Rotary Nickel-Titanium Instruments

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Nickel–titanium alloy (Ni-Ti) rotary instruments must exert torque to cut and eradicate septic dentin during canal preparation; torsional stress, associated with friction between the instrument and dentin wall, accumulates in the instruments.

dynamic torsional test | force | nickel-titanium rotary instrument | root canal preparation | screw-in tendency | torque

1. Introduction

Nickel–titanium alloy (Ni-Ti) rotary instruments must exert torque to cut and eradicate septic dentin during canal preparation; torsional stress, associated with friction between the instrument and dentin wall, accumulates in the instruments [1][2]. The accumulated stress can be retained as residual stress—plastic deformation—after withdrawal of the instrument from the canal if the stress exceeds the elastic limit [3]. The engagement of rotary instruments, especially those with spiral-shaped active cutting edges, with the dentin wall can generate apically-directed screw-in forces, causing the instrument to become locked in the canal [4]. When this occurs, additional torque is required for the instrument to continue rotating. Thus, torsional stress is instantly accumulated in the instrument, leading to torsional fracture [5][6], which is dissimilar to cyclic fatigue fracture caused by the repeated tension/compression stresses at the curvature [7]. Furthermore, screw-in forces may cause the instrument to engage beyond the apical foramen [8] and result in the extrusion of microbes into periapical tissue [9], root weakening, and cracks in the apical area [10].

Numerous studies have been conducted to examine the dynamic torque and force characteristics of Ni-Ti instrument systems to identify factors having an impact on the stress generated within the rotary instruments. Though potential influencing factors, such as instrument pitch length [11][12][13][14] and instrument rake angle [11][15], have been discussed and debated, no single-most important factor has been identified. Thus, there continues to be debate on how the stress generated within Ni-Ti instruments during root canal instrumentation can be limited to a level at which clinical safety is ensured.

2. Data, Model, Applications and Influences

As shown in Figure 1, 4096 articles were identified. After duplicates were removed and preliminary screening was conducted, 75 articles underwent full-text review. Fifty-two studies (Table 1) were eligible for inclusion.

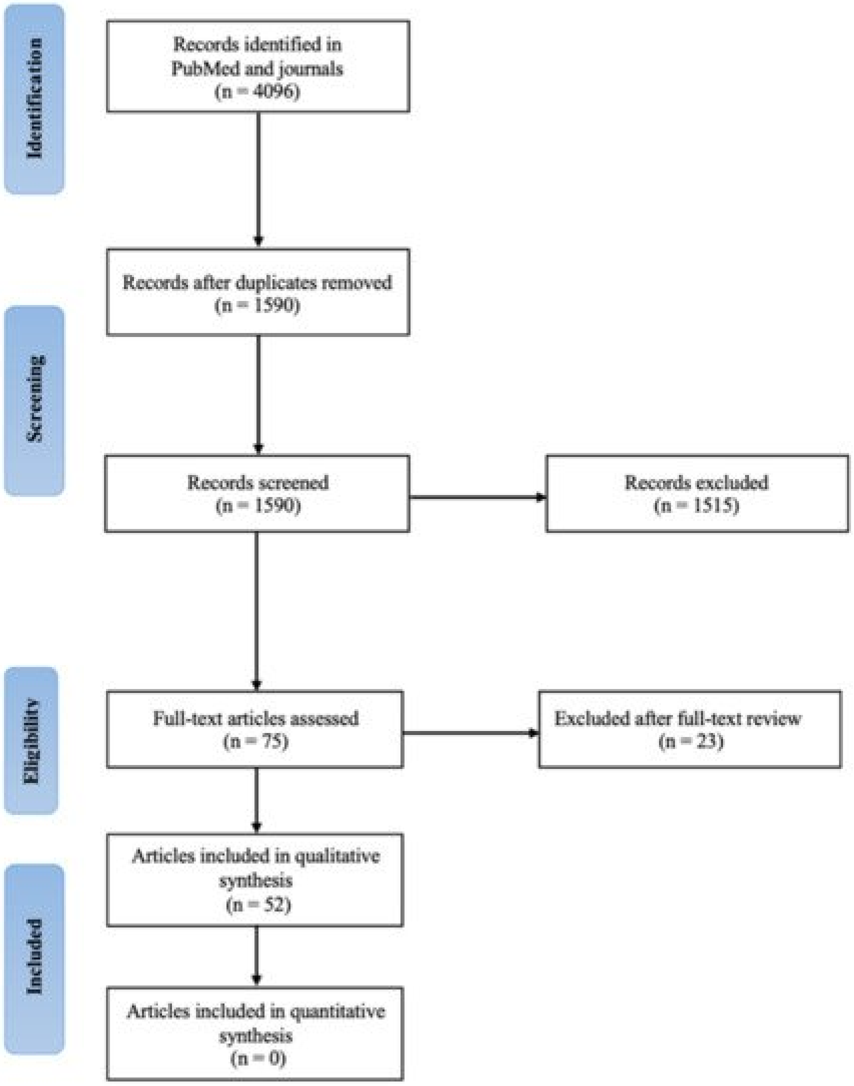

Figure 1. Summary of the search processs.

Table 1. Summary of reviewed studies analyzing torque and force generated by nickel-titanium rotary instruments during root canal preparation.

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
Blum et al., 1999 [16]	In vitro	Mandibular incisors	ProFile	Step-back & crown-down	Students > Endodontist (T) Students < Endodontist (F) Step-back > crown-down
Blum et al., 1999 [17]	In vitro	Mandibular incisors	ProFile	Step-back & crown-down	Contact area- 10 mm (Step-back) and 5 mm (crown-down) from the tip

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
					Step-back > crown-down (T & F)
Sattapan et al., 2000 [18]	In vitro	Maxillary/mandibular central and lateral incisors	Quantec Series 2000	Single file	Small canal > medium canal
Peters et al., 2002 [19]	In vitro	Extracted human teeth/plastic blocks	Profile	Crown-down	Straight canal blocks > curved canal blocks > natural teeth (T) Curved canal blocks > natural teeth > straight canal blocks (F)
Peters et al., 2003 [20]	In vitro	Maxillary molars	ProTaper	Single-length	F3 > F2 > F1 > S1 > S2 (T) F3 > S1 > F2 > F1 > S2 (F)
Blum et al., 2003 [21]	In vitro	Maxillary central incisors/ mandibular central or lateral incisors	ProTaper	Single-Length	Narrow canal > large canal (T) Large canal > narrow canal (F)
Hübscher et al., 2003 [22]	In vitro	Maxillary molars	FlexMaster	Crown-down-like modified sequence	Constricted canal > wide canal (T & F)
Diemer et al., 2004 [13]	In vitro	Resin blocks	Hero	Single file	Shorter pitch length > longer pitch length (T & F)
Da Silva et al., 2005 [23]	In vitro	Maxillary/mandibular central and lateral incisors	Race 720, Race 721, Profile	Single-length	Profile > Race 720 > Race 721 (T & F)
Schrader et al., 2005 [24]	In vitro	Plastic blocks	Profile	Crown-down	35/0.04 had peak T and F in 4% taper sequence 40/0.06 and 35/0.04 had peak T and F in combination of 4% and 6% taper, respectively
Peters et al., 2005 [25]	In vitro	Dentin discs	ProFile, ProTaper	Single file	Glyde > Control > EDTA > H_2O for ProFile (T) Glyde > H_2O > EDTA > Control for ProTaper (T) Glyde > H_2O > Control

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
					> EDTA for ProFile (F) Control > H_2O > Glyde > EDTA for ProTaper (F) ProTaper > ProFile (T) ProFile > ProTaper (F)
Boessler et al., 2007 [26]	In vitro	Dentin discs	ProFile	Single file	Dry Control > NaOCL 1% > H_2O > HEPB 18% (T) Dry Control > H_2O > NaOCL 1% > HEPB 18% (F)
Boessler et al., 2009 [27]	In vitro	Dentin discs	ProTaper	Single-length	Electropolished > machined (T) Machined > electropolished (F)
Diop et al., 2009 [28]	In vitro	Human cadaveric mandivular central/lateral incisors	ProTaper	Single file	Apical > coronal (T & F) Right > left (F) Posterior > anterior (F)
Ha et al., 2010 [15]	In vitro	Resin blocks	K3, Mtwo, NRT, ProFile, ProTaper	Single file	ProTaper > K3 > NRT-safe tip > NRT-active tip > Mtwo > ProFile (F)
Son et al., 2010 [29]	In vitro	Resin blocks	ProTaper, ProFile	Single-length	0° > 10° > 20° > 30° canal curvature (F)
Sung et al., 2010 [30]	In vitro	Resin blocks	ProFile, GT rotary, K3	Single-length	Greater taper > smaller taper (F)
Bardsley et al., 2011 [31]	In vitro	Plastic blocks	Vortex	Crown-down	200 rpm > 400 rpm > 600 rpm (T & F)
Peters et al., 2012 [32]	In vitro	Plastic blocks	Hyflex CM	Single-length & crown-down	Single-length > crown-down (T & F)
Ha et al., 2012 [8]	In vitro	Endo-training blocks	PathFile, NiTiFlex, ProTaper	Single file	#13 > #15 > #18 > #20 (T & F)
Diemer et al., 2013 [33]	In vitro	Resin blocks	HeroShaper, Prototypes	Single file	H6 > H0 > H4 (T) H0 > H6 > H4 (F)
Pereira et al., 2013 [34]	In vitro	Plastic blocks	ProTaper Next	Single-length	250 rpm > 300 rpm > 350 rpm (T & F)

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
Arias et al., 2014 [35]	In vitro	Maxillary incisors/mandibular molars	ProTaper Next, ProTaper Universal	Single-length	Small canals > large canals (T & F)
Pereira et al., 2015 [36]	In vitro	Plastic blocks	ProTaper Universal, Profile Vortex, Vortex Blue, Typhoon Infinite Flex	Single-length	Typhoon > ProTaper Universal > Vortex Blue > ProFile Vortex (T) ProTaper Universal > ProFile Vortex > Vortex Blue > Typhoon (F)
Ha et al., 2015 [9]	In vitro	Resin block	G-1, G-2, uG glide path files	Single file	G-2 > uG > G-1 (F)
Peixoto et al., 2015 [11]	In vitro	Acrylic blocks	Mtwo, Race, ProTaper Universal	Single file	ProTaper Universal > Race > Mtwo (T) ProTaper Universal > Mtwo > Race (F)
Arias et al., 2016 [37]	In vitro	Mandibular molars	PathFile, ProGlider	Single-length & Single file	PathFile 1 > PathFile 2 > ProGlider (T & F) ProGlider (16/.02, single file) > PathFile (16/.02, Sequence) (T & F)
Moreinos et al., 2016 [38]	In vitro	Simulated metal block canal	Gentlefile, ProTaper Next, Revo-S	Single-length	ProTaper X1 > Revo-S SC2 > Gentlefile 1 (F) Revo-S SC3 > ProTaper X2 > Gentlefile 2 (F)
Kwak et al., 2016 [14]	In vitro	Resin blocks	OneG, pG, OneG heat-treated, pG heat-treated glide path files	Single file	pG > OneG > OneG heat-treated > pG heat-treated (F)
Ha et al., 2016 [4]	In vitro	Resin blocks	Mtwo, Reciproc 25, ProTaper Universal, ProTaper Next	Single file	Reciproc 25 > ProTaper Universal > ProTaper Next > Mtwo (F)
Jamleh et al., 2016 [39]	In vitro	Premolar teeth	Twisted File, Twisted File Adaptive, ProTaper Universal, ProTaper Next	Single-length	ProTaper Universal > ProTaper Next > Twisted File > Twisted File Adaptive (L)

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
Arias et al., 2017 [40]	In vitro	Mandibular molars	PathFile, ProGlider, ProTaper Gold	Single-length	Glide path reduced the torque of shaping files
Tokita et al., 2017 [41]	In vitro	Resin canal models	Twisted File Adaptive	Single-length	CR > torque-sensitive reciprocation > time-dependent reciprocation (T) Time-dependent reciprocation > CR > torque-sensitive reciprocation (F)
Ha et al., 2017 [42]	In vitro	Resin Canals	One G	Single-length	4/6 pecking depath > 2/4 pecking depath (F)
Fukumori et al., 2018 [43]	In vitro	Resin canals	EndoWave	Single file	EndoWave (30/0.06) > EndoWave (30/0.04) (T & F)
Kwak et al., 2018 [44]	In vitro	Resin blocks	WaveOne, WaveOne Gold	Single file	WaveOne > WaveOne Gold (T) Without Glide Path > with Glide Path (T)
Jamleh et al., 2018 [45]	In vitro	Maxillary premolar teeth	WaveOne, WaveOne Gold	Single file	WaveOne > WaveOne Gold (F)
Nishijo et al., 2018 [46]	In vitro	Endo training blocks	Hyflex EDM Glide Path File (EDM), Hyflex GPF, Scout Race (Race)	Single file	Hyflex EDM Glide Path File > GPF > Race (CR) (F) Hyflex EDM Glide Path File > Race > Hyflex GPF (Reciprocation) (F)
Gambarini et al., 2019 [47]	In vitro	Maxillary anterior teeth	Twisted File	Single file	Inward pecking motion > outward brushing motion (T)
Abu-Tahun et al., 2019 [48]	In vitro	Resin canals	One G, Hyflex EDM	Single file	No glide path > 5 insertions > 10 insertions > 15 insertions > 20 insertions (T)
Kwak et al., 2019 [49]	In vitro	Resin blocks	ProTaper Universal, ProTaper Gold,	Single-length & Single file	ProTaper Universal > WaveOne > ProTaper Gold > WaveOne Gold (F)

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
			WaveOne, WaveOne Gold		
Nayak et al., 2019 [50]	In vitro	Resin blocks	WaveOne Gold, Self-adjusting file, 2Shape	Single-length &single file	WaveOne Gold > 2Shape 2 > 2Shape 1 > self-adjusting file (F)
Kwak et al., 2019 [51]	In vitro	Resin blocks	K3XF, Twisted File Adaptive	Single-length	K3XF (CR) > K3XF (adaptive motion) > TFA (adaptive motion) (T)
Maki et al., 2019 [52]	In vitro	Resin canal blocks	ProTaper Next	Single-length	High and/or medium-speed > low-speed (clockwise T) High-speed > medium-speed > low-speed (F)
Gambarini et al., 2019 [53]	In vivo	Double-rooted maxillary premolars	ProTaper Next, EdgeFile	Single-length	ProTaper Next > EdgeFile (T & preparation time)
Bürklein et al., 2019 [54]	In vitro	Maxillary incisors	K-flexofile stainless steel, F6 SkyTaper & EndoPilot, DentaPort ZX OTR, VDW.silver	Balanced-force, single-length	Balanced-force > rotary (F) Rotary > balanced-force (T) No significant differences among 3 motors (T)
Almeida et al., 2020 [12]	In vitro	Acrylic blocks	ProTaper Next, ProTaper Universal	Single-length	ProTaper Next X2 > ProTaper Next X1 > ProTaper Universal S1 > ProTaper Universal F1 (T) ProTaper Next X1 > ProTaper Universal S2 > ProTaper Next X2 > ProTaper Universal F1 (F)
Maki et al., 2020 [55]	In vitro	Resin blocks	Reciproc, Reciproc Blue	Single file	Reciproc > Reciproc Blue (T & F)
Lee et al., 2020 [3]	In vitro	Molars	ProTaper Next, One Curve, Hyflex EDM, Twisted File Adaptive	Single-length	CR > adaptive motion (T) Hyflex EDM > One Curve > ProTaper Next > Twisted File Adaptive (T)

Author/Year	Type of Study	Type of Sample	Instrument	Preparation Technique	Result
Htun et al., 2020 [56]	In vitro	Mandibular incisors	Hyflex EDM glide path file, stainless steel K-file	Single file	CR > OGP > stainless steel manual (T in positive domain) CR > stainless steel manual > OGP (T in negative domain) OGP > stainless steel manual > CR (F in positive domain) OGP > CR > stainless steel manual (F in negative domain)
Kimura et al., 2020 [57]	In vitro	Resin blocks	Endowave	Single file, crown-down	Single file (CR) > single file (OTR) (clockwise & counterclockwise T) crown-down (CR) > crown-down (OTR) (clockwise T) crown-down (OTR) > crown-down (CR) (counterclockwise T)
Peters et al., 2020 [58]	In vitro	Plastic blocks	TruNatomy, ProTaper Next	Single-length	ProTaper Next X2 > ProTaper Next X3 > ProTaper Next X1 > TruNatomy 36 > TruNatomy 26 > TruNatomy 20 (T) ProTaper Next X1 > ProTaper Next X2 > ProTaper Next X3 > TruNatomy 36 > TruNatomy 26 > TruNatomy 20 (F)

From these studies, we identified the following 26 factors that influence Ni-Ti rotary instrument torque and force: type of sample [19], canal curvature [19][29], cross-sectional design [11][15][33][49][53], taper [53], blade [15], pitch length [11][12][13][14][15], helix angle [13][15][49], rake angle [11][12][15], cutting efficiency [11][12], instrument size [9][11][12][43][16][30], glide-path preparation [44][40], canal size [35][18][20][21][22], contact area [17][24], preparation technique [8][16][17][24][23][37][31][32][57], preparation time [53][54], insertion depth [19][16][18][20][21][22][17][24][23][37][31][32][57][28][34][52][36][58][42], insertion rate [34][48], displacement [28], motor [54], kinematics [3][4][49][57][41][56][51][46][39][50], operative motion [47], rotational speed [31][34], pecking speed [52], lubricant [25][26], experience of the operators [16], and metallurgy [14][49][53][36][58][46][27][55][45][38].

Pro-branded systems, such as ProFile, ProTaper Next, ProTaper and ProTaper Universal, were most frequently investigated (Figure 2). The highest numbers of articles were published in 2019 and in the first half of 2020 (Figure 3), and 48% of the articles included in this review were published in Journal of Endodontics (Figure 4).

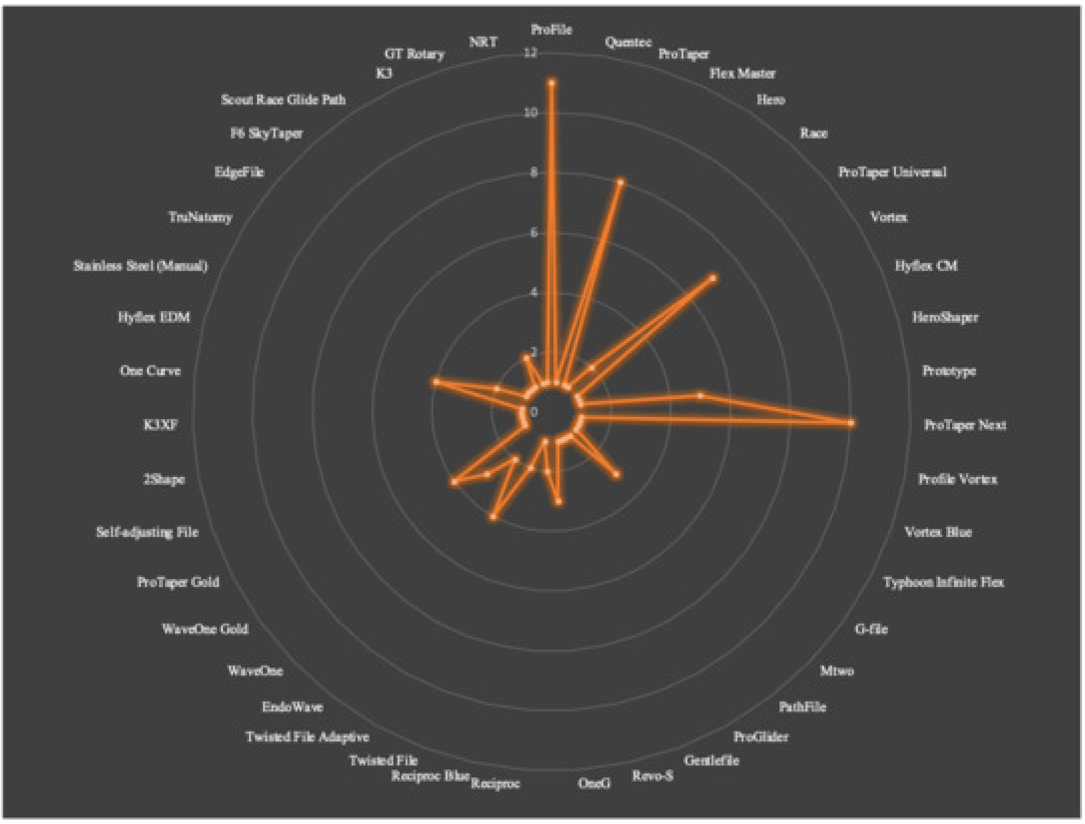

Figure 2. Instrument systems used in the studies included in the review.

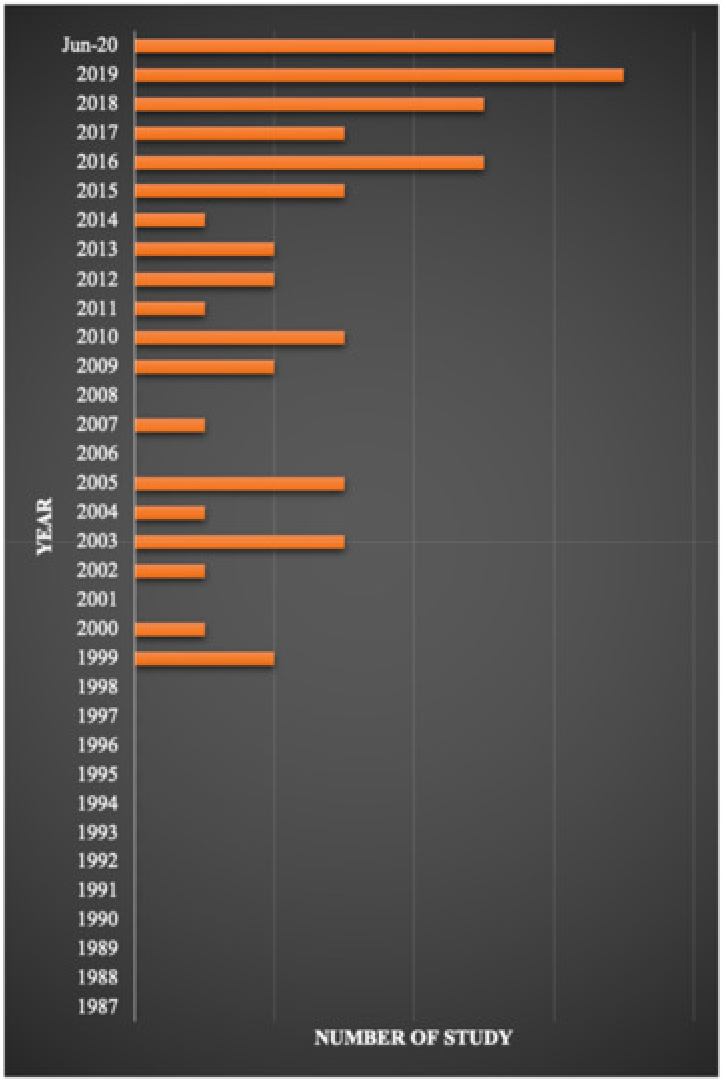

Figure 3. Publication year of the articles included in the review.

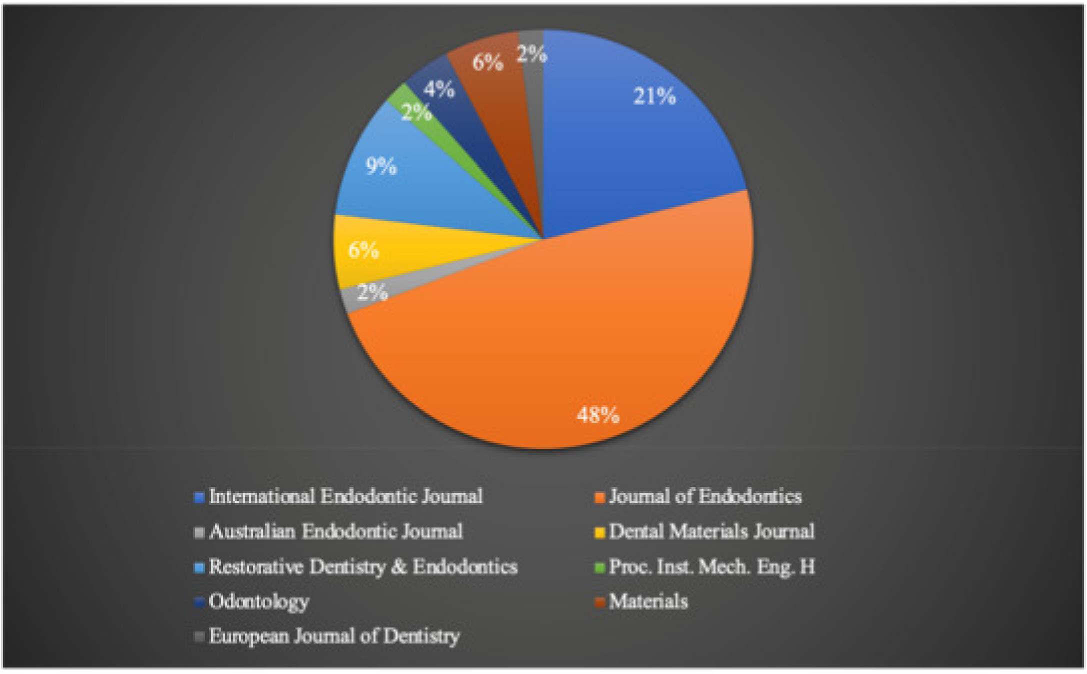

Figure 4. Journals in which articles included in the review were published (by percentage). "Proc. Inst. Mech. Eng. H" refers to "Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine".

The main findings obtained from the present systematic review can be summarized as: Higher torque or force generation was related to convex triangle cross-sectional design, regressive taper, short pitch length, large instrument size, small canal size, single-length preparation technique, long preparation time, deep insertion depth, low rate of insertion, continuous rotation (torque), reciprocating motion (force), lower rotational speed and conventional alloy.

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