (13).

Results

Following the PRISMA selection process, a total of 33 full-text articles were included in this systematic review: 27 were ex vivo studies, 6 were finite element analysis (FEA) studies, and no clinical study was available (Fig. 2). All studies referred to TradAC as a study group of comparison with either ConsAC and/or UltraAC and/or TrussAC (Table 1). Two out of 33 studies investigated the impact of endodontic AC on anterior teeth.

Terminology and classification of the AC

The terminology, descriptions, and illustrations of the different AC types were assessed in all studies and arranged into the 4 categories previously mentioned: TradAC, ConsAC, Ultra AC, and TrussAC (8). Inconsistencies were noticed in 6 publications between the description of the AC type and their nomenclature given by the authors:

- One TrussAC was designated as a ConsAC although there were two distinct occlusal cavities separated by an enamel/dentinal bridge (7).
- 5 UltraAC were designated as ConsAC although the occlusal access was punctual with no extension (14–18).

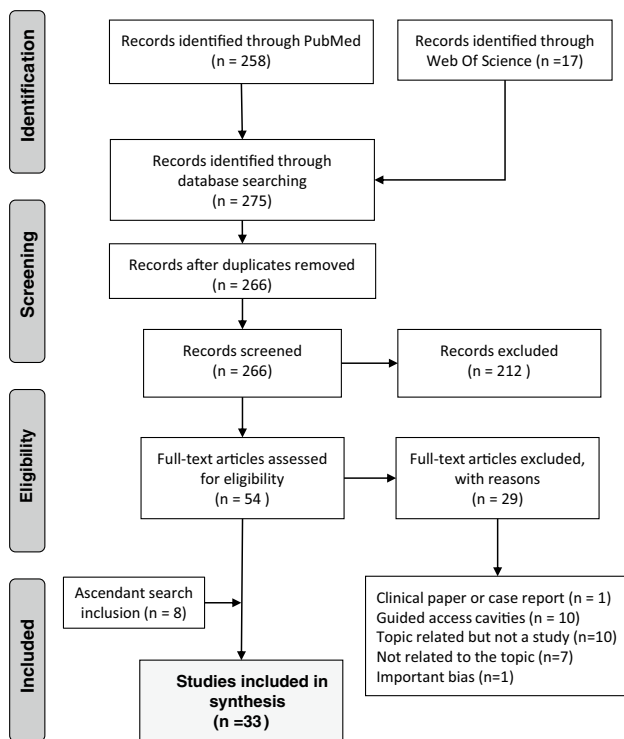


Fig. 2 PRISMA flowchart for studies selection

Final categorization of the AC types and renaming was validated by the reviewers.

Quality assessment

Of the 33 studies included, the risk of bias was evaluated as low ($n = 12$) (19–30), moderate ($n = 16$) (7,14,16,18,31–42), and high ($n = 5$) (15,17,43–45) (Fig. 3). The global evaluation of the risk of bias was assessed as moderate when considering all the studies (Fig. 4).

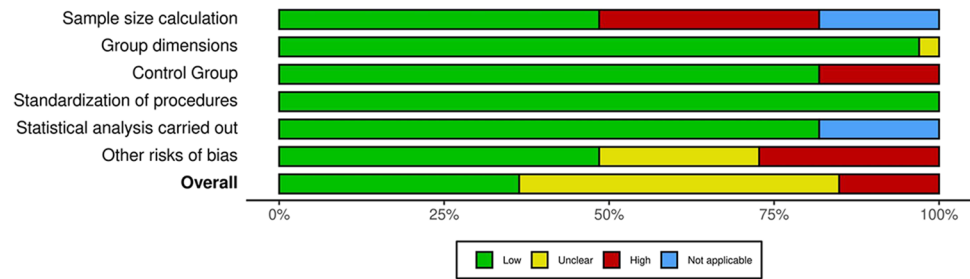
Study	Risk of bias						Overall
	D1	D2	D3	D4	D5	D6	
Abou-Elnaga et al. 2019 [19]	+	+	+	+	+	-	+
Allen et al. 2018 [18]	○	+	+	+	○	×	-
Alovisi et al. 2018 [20]	+	+	+	+	+	+	+
Barbosa et al. 2020 [31]	+	+	×	+	+	+	-
Chlup et al. 2017 [32]	×	+	+	+	+	-	-
Corsentino et al. 2018 [33]	×	+	+	+	+	-	-
Freitas et al. 2020 [21]	+	+	+	+	+	+	+
Ivanoff et al. 2017 [43]	×	+	+	+	+	×	×
Jiang et al. 2018 [22]	○	+	+	+	○	+	+
Kainath et al. 2018 [34]	×	+	+	+	+	+	-
Krishan et al. 2014 [35]	+	+	+	+	+	×	-
Makati et al. 2018 [44]	×	+	×	+	+	-	×
Marchesan et al. 2018 [36]	×	+	+	+	+	-	-
Maske et al. 2020 [14]	+	+	+	+	+	×	-
Mendes et al.2020 [23]	+	+	+	+	+	+	+
Moore et al. 2016 [24]	+	+	+	+	+	-	+
Neelakantan et al. 2018 [37]	×	-	+	+	+	+	-
Niemi et al. 2016 [38]	×	+	+	+	+	+	-
Özyürek et al. 2018 [7]	+	+	+	+	+	×	-
Plotino et al. 2017 [39]	×	+	+	+	+	-	-
Rover et al. 2017 [40]	+	+	×	+	+	+	-
Saber et al. 2020 [25]	○	+	+	+	○	+	+
Saberi et al. 2020 [26]	+	+	+	+	+	+	+
Sabeti et al. 2018 [45]	×	+	+	+	+	×	×
Saygili et al. 2018 [41]	×	+	+	+	+	+	-
Silva et al.2020 [42]	+	+	×	+	+	+	-
Silva et al. 2020 [27]	+	+	+	+	+	+	+
Tüfenkçi et al. 2020 [28]	+	+	+	+	+	+	+
Tüfenkçi et al. 2020 [29]	+	+	+	+	+	-	+
Vieira et al. 2020 [30]	+	+	+	+	+	+	+
Wang et al. 2020 [17]	○	+	×	+	○	×	×
Yuan et al. 2016 [15]	○	+	×	+	○	×	×
Zhang et al. 2019 [16]	○	+	+	+	○	×	-

D1: Sample size calculation
D2: Group dimensions
D3: Control Group
D4: Standardization of procedures
D5: Statistical analysis carried out
D6: Other risks of bias

Judgement
● High
● Moderate
● Low
○ Not applicable

Fig. 3 Risk of bias of included studies

Fig. 4 Risk of bias summary of all included studies



Outcomes of the different endodontic AC designs

1. Impact of the AC design on fracture resistance

Ex vivo studies

The impact of the AC design on the tooth fracture resistance was the most evaluated parameter (15 out of 28 ex vivo studies). All studies examined fracture resistance through a static experimental model; one also implemented dynamic tests (24).

Seven studies showed no significant difference in the fracture resistance results in posterior teeth accessed with ConsAC and TradAC (24,31–33,40,43,45), similar to one study performed in maxillary incisors (35). On the other hand, 3 studies contradicted this finding (35,39,44). For UltraAC, 2 studies reported no difference over TradAC in maxillary premolars (42) and mandibular molars (14), and another found higher fracture resistance compared to TradAC but with no difference compared with ConsAC (39) (Table 2).

Five studies compared fracture resistance of teeth accessed with TrussAC and TradAC and they were all conducted on mandibular molars. Two studies concluded that TrussAC led to a higher fracture resistance than TradAC (19,26) while three investigations did not show any significant difference (7,31,33).

From the meta-analysis, the following can be concluded:

- (i) There is a significant higher fracture resistance of teeth with ConsAC, TrussAC, or ConsAC/TrussAC compared to TradAC when all marginal ridges are preserved (class I) (Fig. 5).
- (ii) Despite being higher, there is no significant effect of the type of AC on the fracture resistance of teeth when one or two marginal ridges are lost (class II) (Fig. 6).

The overall quality of the ex vivo studies related to fracture resistance was assessed to have moderate risk of bias (Fig. 7). The evidence was rated to be low as all studies are in vitro studies with moderate risk of bias, and the results

suffered from inconsistency and imprecision (Fig. 5a, c), which could be resulted from different study designs and tooth type used. Notably, the meta-analysis results did not change in terms of significant difference with the removal of results from Makati et al. (44), which shows an obvious difference in results compared to other studies (Fig. 5).

In addition to the fracture resistance, 8 studies examined the type of fracture depending on the AC design and fractures pattern were classified as “favorable/restorable” or “unfavorable/unrestorable” depending on the extension of tooth fracture compared to the level of bone simulation (Table 2). In general, different AC designs do not have a significant effect on the fracture pattern (14,19,24,31,39,43,44) except for one study reporting more restorable fractures with TrussAC compared to TradAC (7).

Finite element analysis (FEA) studies

All FEA studies explored stress distribution in molars under static masticatory forces application (occlusal and/or oblique) (Table 3). Five studies found that more conservative AC resulted in lower stress values in the pericervical dentin area compared to TradAC (15–18,22). On the opposite, one study concluded that stress concentration in the pericervical dentin area was higher with ConsAC and TrussAC compared to TradAC for which maximum stress was found to be more apical (30). Four studies reported that the maximum stress concentration was found on the cavity margins when it corresponds with the occlusal contacts (15,17,22,25).

2. Impact of the AC design on cleaning/disinfection ability

Untouched canal walls (UCW)

Four studies showed no statistical differences between TradAC and ConsAC for the percentage of UCW by endodontic files in maxillary incisors (35), mandibular incisors (30), mandibular premolars (35), and maxillary molars (24,40). Two studies reported more UCW with ConsAC versus

Table 2 Results of ex vivo studies evaluating the impact of the AC design on fracture resistance

Authors, year	Type of access cavity (AC)			Type of teeth	Global AC configuration	Periodontal ligation simulation	Teeth Restored before testing	Conclusions toward the type of tooth fracture*	Conclusions toward the fracture resistance load*
	TradAC	ConsAC	UltraAC						
About-Elhaga et al. 2019 ¹⁹	X			X	Class II ^{MOD}	No	Yes	No significant difference	TrussAC > TradAC
Barbosa et al. 2020 ³¹	X	X		X	Class I	Yes	Yes	No significant difference	No significant difference
Chlup et al. 2017 ³²	X	X		X	Class I	No	Yes	NE	No significant difference
Corsentino et al. 2018 ³³	X	X		X	Class I Class II ^{OM} Class II ^{MOD}	No	Yes	NE	No significant difference
Ivanoff et al. 2017 ⁴³	X	X		X	Class II ^{MOD}	No	Yes	No significant difference	No significant difference
Krishan et al. 2014 ³⁵	X	X		X	Class I	No	No	NE	ConsAC > TradAC
Makati et al. 2018 ⁴⁴	X	X		X	Class I	Yes	Yes	No significant difference	ConsAC > TradAC
Maske et al. 2020 ¹⁴	X		X	X	Class I	No	No and Yes	No significant difference	No significant difference
Moore et al. 2016 ²⁴	X	X		X	Class I	Yes	Yes	No significant difference	No significant difference
Özyürek et al. 2018 ⁷	X			X	Class II ^{OM}	Yes	Yes	More restorable fractures with TrussAC VS TradAC	No significant difference
Plotino et al. 2017 ³⁹	X	X	X	X	Class I	No	Yes	No significant difference	ConsAC/Ultra AC > TradAC
Rover et al. 2017 ⁴⁰	X	X		X	Class I	Yes	Yes	NE	No significant difference
Sabeti et al. 2020 ²⁶	X			X	Class I	Yes	Yes	NE	TrussAC > TradAC when thermocycled
Sabeti et al. 2018 ⁴⁵	X	X		X	Class I	Yes	No	NE	No significant difference
Silva et al. 2020 ⁴²	X		X	X	Class I	Yes	Yes	NE	No significant difference

NE non-evaluated, OM, occluso-mesial extension, MOD mesio-occluso-distal extension, Y yes, N no

*This table presents only the statistically significant results

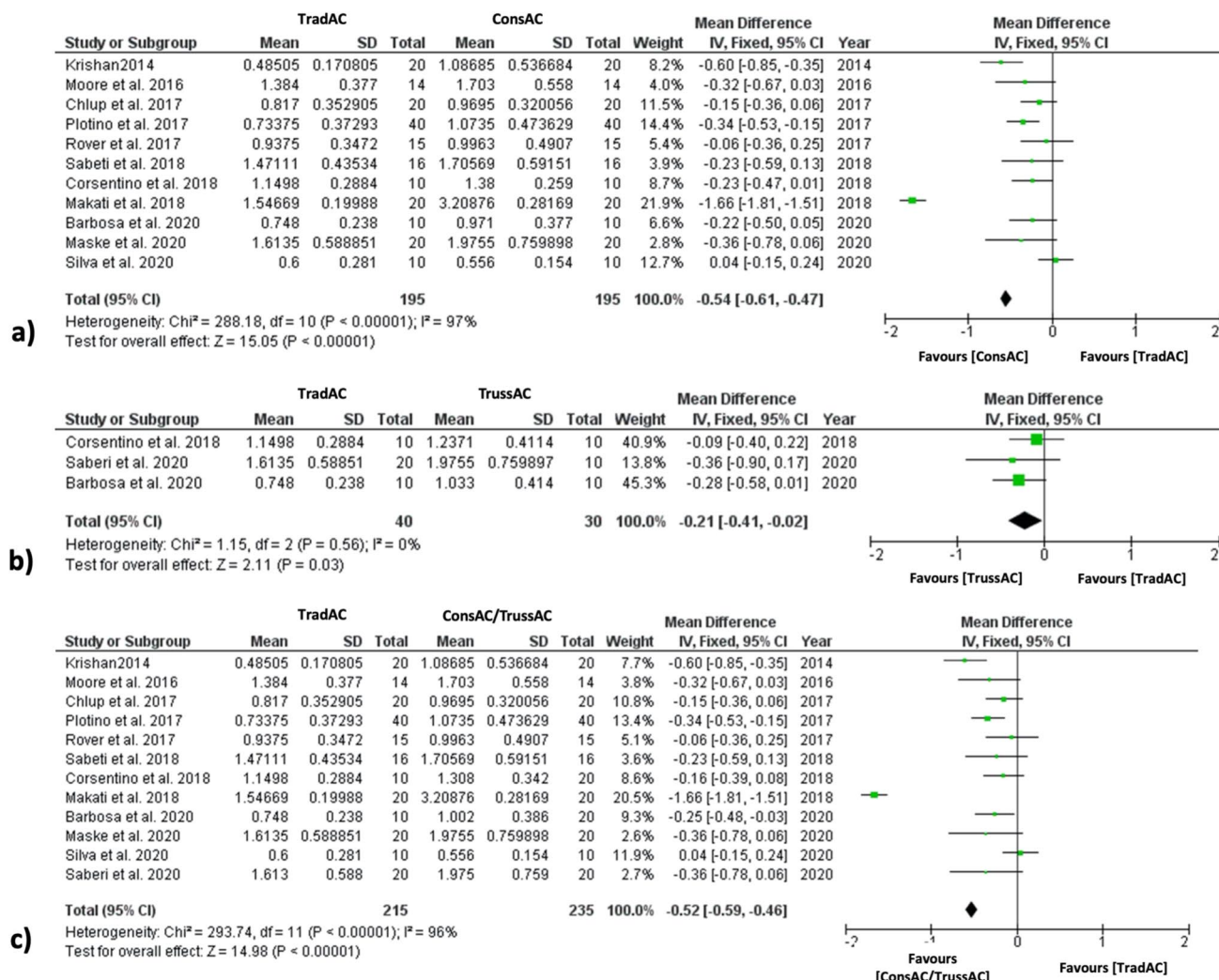


Fig. 5 Results of meta-analysis for fracture resistance according to different AC types with preservation of the marginal ridges (class I configuration), **a** TradAC versus ConsAC, **b** TradAC versus TrussAC, **c** TradAC versus ConsAC/TrussAC as one group

TradAC, both in mandibular molars (31,35). UltraAC was not associated with more UCW in maxillary premolars (42).

Pulp tissue remnants, reduction of microbial count, and accumulation of hard tissue debris

One study showed that more pulp tissue remnants were observed in the pulp chamber with TrussAC compared to TradAC and ConsAC. However, no significant difference in pulp tissue remnants inside the root canals was reported between the 3 AC types above (37). This also was consistent with two studies performed in mandibular molars which showed no significant difference in the reduction of *Enterococcus faecalis* using ConsAC or TradAC (28,31), but was contradicted in one study (30) performed in mandibular incisors with long oval canals. For accumulation of hard tissue

debris, there was no significant difference between TradAC and ConsAC (40) while it was increased with UltraAC (42).

Removal of root canal fillings

Two studies showed that ConsAC resulted in significantly higher amounts of remaining root canal filling materials on the canal walls of oval-shaped canals in mandibular premolars compared to TradAC (34,38).

3. Impact of the AC design on procedural errors

Canal transportation

Two studies found that different AC types (TradAC, ConsAC, and TrussAC) did not have an effect on transportation of curved canals (31,36). However, two other studies showed

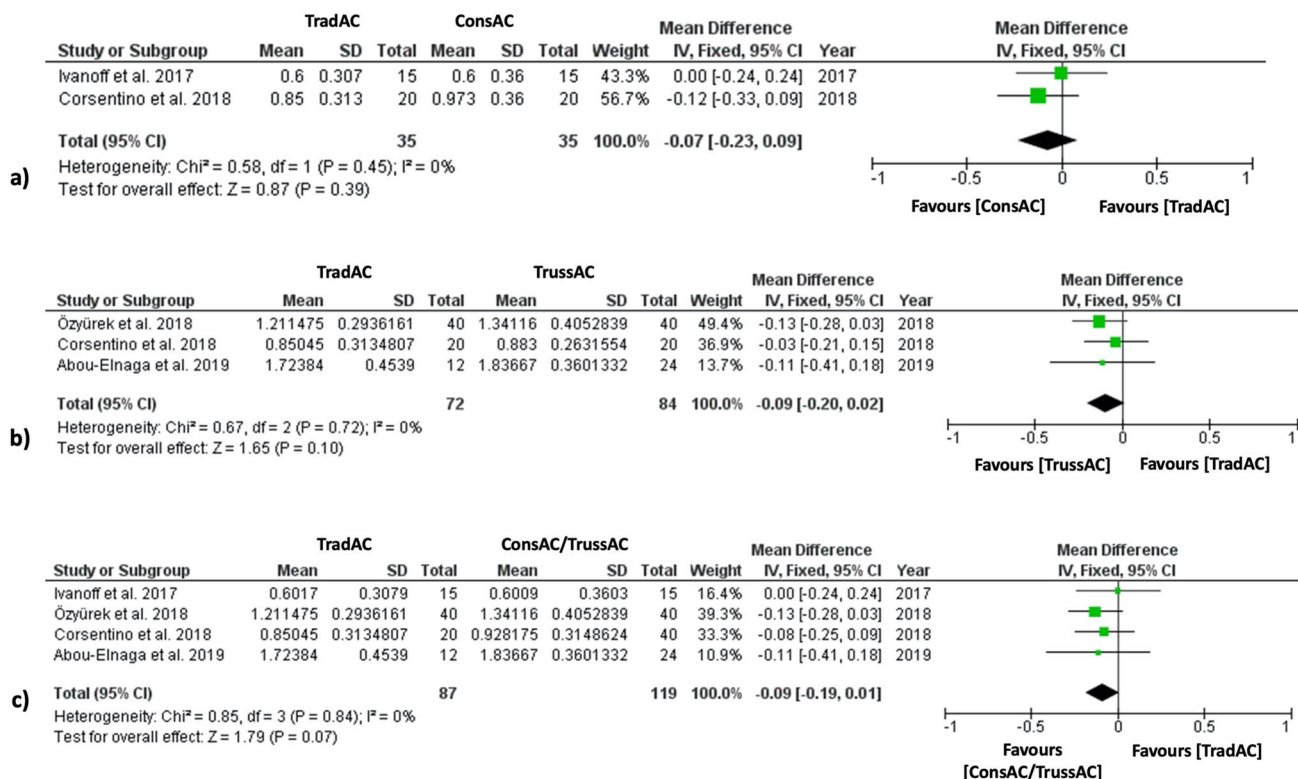


Fig. 6 Results of meta-analysis for fracture resistance according to different AC types with loss of one or two marginal ridges (class II configuration), **a** TradAC versus ConsAC, **b** TradAC versus TrussAC, **c** TradAC versus ConsAC/TrussAC as one group

more apical transportation with ConsAC than with TradAC despite the use of heat-treated files (20,40). One study found no difference in canal transportation and centering ability in curved canals of mesial root of maxillary molars with TradAC versus UltraAC with a 0.04 shaping taper (21).

Impact of the AC design on mechanical properties of endodontic files

Compared to TradAC, one study found that UltraAC was associated with reduced cyclic fatigue resistance of Reciproc® and Reciproc Blue® files (27). Another study reported 2 files separation (Reciproc blue®) with ConsAC but none with TrussAC or TradAC (31). In contrast, 5 studies reported no file separation with heat-treated NiTi instruments used through ConsAC or TradAC (20,24,35,36,40). In 3 of them,

a mechanical glide path enlargement was carried out before using the shaping file to the working length (20,24,36).

4. Impact of the AC design on treatment time

Four studies concluded that ConsAC significantly increased the treatment time in primary root canal treatment (20,36) or retreatment procedures (34,38) compared to TradAC:

- Time dedicated to canal instrumentation in mandibular molars was 2.5-fold longer with ConsAC (ConsAC, 83.17 ± 6.71 min; TradAC, 33.18 ± 9.20 min) (36).
- ConsAC required more pecking motions (PM) for both glide path completion with Proglider (ConsAC, 5.1 ± 2.2 PM; TradAC, 3.6 ± 1.6 PM) and root canal shaping

Fig. 7 Risk of bias summary of studies investigating fracture resistance

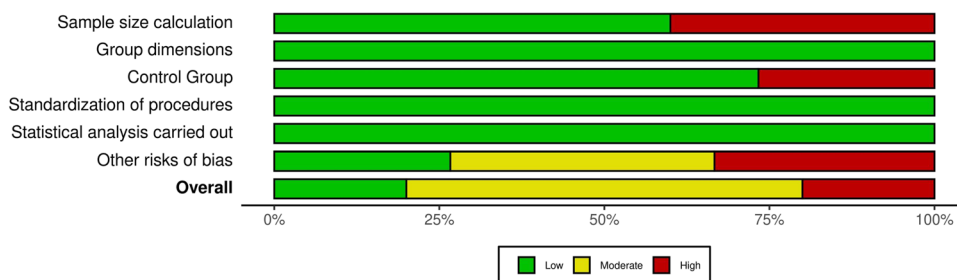


Table 3 Results of finite element analysis studies evaluating stress distribution and concentration in loaded teeth with different AC designs

Authors, year	Type of access cavity (AC)			Tooth type	Experimental groups	Periodontal ligament simulation	Test modalities	Conclusions regarding stress concentration (SC)
	ExtAC	TradAC	ConsAC					
Allen et al. 2018 ¹⁸	X		X	Mandibular 1st molar	Control group ConsAC+RC ConsAC+RC+gold crown TradAC+RC+gold crown	No	Vertical load (100 N)	UltraAC reduced the SC within the dentin TradAC may render a tooth more susceptible to fracture compared with an UltraAC
Jiang et al. 2018 ²²	X	X		Maxillary 1st molar	Control group TradAC+RC ConsAC+RC Extended AC+RC	Y	Vertical load (250 N) Lateral load (225 N) Vertical load in 5 points (800 N)	Similar SC on the occlusal surface between the 3 AC types Stress on the cervical area showed an increasing trend with the gradual enlargement of the AC
Saber et al. 2020 ²⁵	X	X		Mandibular 1st molar	Control group TradAC+RC ConsAC+RC UltraAC+RC	Y	Vertical load (250 N) Lateral load (250 N)	Decreasing the size of the AC was associated with a higher magnitude of cervical SC Increasing the size of the access cavity was associated with the transmission of stresses to a further apical direction
Wang et al. 2020 ¹⁷	X		X	Maxillary 1st molar	TradAC+RC UltraAC+RC	Y	Vertical load in 4 points (800 N)	Similar SC on the occlusal surface UltraAC significantly reduced the maximum SC in cervical area and root furcation
Yuan et al. 2016 ¹⁵	X		X	Mandibular 1st molar	TradAC+RC ConsAC+RC	Y	Vertical load (250 N) Lateral load (250 N)	ConsAC reduced the SC in crown and cervical area compared with TradAC
Zhang et al. 2019 ¹⁶	X	X	X	Maxillary 1st molar	Control group TradAC+RC ConsAC+RC UltraAC+RC	Y	Vertical load in 4 points (800 N)	ConsAC and UltraAC reduced the SC in cervical area versus TradAC More conservative access increased the estimated fracture load of dentin

ExtAC extended access cavity, RC resin composite

with WaveOneGold (ConsAC, 13.5 ± 2.4 PM; TradAC, 8.2 ± 2.3 PM) (20).

- One study found that gutta percha removal took significantly more time with ConsAC; however, the maximum time for gutta percha removal was 2.19 min and the difference with TradAC was less than 1 min (34).
- In another study, time for gutta percha removal with ConsAC + ProFile Vortex Blue instrument (20.1 ± 3.3 min) showed no difference with TradAC + ProFile Vortex Blue (22.6 ± 1.7 min) or TradAC + TRUShape instrument (23.9 ± 5.1 min), whereas this time significantly increased with ConsAC + TRUShape instruments (27.7 ± 1.4 min) (38).

Compared to TradAC, UltraAC were associated with an increase of the total time to perform root canal treatment (UltraAC, 84 ± 13 min; TEC, 70 ± 15 min). Time required to access and prepare the root canals was equivalent but a significantly longer time for root canal filling and cleaning of the pulp chamber was needed with UltraAC (42). No data was available regarding the treatment time with TrussAC.

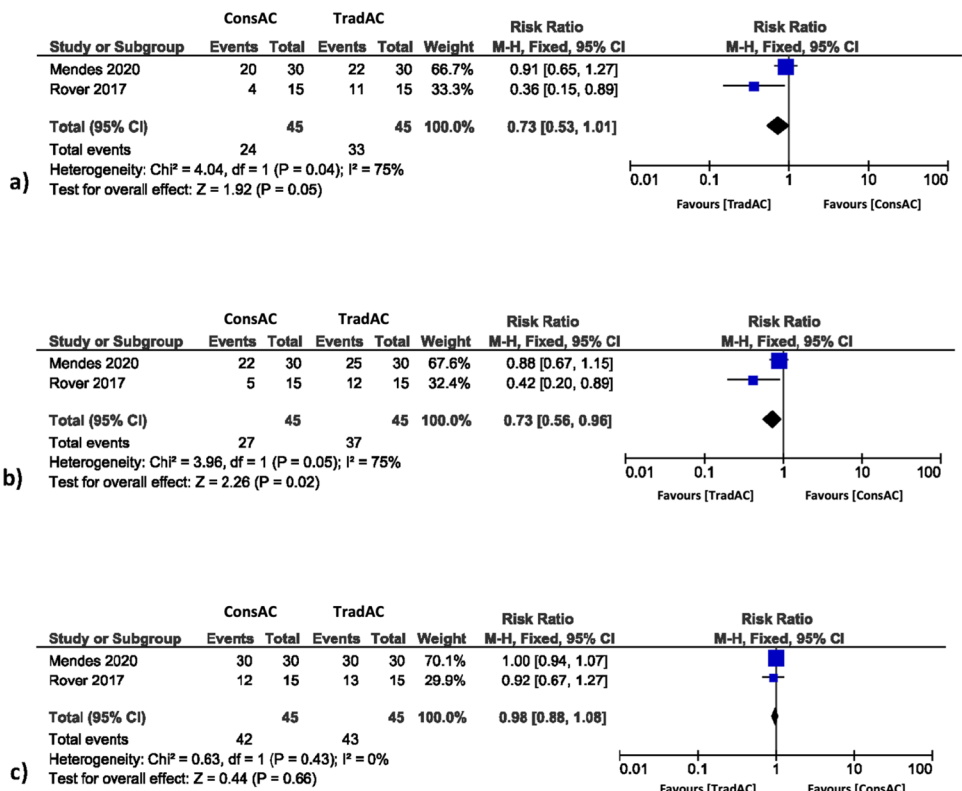
5. Impact of the AC design on detection of canal orifices

Among the 3 studies evaluating the impact of the AC design on detection of canals, 2 studies examined the detection of MB2 canals in maxillary first molars (40,41) and one the detection of middle mesial canal (MMC) in mandibular

molars (23). With no magnification or with the aid of operating microscope (OM), more MB2 canals were detected with TradAC compared to ConsAC (40). When combining OM and ultrasonic tips (US), there was no significant difference between these two AC designs in detecting MB2 or MMC (40,41). However, significantly less MB2 canals were identified with UltraAC compared to TradAC (-47%), even when OM is combined with US (41). The AC design (TradAC or ConsAC) did not significantly affect detection of MMC in extracted mandibular first molars regardless of the operative conditions (no magnification or OM or OM + US). However, for both types of AC, the use of OM increased the accuracy of the MMC identification, especially when combined with US (23).

A meta-analysis was performed, excluding one study since its methodology was different from other studies and cannot be combined (41) (Fig. 8). Results showed marginal significance with regard to detection of more root canals with TradAC compared to ConsAC without magnification (Fig. 8a), and significance difference was identified with magnification using the OM alone (Fig. 8b). However, there was no significant difference between TradAC and ConsAC if the OM is assisted with the use of US tips (Fig. 8c). In general, related studies showed low risk of bias; however, the results suffered from inconsistency and imprecision (Fig. 8a, b), which may reduce quality of evidence; in addition, the evidence provided is from in vitro studies.

Fig. 8 Results of meta-analysis for canal detection according to different AC types (TradAC versus ConsAC) and operating conditions, **a** no magnification, **b** operative microscope only, **c** operative microscope + ultrasonic tips



6. Impact of the AC design on apical debris extrusion

One study found that both TradAC and ConsAC had similar results with regard to the amount of apical debris extrusion (29).

7. Impact of the AC design on root canal filling

Under UltraAC conditions, one study showed that single-cone technique obturation with AH Plus® root canal sealer (Dentsply De Trey, Konstanz, Germany) did not result in more voids in root canal fillings; however, larger amount of filling material remnants within the pulp chamber was observed compared to TradAC (42).

Discussion

Based on the growing interest toward conservative endodontic AC designs, this systematic review aimed to discuss the current research findings of this topic. It was decided to use a recently proposed classification of AC designs in which we used 4 of the 8 AC types described (TradAC, ConsAC, Ultra AC, and TrussAC) because it corresponded well to the AC designs investigated in ex vivo studies (8). If these 4 categories appeared appropriately, a difficult distinction based on objective criteria between ConsAC and UltraAC led to inconsistencies in several publications between the description of the AC type and their nomenclature given by the authors (7,14–18). In most of these publications, UltraAC was categorized as ConsAC although there was an occlusal outline only limited to the bur penetration with no further proximal/buccolingual extension. The term “point-access cavity” used in previous publication to designate UltraAC might be more appropriate than UltraAC (41). Moreover, it is noted that the little the surface on which the AC is implemented, the more difficult it is to distinguish ConsAC from UltraAC. As such, the differentiation between these two categories is easier in molars compared to other teeth.

The trend toward more conservative AC can be considered one evolution shift in endodontic practice, consistent to the evolving trends for minimally invasive dentistry. Similar to the concept of maximal tissue conservation during restorative treatment to extend teeth lifespan, hard tissue preservation during endodontic AC preparation has been suggested to improve the tooth fracture resistance (7). This may explain why the vast majority of the studies focused on the impact of AC design on this parameter.

Interestingly, the meta-analysis conducted in this review showed that ConsAC and TrussAC significantly increase the fracture resistance of teeth having class I AC, but not class II.

Therefore, the clinical relevance of more conservative access for better fracture resistance purpose is questionable since root canal treatment indications are mostly related to carious lesions or traumatic injuries which frequently involve the loss of one or two marginal ridges (46,47). Moreover, one study concluding that ConsAC leads to better resistance of teeth compared to TradAC was conducted on unrestored teeth (35). This is an important limitation considering that a coronal restoration must be placed as soon as root canal filling is performed to provide adequate coronal seal and to protect the remaining dental structures (48,49). Moreover, differences could be noted in the speed and axis for the load application (parallel or oblique to the long axis of the teeth), the crosshead diameter and the simulation of the periodontal ligament. Thus, the fracture resistance could be impacted by these various experimental conditions (50).

The pericervical dentin (approximately 4 mm above the crestal bone and extending 4 mm apical to the crestal bone) has an influence on the fracture resistance of endodontically treated teeth because it is the area where most of the fractures initiate (2). Majority of FEA studies reported that stress values in this area decrease with the size of AC, which would result in better teeth resistance. However, since tests were always conducted on class I AC configuration and did not simulate the loss of marginal ridge, the same limitation as for ex vivo studies can be raised. On the other hand, FEA studies concluded that AC margins should always be kept away from the occlusal contact area (15,17,22,25), which is not a critical concern for teeth scheduled for cuspal coverage restorations and crowns.

For ex vivo and FEA studies, the use of static rather than dynamic resistance models that would simulate the fatigue phenomenon can be considered as a limitation in terms of clinical significance (50). The only ex vivo study that used dynamic models reported no mechanical benefits of ConsAC over TradAC (24). Furthermore, except for one study evaluating TrussAC (7), the type of AC did not result in difference regarding the fracture pattern and the subsequent restorability of the teeth.

When performing root canal treatment, each missed canal should be considered as a potential source of endodontic failure (51). Consequently, the impact of the AC design on root canal detection should be of a major concern when evaluating the risk/benefit ratio of more conservative AC. The authors believe that this critical consequence of missing canals requires more investigations since it is directly linked to clinical outcomes. As shown in the meta-analysis, the use of OM together with US instrumentation enhances canal detection in teeth accessed with the conservative approach. In these conditions, TradAC or ConsAC did not impact the MB2 detection rate in maxillary molars (40,41) and the MMC detection rate in mandibular molars (23). However, from the 3 studies, only one simulated clinical conditions by

aligning the teeth similar to their intraoral positioning (23). With almost a half more undetected MB2 canals, UltraAC design appears to be unjustified (41), especially considering that this cavity design does not increase the fracture resistance over ConsAC (39). Same concern applies in mandibular molars which show considerable variations in the canal configurations of the mesial and distal roots (52).

The occasion of file separation with different AC designs is an important parameter since it may lead to endodontic treatment failure (51). Indeed, more conservative AC increases the curvature of the endodontic instrument, which has been shown to increase the risk of fracture incidence (53). This parameter was most often reported as a side observation; one study reported more file separation in mandibular molars with ConsAC compared to TradAC, without specifying which canals were concerned (31). UltraAC has been shown to reduce the cyclic fatigue resistance of endodontic instruments (27). All studies used heat-treated NiTi reciprocating instruments and the majority used a prior mechanical glide path enlargement. There is a need for further evaluation of the importance of these parameters when reducing the AC size, taking into account that experimental conditions should better simulate clinical situation. Moreover, despite the use of heat-treated files that show high flexibility, more apical canal transportation has been reported as an undesirable outcome with ConsAC (20,40), and this should also be evaluated with UltraAC.

This systematic review shows that more conservative AC did not seem to decrease the quality of root canal debridement and cleaning in primary root canal treatments. When comparing ConsAC and TradAC, studies generally reported comparable results with regard to instrumentation to the canal walls (24,30,35,42), intra-canal remnants (37), and bacteria load reduction after instrumentation (28,31). These parameters were little evaluated with UltraAC and TrussAC. Some serious concerns can be raised with TrussAC where pulp remnants in the pulp chamber and the architecture of the AC cavity may negatively impact the disinfection process and the quality of bonded post-endodontic restorations (37). The impact of different AC types on disinfection deserves to be investigated in more studies, as well as the circulation of root canal irrigants (with or without activation techniques). When retreating oval canals, decreasing the size of the AC can lead to more root canal material remnants on the canal walls (34,38), which may negatively affect the clinical outcome by preventing effective disinfection of the root canal space (54). Once again, concerns about the proper cleaning of the pulp chamber in case of retreatment can be raised with TrussAC. Apical debris extrusion could impact postoperative pain occurrence (55) and this parameter did not seem to depend on the AC volume (TradAC or ConsAC) (29). However, one study is not sufficient to come out with valid conclusions.

Some studies reported an increase in treatment time with more conservative AC. However, since the experimental conditions and the treatment steps were different, these results are difficult to compare. In one study, the increased treatment time could result more from the shaping protocol and the files used rather than the AC type (38). In another study considering retreatment conditions, the supplementary time for gutta percha removal was less than 1 min for ConsAC compared to TradAC, which is not of clinical significance (34). On the other hand, another study reported a $2.5 \times$ increase of the treatment time representing up to 1 h of extra time with ConsAC compared to TradAC (36). Such discrepancy between the results is confusing and this parameter would need further evaluation with clear definition of the conditions of the experiment. It would be beneficial to consider the whole treatment time (from the AC realization to the obturation step). Extension of the treatment time might be acceptable if it remains within the limits of chair time convenient to both the operator and patient, and that more conservative AC design would bring an added value on other parameters, which is not clear so far. In case of UltraAC, root canal filling and cleaning of the pulp chamber required a few more minutes compared to TradAC (42). However, a single-cone technique was used, and the possibility to efficiently apply lateral and warm compaction techniques in different canal morphology (such as oval canals) remains unclear.

It has to be noted that the position of the tooth in the oral cavity and the mouth opening of the patient are potential challenges for access cavity designs. Indeed, considering this challenge in experimental settings is advantageous; however, only 2 studies out of 28 took this into consideration and used phantom heads (23,42).

This systematic review investigated the overall impact of different access cavity designs on several outcomes related to teeth fracture resistance, canal transportation, reduction of microbial counts, detection of canal orifices, and others. Moreover, the meta-analysis highlighted the impact of the previous structural damage (class I compared to class II) on teeth fracture resistance. These points may pave the way to better understand the risk benefit ratio of the different cavity designs investigated. However, conclusions from this systematic review should be taken with caution, since the risk of bias was moderate to high in 21 out of 33 studies. The terminology used for the different cavity designs remains controversial. Moreover, no clinical study was available and in vitro conditions are often not representative to most of clinical situations. It is also important to highlight that only 2 out of 33 studies investigated the impact of endodontic access cavity on anterior teeth. Despite these limitations, it was possible to propose decision-making criteria for clinical practice which may help the clinician to plan for access cavity designs according to certain criteria as discussed.

A proposal for decision-making criteria

Based on this systematic review, decreasing the AC extent does not necessarily present a favorable risk/benefit ratio and there are still a number of points to be clarified. However, since the amount of tooth structure loss has a direct impact on the choice of the future coronal restoration, preserving sound tissue during endodontic access definitely makes sense. It is especially true in young patients who may be a subject to future recurrent caries, broken restorations, or fracture (56). This section aims to discuss the criteria for decision-making of different AC designs. TrussAC will not be addressed here because there is not enough evidence that potential mechanical benefits would supplant biological issues.

1. *Pre-existing loss of tooth structure*

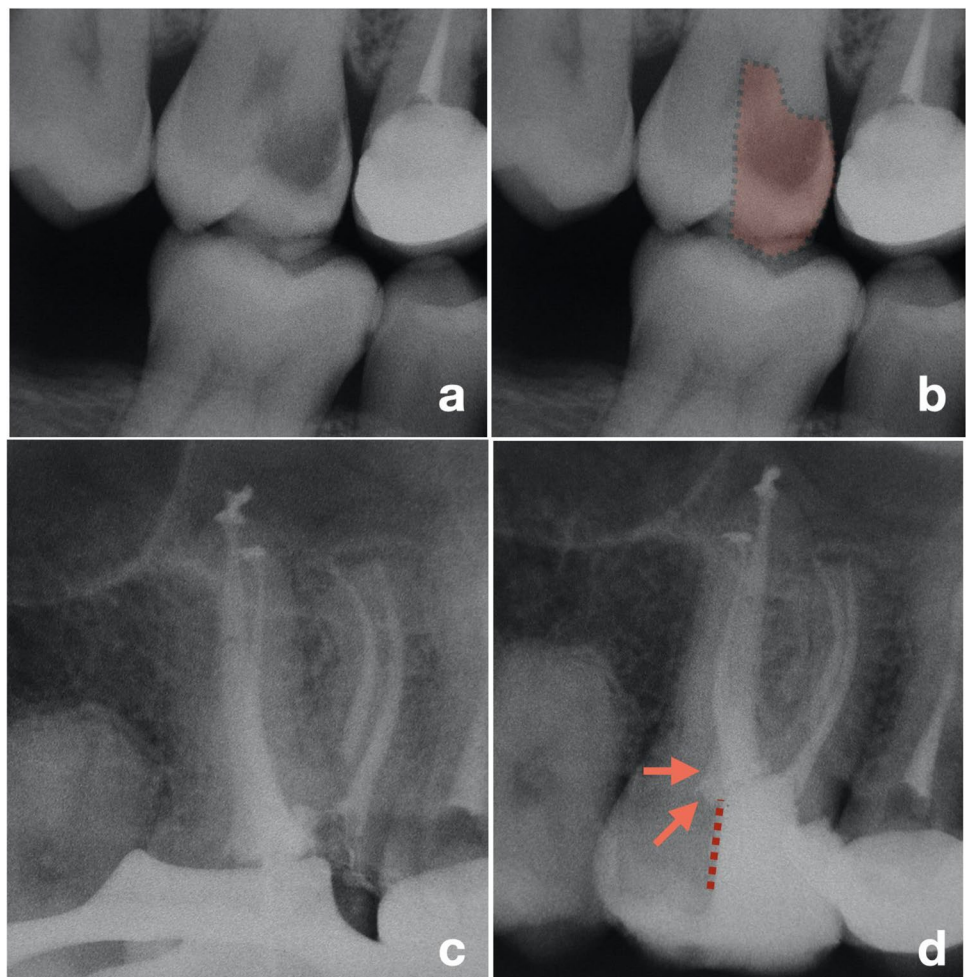
The actual clinical conditions lead to a wide range of AC designs, far from the geometrical “ideal” ones evaluated in *ex vivo* studies and often taught in the dental curriculum. The cause is that root canal treatments (or

retreatments) are mainly performed in teeth with decays and/or defective restorations that must be removed before initiating root canal treatment. Consequently, only a small or moderate occlusal structural damage can be considered a favorable condition to indicate ConsAC over TradAC, especially when the marginal ridges are preserved.

Using decays has been proposed to avoid additional sacrifice of sound tooth tissues (“caries-driven AC”) (8) (Fig. 9). However, it cannot be recommended as a general rule because the axis provided by such access and the amount of dental tissue overhanging the pulp floor might not be favorable for accessing the root canals. Moreover, this strategy ignores the need for a pre-endodontic restoration, which is also needed to improve the efficacy of endodontic irrigants activation in the apical third (57).

Root canal treatments can also sometimes be performed without removing a pre-existing restoration, provided that it has been evaluated as satisfactory (“restorative-driven AC”) (8). If the latter only aims to be temporarily maintained as a pre-endodontic restoration, then there is no need to limit the AC extent by preserving

Fig. 9 Caries-driven AC (a, b). The occluso-mesial access allowed to perform the root canal treatment (c) while preserving the distal pulp horn and limiting sound tissue loss in a distal extent (arrows) (d)



the restorative dental materials. If it aims to be maintained in the long term, then a conservative access can be performed to limit damages on the restoration while preserving sound dental tissues (Fig. 10). In both cases, special attention should be put on preserving sound tissue once dentin is reached (“stepped-access”) (2). It has to be noted that maximal preservation of pre-existing restorations can be obtained with guided root canal treatment. In this approach, the AC is done through a guide designed from CBCT analysis, most of the time resulting in an UltraAC approach (58).

2. Level of complexity of the root canal morphology

Since missed canals have a negative impact on root canal treatment outcomes (59), the choice for AC design should not be at the expense of root canal detection. The AC design can be planned after careful pre-operative evaluation of the potential complexity of the root canal anatomy (such as pulp chamber volume, root canal configuration and number, curvatures, and calcifications). CBCT (if indicated) allows the clinician to get more information on the root canal space anatomy, and can help for selection of the appropriate AC design (60). However, the risk/benefit of exposure to radiation must be evaluated carefully.

3. Operative accessibility

A limited mouth opening and/or an unfavorable tooth positioning can strongly complicate root canal treatment procedure, especially in molars. In these situations, UltraAC and ConsAC might not be suitable. However, the AC preparation is a “dynamic procedure” which can be initiated as a conservative cavity which can be extended (if needed) for safe root canal treatment procedures. When doing so, extension should avoid the marginal ridges as much as possible because of their high value in teeth resistance (22).

4. Pre-operative condition of the tooth

Based on the findings of our systematic review, ConsAC has been shown to provide root canal debridement and cleaning outcomes comparable to TradAC in primary root canal treatments. However, there is no evidence to support this in teeth with different pulp and periapical diseases, which requires well-designed clinical trials.

It is obvious that in instances of teeth scheduled for non-surgical root canal “retreatment” procedures, TradAC should be preferred over ConsAC since the latter usually associated with higher amount of filling materials remnants, in addition to possibilities of missed canals during the initial root canal treatment, which may have an impact on root canal treatment outcomes (34,38).

Fig. 10 A ConsAC done through a previous restoration (a, b) with preservation of the distal pulp horn (red arrow) (c). Endodontic treatment is followed by a direct composite resin restoration (d)

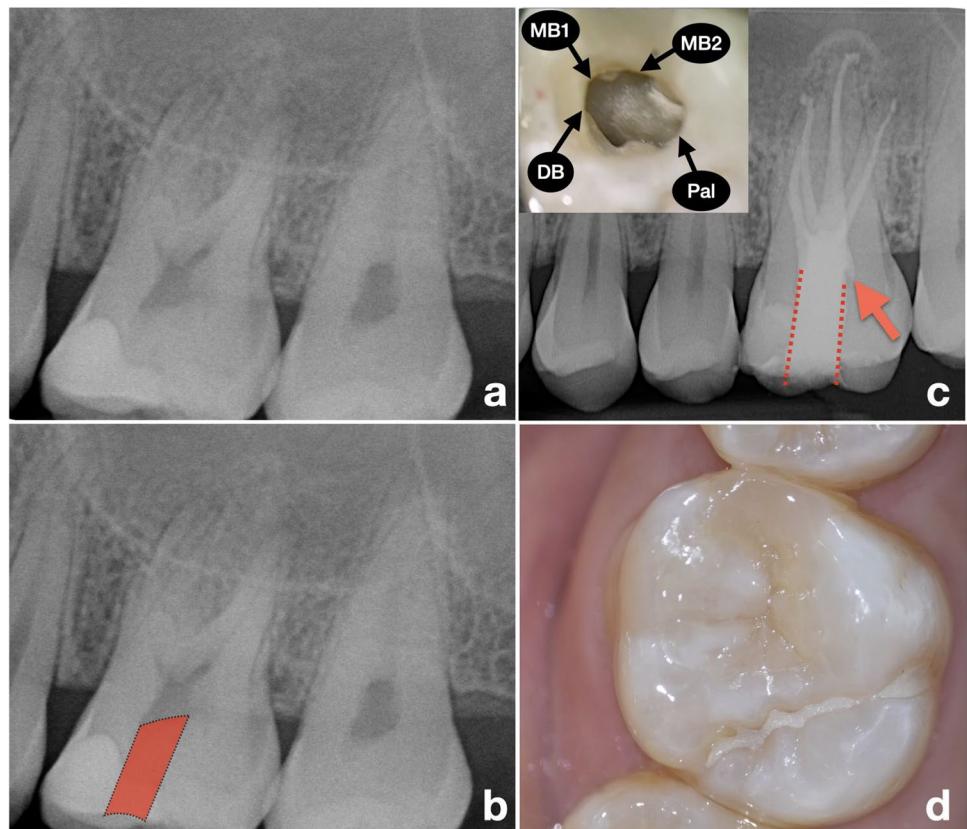


Table 4 Summary of factors in favor of conventional or conservative AC outline

Factors in favor of conventional AC outline	<ul style="list-style-type: none">• Extensive dental structural damage with loss of marginal ridges• Cavity margins in relation with the occlusal contact areas• A crown is indicated• Severe/abrupt curvatures implying additional sound tissue removal for safer root canal negotiation/preparation• Limited mouth opening implying additional sound tissue removal for safer root canal procedure• Indication of nonsurgical retreatment (wide canals with apical periodontitis)
Factors in favor of conservative AC outline	<ul style="list-style-type: none">• Small and moderate dental structural damage with marginal ridges preservation• A bonded partial restoration is indicated after root canal therapy• Root canal treatment performed through a satisfactory crown or restoration• Straight canals, moderate curvatures• Operative accessibility compatible with safe root canal procedure• Experienced practitioner familiar with technological advances such as CBCT, magnifying devices, ultrasonics, heat-treated files

5. *Experience of the practitioner and technological aspects*

Tending toward more conservative AC implies a substantial level of expertise and anticipation. Indeed, a small AC is likely to have more challenges with potential risks compared to TradAC. On the other hand, performing TradAC for every clinical situation because of practitioners' lack of expertise and/or sufficient armamentarium may be considered invasive treatment approach. The use of magnifying tools (operating microscope) combined with ultrasonic technology allows more conservative AC without compromising proper detection of root canal orifices (61). In the same way, a more conservative access potentially implies more mechanical stress on instruments, and heat-treated endodontic files should be preferred since they present enhanced flexibility and cyclic fatigue resistance (62).

6. *Coronal restoration*

Identification of the occlusal contacts should be carried out before selecting a given AC design. If no cuspal coverage is indicated after root canal treatment, then the AC margins should be kept far from occlusal contact areas to avoid high stresses on the tooth/coronal restoration interface and subsequent failure and this could indicate an AC extent (15,17,22,25).

According to this decision-making criteria proposal, Table 4 summarizes factors in favor of extension or decrease of AC outline.

Conclusions

The optimal extent of AC outline form varies from case to case. So far, mechanical implications of more conservative AC have been extensively addressed to the detriment of biological ones. However, maintaining the extent of AC design as small as practical. AC can progressively

be extended during the procedure to adapt to the encountered difficulties and the level of sound tissue preservation is highly dependent on the practitioner experience and armamentarium. Based on the current knowledge, TrusSAC should not be recommended and UltraAC applied in limited occasions. In the future, more emphasis should be placed on standardization of the methodologies used in ex vivo studies and better simulation of clinical conditions.

Declarations

Ethics approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

Conflict of interest The authors declare no competing interests.

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