

The Effect of Glide Path Preparation on Root Canal Shaping Procedures and Outcomes

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ABSTRACT

The 'glide path' in non-surgical root canal treatment refers to a smooth radicular tunnel from the root canal orifice to its terminus. Its establishment is aimed at creating sufficient space to facilitate the subsequent and safer use of engine-driven nickel titanium (NiTi) shaping files. Glide paths were originally prepared using stainless steel hand files to, at least, a loose International Organisation for Standardisation (ISO) size 10 or larger. However, the advent of engine-driven NiTi instrumentation has led to the availability of many engine-driven NiTi glide path files. The aims of this review were to assess the effects of engine-driven and manual glide path preparation (GPP) on root canal shaping procedures and outcomes. An online search of the PubMed, Embase, Scopus and ScienceDirect databases was conducted and 32 studies were identified. The published literature suggests the use of engine-driven glide path files to be beneficial in maintaining the original root canal anatomy, reducing preparation time, decreasing apical extrusion of debris and causing less postoperative pain. However, there was no difference between engine-driven and manual GPP with regards to the physical strain exerted on the shaping files. Future research focused on clinical outcomes is needed to help ascertain the clinical benefits for patients.

Keywords: Engine-driven instrumentation, glide path, nickel-titanium, outcome, preflaring, root canal shaping

HIGHLIGHTS

- Engine-driven GPP maintains the original root canal anatomy as good as, or better than, manual GPP.
- Engine-driven glide paths allow for final shaping of the root canal which conforms to the original root canal anatomy to the same degree or better than a prior manual glide path.
- The glide path can be prepared faster with engine-driven glide path files compared with manual K-files.
- Engine-driven GPP results in less apical extrusion of debris and a reduction in postoperative pain compared with manual GPP.
- There is still room for more clinical research on the clinical effectiveness of engine-driven GPP.

INTRODUCTION

Non-surgical root canal treatment entails a combination of mechanical preparation and chemical disinfection to eliminate microbes from the root canal system. Mechanical preparation was originally carried out using carbon steel hand files, which were superseded by stainless steel hand files (1) and, lately, engine-driven nickel titanium (NiTi) instruments.

The advantages of using engine-driven NiTi instruments include efficient, well tapered preparations and reduced operator fatigue (2). However, clinicians experienced less tactile feedback (2). In narrow

root canals, the taper lock effect may occur (3, 4), resulting in procedural errors such as file separation, ledge or zip formation and perforations (5). The establishment of a 'glide path' prior to the use of shaping files has been proposed (3, 6) to prevent these problems.

Early on, 'manual pre-flaring' was a term synonymous with 'glide path' (3, 4, 7); however, this can be confused with 'coronal pre-flaring'. Subsequently, the 'glide path' became more clearly defined; for example, it is a smooth radicular tunnel from the root canal orifice to its physiologic terminus able to accommodate a 'super loose' ISO size 10 hand file (8). Others had described the 'glide path' as the creation of a root canal diameter larger than or the same size as the tip of the first engine-driven file being used (4); however, this is not practical for certain file systems.

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Recently, a systematic review by Plotino et al. (9) has proposed separating the terms 'glide path' and 'pre-flaring'. The 'glide path' is preparation of the root canal which allows for a 'super loose' ISO size 10 hand file while 'pre-flaring' is further enlargement of the root canal to its terminus using a file with an ISO tip size at least equal to the first engine-driven file used (9). However, West (8) stated that the minimum size of the glide path is a 'super loose' ISO size 10 hand file, which allows for further canal widening if desired. Furthermore, the pre-flaring studies in the systematic review by Plotino et al. (9) were focussed on 'coronal pre-flaring'.

In the early 2000s the term 'glide path' was not common and 'manual pre-flaring' was used as an extension of 'coronal pre-flaring' (3, 4, 7). Hence, the term 'glide path' is best defined as preparation of the root canal before using an engine-driven NiTi shaping system and 'pre-flaring' is confined to the initial coronal preparation.

A 'manual glide path' is prepared using stainless steel hand files. An ISO size 10 K-file is used to instrument to the apical terminus in a watch-winding motion. Once at the apical terminus, a short vertical filing motion is used to remove root canal wall interferences. Larger K-files can then be used in the same manner if a wider glide path is desired.

It has been reported that improved safety and superior root canal preparation can be achieved when using engine-driven NiTi final shaping files with initial 'manual glide path' preparation (GPP) compared with no prior glide path (3, 6, 7, 10). A reduction in the rate of fracture of engine-driven NiTi shaping files was shown when they were used after manual GPP (3, 6, 7). Furthermore, improved preservation of the original root canal anatomy was achieved with prior preparation of a manual glide path (10).

Given there are now many different engine-driven glide path files available (Table 1), the aims of this review were to assess the published research on the effect of engine-driven glide path files on root canal shaping procedures and outcomes compared with manual GPP.

LITERATURE REVIEW

Methodology

An online search, which ended in June 2021, of the PubMed, Embase, Scopus and ScienceDirect databases using the terms: 'glidepath', 'glide path', 'endodontics', 'rootcanal' and 'root canal' was conducted and 837 studies were identified. After removal of duplicates, the abstracts were reviewed to select experimental studies in the English language only and those which assessed at least one engine-driven glide path file in comparison with manual GPP. Reference lists from the selected studies were manually searched for relevant papers. Studies were excluded if a root canal shaping procedure or outcome was not assessed, for example, cyclic fatigue or torsional failure of engine-driven glide path files. This search produced a total of 32 studies, which were then reviewed. The studies comparing engine-driven GPP can be divided into its effect on root canal anatomy, preparation time, shaping files, apical extrusion of debris and postoperative pain.

Root canal anatomy

Changes in root canal anatomy is by far the most investigated outcome of engine-driven GPP systems. The importance of maintaining the original root canal shape as an objective of root canal preparation was emphasised by Schilder (11); two of these objectives are that the root canal preparation should flow with the shape of the original root canal and the apical foramen should remain in its original position. Adhering to these objectives will ensure fulfilment of the goals of mechanical preparation (5).

The effect of engine-driven GPP on root canal anatomy was investigated in 17 published studies (Table 2). The different aspects of root canal anatomy assessed were: curvature, transportation, centring, area/volume and aberrations.

Root canal curvature

Changes in root canal curvature have been investigated by three studies. Acrylic Endodontic Training Blocks (AETB) were used in one study (4) and the other two studies used mesial root canals of mandibular molars (12, 13).

All three studies focused on the prepared glide path. Berutti et al. (4) found less variation in root canal curvature when using engine-driven glide path files compared with K-files. However, no difference between engine-driven and manual GPP was demonstrated by the others (12, 13). In addition, Berutti et al. (4) also investigated the clinician's ability to use these files; interestingly, it was found that inexperienced clinicians using PathFiles (Dentsply Sirona, Ballaigues, Switzerland) were able to produce less variation in root canal curvature compared with expert endodontists using K-files.

Root canal transportation

Fourteen studies, using either mesial root canals of mandibular molars or mesiobuccal root canals of maxillary molars, measured the degree of canal transportation (Table 2). The prepared glide path was the focus of six of these studies. Two studies found no difference in root canal transportation between engine-driven and manual GPP (12, 13). Whereas three studies found the engine-driven glide path files produced less root canal transportation compared with K-files (14-16). However, van der Vyver et al. (15) found this to be the case only at the apical level as root canal transportation was similar at the mid-root and coronal levels. Conversely, Htun et al. (17) found that the glide path prepared with K-files caused less canal transportation compared with engine-driven files.

Root canal transportation after final shaping was investigated in four studies in which final shaping was completed with various shaping instruments with ISO size 25 tips (ProTaper, Dentsply Sirona; ProTaper Next, Dentsply Sirona; Reciproc, VDW, Munich, Germany; WaveOne Gold, Dentsply Sirona; One Shape, Micro-Méga, Besançon, France; XP Endo Shaper, FKG Dentaire, La Chaux-de-Fonds, Switzerland; HyFlex EDM, Coltène, Langenau, Germany; One Curve, Micro-Méga). No difference in root canal transportation was seen in three studies (18-20). An increased degree of root canal transportation was shown when a prior manual glide path was performed compared with an engine-driven glide path created with the ProGlider file (Dentsply Sirona) (21); however, this was

TABLE 1. A selection of engine-driven glide path files

Name (company)	Alloy	Sizes	Motion	Method of use
PathFile (Dentsply Sirona)	NiTi	1-ISO 13, 2% taper 2-ISO 16, 2% taper 3-ISO 19, 2% taper	Continuous rotation 300 rpm at 5 N.cm torque	Used in sequence after manual glide path with ISO size 10 hand file
ProGlider (Dentsply Sirona)	NiTi M-Wire	ISO 16, variable taper starting at 2%	Continuous rotation 300 rpm at 2-5.2 N.cm torque	Used after manual glide path with ISO size 10 hand file
HyFlex Glide Path File Sequence (Coltène)	1-NiTi 2&3-NiTi CM Wire	1-ISO 15, 1% taper 2-ISO 15, 2% taper 3-ISO 20, 2% taper	Continuous rotation 300 rpm at 1.8 N.cm torque	Used in sequence after manual glide path with ISO size 10 HyFlex® X-File (NiTi hand file)
HyFlex EDM Glide Path File (Coltène)	NiTi CM Wire, EDM process	ISO 10, 5% taper	Continuous rotation 300 rpm at 1.8 N.cm torque	Used after manual glide path with ISO size 10 hand file
ScoutRace (FKG Dentaire)	NiTi, electrochemical polishing	1-ISO 10, 2% taper 2-ISO 15, 2% taper 3-ISO 20, 2% taper	Continuous rotation 600-800 rpm at 1.5 N.cm torque	Used in high curvature or S-shaped root canals after working length is established with an ISO size 08 hand file
Race ISO 10 (FKG Dentaire)	NiTi, electrochemical polishing	1-ISO 10, 2% taper 2-ISO 10, 4% taper 3-ISO 10, 6% taper	Continuous rotation 600-800 rpm at 1.5 N.cm torque	Used to reach the working length when ISO sizes 06 and 08 have reached estimated working length
One G (Micro-Méga)	NiTi	ISO 14, 3% taper	Continuous rotation 250-400 rpm at 1.2 N.cm torque	Used after an ISO size 10 hand file has reached the working length
R-Pilot (VDW)	NiTi M-Wire	ISO 12.5, 4% taper	Reciprocating motion at Reciproc settings	Used when glide path is needed for Reciproc files, ISO size 08 used to confirm patency first, R-Pilot® used in three up-and-down movements, then cleaned and repeated until working length is reached
WaveOne Gold Glider (Dentsply Sirona)	NiTi Gold heat treated	ISO 15, variable taper starting at 2%	Reciprocating motion at WaveOne settings	Used after manual glide path with ISO size 10 hand file

ISO: International Organisation for Standardisation, NiTi: Nickel titanium, CM: Controlled memory, EDM: Electrical discharge machining

only at the coronal level and only with the ProTaper Next system (Dentsply Sirona), which was used compared with WaveOne Gold (Dentsply Sirona) and OneShape (Micro-Méga).

Root canal transportation after GPP and after final shaping were assessed in four studies. Manual GPP was demonstrated to produce glide paths with increased root canal transportation compared with engine-driven GPP (22-24). However, Türker & Uzunoğlu (25) found no difference between manual and engine-driven glide paths. After final shaping the results were divided equally, prior engine-driven and manual GPP had the same effect on root canal transportation (24, 25). In the remaining two studies, greater root canal transportation after final shaping was found with prior manual GPP compared with engine-driven GPP (22, 23).

Root canal centring

The influence on root canal centring has been investigated in nine studies; one used AETB while eight used root canals of human teeth (Table 2). Liu et al. (16) reported that a glide path prepared with engine-driven instruments was just as centred as that prepared manually. Four studies found engine-driven files were able to produce more centred glide paths compared with GPP using K-files (14, 15, 26, 27). Whether a manual or engine-driven glide path was established beforehand, there was no difference in centring ability when the final shaping was completed using ISO size 25 tip engine-driven instruments (ProTaper Next, Dentsply Sirona; Reciproc, VDW; WaveOne Gold, Dentsply Sirona; One Shape, Micro-Méga) (19, 21)

When centring ability was examined after GPP and after final shaping, it was found that glide paths were more centred in the apical area when engine-driven glide path files were used compared with K-files (22). However, after final shaping, no difference was noticed between the two GPP methods (22). In addition, Vorster et al. (24) found no difference in centring ability between engine-driven or manual GPP after glide path establishment or after final shaping.

Root canal area and volume

The amount of dentine removed can be assessed by measuring the difference

TABLE 2. Main characteristics of the studies assessing root canal anatomy

Authors	Groups (ISO tip)	Teeth	Imaging	Measurement	Result
Berutti et al. 2009 (4)	PathFile (13,16,19) K-Files (08,10,15,20)	100 S-Shaped AETB	Digital camera	Canal curvature and Canal aberrations	PathFile group showed less variation of curvature and less canal aberrations
Alves et al. 2012 (12)	PathFile (13,16,19) Mtwo (10,15,20) K-files (10,15,20)	45 mesial canals of mandibular molars, 25-35° curvature	Digital radiographs	Apical transportation, Canal curvature and Canal aberrations	No difference between the groups No canal aberrations observed
Pasqualini et al. 2012a (26)	PathFile (13,16,19) K-Files (08,10,12,15,17,20)	16 buccal canals from maxillary molars, moderate curves (<35°) or severe curves (>40°)	Micro-CT scan	Centring ability and Canal area	PathFile group showed less canal modifications
Meireles et al. 2012 (18)	PathFile (13,16,19) K-files (15,20) K-Files (15,20,25)+GG 2+3 Final shaping: ProTaper up to F2	45 mesial canals of mandibular molars, 20-55° curvature	Digital radiographs	Apical transportation	No difference between the groups
Ajuz et al. 2013 (27)	PathFile (13,16,19) ScoutRace (10,15,20) K-Files (08,10,15,20)	60 S-Shaped AETB	Dental operating microscope	Centring ability (8 levels)	ScoutRace more centred than K- files at all levels. PathFile more centred than K-files except at 0 mm level.
D'Amario et al. 2013 (13)	G-file (12,17) PathFile (13,16,19) K-Files (10,15,20)	45 mesio-buccal canals of mandibular molars, 25-35° curvature	Digital radiographs	Apical transportation and Canal curvature	No difference between any groups
Carvalho et al. 2015 (19)	PathFile (13,16,19) K-files (10,15) No glide path No prep Final shaping: Reciproc R25	52 mesial canals of mandibular molars, 20-30° curvature	Cone Beam Computed Tomography	Canal transportation and Centring ability (2 levels)	No difference between the groups
Türker&Uzunoglu 2015 (25)	PathFile (13,16,19) ProGlider (16) K-Files (10,15,20) No glide path Final shaping: ProTaper Next X1+ X2	40 mesio-buccal canals of mandibular molars, 25-35° curvature	Digital radiographs	Apical transportation	No difference between the groups in apical transportation after glide path preparation or final preparation
Paleker&van der Vyver 2016 (14)	ProGlider (16) G-file (12,17) K-Files (10,15,20)	90 mesial canals of mandibular molars, 25-30° curvature	Micro-CT scan	Centring ability and Apical transportation (3 levels)	Less apical transportation in ProGlider and G file groups compared to K-Files. ProGlider has greater centring ability than K-Files at all points and compared to G files at point of maximum curvature.
Alovisi et al. 2017 (22)	PathFile (13,16) ProGlider (16) K-Files (12,15) Final shaping: ProTaper Next X1+X2	45 mesio-buccal canals of mandibular molars, 25-40° curvature	Micro-CT scan	Centring ability, Canal area and Canal transportation (3 levels)	Post glide path prep: K-files showed increase centre of gravity shift and increase canal modifications at apical level, ProGlider showed increase canal enlargement at middle and coronal levels. Post Shaping: ProGlider group showed less centre of gravity shift at all levels.

TABLE 2. Cont.

Authors	Groups (ISO tip)	Teeth	Imaging	Measurement	Result
Zheng et al. 2018 (23)	PathFile (13,16,19) ProGlider (16) K-Files (15,20) Final shaping: WaveOne primary	60 mesial canals of mandibular molars, 25-40° curvature	Micro-CT scan	Canal transportation and Canal volume (3 levels)	Post glide path prep: more transportation with K-Files at all levels, Canal volume increase larger for ProGlider group Post shaping: more transportation with K-Files at 3 and 5mm levels, ProGlider had less transportation at 5mm then other groups, no difference in canal volume
Vorster et al. 2018a (24)	PathFile (13,16,19) WaveOne Gold Glider (15) K-files (10,15,20) No glide path Final shaping: WaveOne Gold Primary	60 mesio-buccal canals of mandibular molars, 25-35° curvature	Micro-CT scan	Canal transportation and Centring ability (3 levels)	Post glide path prep: K-Files resulted in more transportation, no difference between groups for centring ability Post shaping: No difference between all groups for centring ability or canal transportation
van der Vyver et al. 2019a (15)	ProGlider (16) One G (14) K-files (10,15,20)	135 mesio-buccal canals of maxillary molars, 25-35° curvature	Micro-CT scan	Centring ability, Canal transportation and Canal volume (3 levels)	Centring ability greater for ProGlider and One G compared to K-files Apical transportation greater for K- files compared to ProGlider and One G
van der Vyver et al. 2019b (21)	ProGlider (16) One G (14) K-files (10,15,20) Final shaping: WaveOne Gold Primary, One Shape, ProTaper Next all ISO 25 tips	135 mesio-buccal canals of maxillary molars, 25-35° curvature	Micro-CT scan	Centring ability, Canal transportation and Canal volume (3 levels)	No difference in changes in canal volume No difference in centring ability. ProGlider with WaveOne Gold provided lowest canal transportation values at all levels, only significant to a portion of other groups. ProTaper Next had increased volume change compared to all other groups regardless of glide path preparation.
Htun et al. 2020 (17)	HyFlex EDM GPF (10) K-file (15)	245 mandibular incisors, curvature less than 5°	Micro-CT scan	Canal transportation and Canal volume (3 levels)	Less canal transportation and canal volume changes with K-files
Alhalabi et al. 2021 (20)	R-Pilot (1.2.5) K-file (20) Final shaping: XP Endo Shaper, HyFlex EDM and One Curve	60 S-shaped AETB	Digital camera	Apical transportation and Canal volume (10 levels)	No difference in apical transportation, R-Pilot resulted in increased canal volume
Liu et al. 2021 (16)	Mechanical Glide Path super-files (10,15) K-file (10,15)	15 mesial roots of mandibular molars, 25-40° curvature	Micro-CT scan	Canal transportation and Canal centring (3 levels)	Less canal transportation with the Mechanical Glide Path super-files, no difference in canal centring

ISO: International Organisation for Standardisation, NiTi: Nickel titanium, AETB: Acrylic Endodontic Training Blocks, EDM: Electrical discharge machining

in root canal area and volume. A reduction in the amount of dentine removed will result in fewer changes in the root canal area or volume, thereby reducing the chance of strip perforations whilst maintaining the tooth's structural integrity.

Pasqualini et al. (26) found less dentine removal when the glide path was prepared using an engine-driven file compared with K-files. However, van der Vyver et al. (15) found no difference in dentine removal between the two GPP methods. Different GPP methods were shown to have no effect on the degree of dentine removal when final shaping was completed to an ISO size 25 tip shaping file (21). However, Alhalabi et al. (20) showed greater canal volume changes with engine-driven GPP compared with K-files after final shaping.

Alovisi et al. (22) reported greater dentine removal at the apical level after GPP when K-files were used; however, at the middle and coronal levels the use of a specific engine-driven glide path file (ProGlider, Dentsply Sirona) resulted in more dentine removal compared with K-files. Zheng et al. (23) reported that the same engine-driven glide path file removed more dentine compared with K-files when preparing the glide path. Htun et al. (17) also found more dentine removal when using the HyFlex EDM Glide Path File (Coltène). After final shaping with an ISO size 25 tip shaping instrument (ProTaper Next, Dentsply Sirona; WaveOne, Dentsply Sirona), no difference in dentine removal was seen between the two GPP methods (22, 23).

Root canal aberrations

Root canal aberrations resulting from asymmetrical removal of dentine from the root canal wall may produce ledges, elbows or zips. Once created these aberrations may be difficult to bypass and may lead to incomplete root canal preparation and disinfection jeopardising treatment outcome; also, its correction may lead to excessive dentine removal.

The influence of different GPP methods on root canal aberrations was investigated using AETB (4) and mesial root canals of mandibular molars (12). Less root canal aberrations were reported by Berutti et al. (4) with engine-driven glide path files compared with K-files. Whereas, Alves et al. (12) observed no root canal aberrations in both the engine-driven and manual GPP groups.

Overall, the results suggest engine-driven GPP to be as good as, or better than, manual GPP at maintaining the original root canal anatomy; this is true after GPP and after final shaping. Hartmann et al. (28) also found engine-driven GPP to be as good as, or better than, manual GPP in their systematic review assessing root canal centring and apical transportation on human teeth. Only three studies (17, 22, 23) showed more dentine removal during glide path establishment with the engine-driven glide path files compared with K-files; this is due to the increased taper design of these files, which may be beneficial in reducing the taper lock effect on subsequent shaping instruments.

Preparation time

Reducing the time required to prepare root canals by using engine-driven instruments reduces operator fatigue and allows more time for irrigation and disinfection, thus potentially improving treatment outcome (29). The effect of engine-driven

GPP on preparation time has been investigated in studies utilising AETB (30) and mesial root canals of mandibular molars or root canals of mandibular central incisors, with curvatures ranging from 25-40° (13, 22, 23, 31-33) (Table 3).

Two studies measured the time required for GPP and found engine-driven systems to be faster than K-files (13, 31). Alovisi et al. (22) assessed the time taken for final shaping with ProTaper Next X1 and X2 files (Dentsply Sirona), which was statistically similar whether the glide path was prepared using an engine-driven system or K-files.

The time taken for GPP and final shaping were measured separately in two studies (30, 32). The PathFile system (Dentsply Sirona) was found to prepare the glide path faster than K-files; final shaping with the WaveOne Primary file (Dentsply Sirona) was achieved fastest in the PathFile (Dentsply Sirona), compared with the K-file, group (30). Measuring the time taken for GPP, Vorster et al. (32) reported that engine-driven systems were faster than K-files; final shaping was completed with the WaveOne Gold Primary file (Dentsply Sirona). However, there was no difference in final shaping times between the engine-driven and manual glide path groups (32).

Two studies measured preparation times of GPP and final shaping combined. Adiguzel & Tufenkci (33) compared the R-Pilot file (VDW) with an ISO size 12.5 C-pilot file (VDW) and final shaping was completed with Reciproc R25 or Reciproc Blue R25 files (VDW); a faster preparation time was recorded in the C-pilot groups compared with the R-Pilot groups. Zheng et al. (23) had three GPP groups, ProGlider (Dentsply Sirona), PathFile system (Dentsply Sirona) and K-files, and the WaveOne Primary file (Dentsply Sirona) was used for final shaping; their results revealed the ProGlider group to be the fastest, followed by the PathFile group and then the K-file group (23).

In summary, engine-driven glide path files prepare the glide path faster than manual preparation. Engine-driven GPP allows for final shaping times as fast as or faster than manual GPP. The only study that suggested otherwise measured the time for GPP and final shaping together (33); manual GPP resulted in an overall shorter preparation time compared with engine-driven GPP. This may be attributed to the increased taper of the engine-driven glide path file compared with the C-pilot file (4% compared with 2%).

Effect on shaping files

One of the aims of GPP is to prevent the taper lock effect on engine-driven NiTi shaping files, thereby reducing the possibility of instrument separation. All endodontic instruments will experience cyclic fatigue or torsional failure. Cyclic fatigue will occur after an instrument's limit of tension-compression cycles has been reached, and torsional failure will occur when the instrument is locked in the root canal and is rotated beyond its elastic limit. By decreasing the physical deformation through a reduction of the stresses experienced, glide path establishment may prevent instrument separation. The effect of engine-driven GPP on shaping files have been investigated, in several studies (30, 34, 35), by looking at various aspects including screw-in effect, torque generation, surface topography, and preparation until instrument separation occurs.

TABLE 3. Main characteristics of the studies assessing preparation time

Authors	Groups (ISO tip)	Teeth	Measurement	Results
D'Amario et al. 2013 (13)	G file (12,17) PathFile (13,16,19) K-Files (10,15,20)	45 mesio-buccal canals of mandibular molars, 25-35° curvature	Preparation time including irrigation between instruments	G file fastest then PathFile then K-files
Jonker et al. 2014 (30)	PathFile (13,16,19) K-file (10,15,20) No glide path Final shaping: WaveOne Primary PathFile (13,16) ProGlider (16) K-Files (12,15) Final shaping: ProTaper Next X1+X2	300 AETB blocks	Preparation time when instrument in canal, time not recorded for irrigation, changing files, cleaning files, recapitulation	Post glide path: PathFile faster than K-files Post shaping: PathFile fastest then K-file then no glide path
Alovisi et al. 2017 (22)	PathFile (13,16) ProGlider (16) K-Files (12,15) Final shaping: ProTaper Next X1+X2	45 mesio-buccal canals of mandibular molars, 25-40° curvature	Preparation time	Post glide path prep: ProGlider faster than PathFile Post shaping: no difference between the three groups
Paleker & van der Vyver 2017 (31)	ProGlider (16) G File (12,17) K-Files (10,15,20) WaveOne Gold Glider (15) PathFile (13,16,19) K-Files (10,15,20) No glide path Final shaping: WaveOne Gold primary	90 mesial roots of mandibular molars, 25-35° curvature	Preparation time with electronic stopwatch, only when instrument in canal	K-files took more time than the other groups, no difference between engine-driven groups
Vorster et al. 2018b (32)	WaveOne Gold Glider (15) PathFile (13,16,19) K-Files (10,15,20) No glide path Final shaping: WaveOne Gold primary	60 mesio-buccal roots of mandibular molars, 25-35° curvature	Preparation time with electronic stopwatch, only when instrument in canal	Post glide path prep: WaveOne Gold Glider fastest then PathFile then K-files Post shaping: WaveOne Gold primary prep faster when glide path prepared but no difference between the glide path groups
Adiguzel & Tufenkci 2018 (33)	C-pilot (12.5) R-pilot (12.5) No glide path Final shaping: Reciproc R25 and Reciproc blue R25	300 mesial canals of mandibular molars, 25-39° curvature	Preparation time with electronic stopwatch, included irrigation and patency exploration	No glide path group fastest then C-pilot then R-pilot

ISO: International Organisation for Standardisation, AETB: Acrylic Endodontic Training Blocks

The effect of GPP on shaping files was covered in three studies (Table 4); AETB were used in two studies (30, 34), and the remaining study used root canals of molar teeth with 10-30° curvatures (35).

Screw-in effect and torque generated was measured by Ha & Park (34) on ProTaper S1 files (Dentsply Sirona) while preparing AETB. There were four experimental groups; PathFile number 1 (Dentsply Sirona), modified PathFile number 2 (Dentsply Sirona), ISO size 15 NiTi K-file and ISO size 20 NiTi K-file. The measurements were recorded with a dynamometer and a torque sensor. The results revealed the ISO size 20 NiTi K-file group had the lowest screw-in effect, and also generated lower torque than the PathFile number 1 (Dentsply Sirona) and the ISO size 15 NiTi K-file groups (34).

The number of AETB prepared before separation of a WaveOne Primary file (Dentsply Sirona) after GPP using either the PathFile system (Dentsply Sirona) or K-files was recorded by Jonker et al. (30). There was no difference between the two glide path groups in number of AETB prepared before file separation occurred.

The surface topography of used final shaping files, Race (FKG Dentaire) and HyFlex (Coltène), were examined using a scanning electron microscope by Patel et al. (35) in an *in vivo* experiment comparing manual GPP (K-files) with engine-driven GPP (PathFile system; Dentsply Sirona). No difference in the surface topography of the shaping files used in both the manual and engine-driven glide path groups was reported.

The results of the studies on the effect of GPP on shaping files suggest there is no difference in the surface topography of used final shaping files after engine-driven or manual GPP. Engine-driven glide paths are as good as manually prepared glide paths in reducing screw-in effect, torque generated and fracture rate; a larger glide path, whether engine-driven or manually prepared, is superior.

Extrusion of apical debris

During mechanical preparation, debris is extruded beyond the apical foramen into the periapex. This debris consists of dentine chips, necrotic pulpal remnants, bacteria and their by-products and may lead to an increased inflammatory response resulting in postoperative pain (36, 37).

TABLE 4. Main characteristics of the studies assessing the effect on the shaping file

Authors	Groups (ISO tip)	Teeth	Investigation	Assessment	Results
Ha & Park 2012 (34)	PathFile (13) NiTi K-File (15) PathFile (18) NiTi K-File (20) Final shaping: ProTaper S1 PathFile (13,16,19) K-file (10,15,20)	40 AETB	Screw-in effect and torque generated by ProTaper S1	Dynamometer and torque sensor	NiTi K-File (20) had lowest screw-in effect. PathFile (18) lower torque than PathFile (13), NiTi K-File (20) lower torque than PathFile (13) and NiTi K-File (15)
Jonker et al. 2014 (30)	No glide path Final shaping: WaveOne Primary	300 AETB	Instrument failure	Number of blocks prepared until instrument failure	No difference between PathFile and K-file groups More canals prepared in PathFile and K-file groups compared to no glide path
Patel et al. 2016 (35)	PathFile (13,16,19) K-file (15,20) Final Shaping: HyFlex and Race ISO 25	60 mesio-buccal canals of mandibular molars, 20-30° curvature	Surface topography of final shaping file	Scanning electron microscope	No difference between PathFile group or K-file group

ISO: International Organisation for Standardisation, NiTi: Nickel titanium, AETB: Acrylic Endodontic Training Blocks

The influence of engine-driven GPP on apically extruded debris has been investigated by eight research groups (Table 5) using roots of human teeth with curvatures ranging from 10-40°. Seven of these studies used the same method in measuring the weight of the extruded debris (23, 38-43) and the remaining study measured the microbial colony forming units grown from the extruded debris (44).

Ha et al. (38) compared ProGlider files (Dentsply Sirona), One G files (Micro-Méga), the ScoutRace system (FKG Dentaire) and K-files and found that the engine-driven systems extruded less debris than K-files. Gunes & Yeter (40) compared the G-file system (Micro-Méga), One G files (Micro-Méga), ProGlider files (Dentsply Sirona), the first two files of the PathFile system (Dentsply Sirona) and K-files; they found that the K-file group produced more extruded debris compared to the One G file (Micro-Méga) group with no differences between all other groups. Similarly, Abdallah et al. (39), Yahya et al. (41), Keskin et al. (42) and Anshida et al. (43) found that there was more debris extruded when glide paths were prepared with K-files compared with engine-driven files.

Zheng et al. (23) found final shaping with the WaveOne Primary file (Dentsply Sirona) extruded less debris, when engine-driven glide path files were used beforehand, compared with an initial glide path prepared with K-files.

Dagna et al. (44) used mandibular molars infected with *Enterococcus faecalis* and prepared glide paths using either ProGlider files (Dentsply Sirona), One G files (Micro-Méga), the PathFile system (Dentsply Sirona), the G-file system (Micro-Méga) or K-files. The extruded debris was collected and incubated, and those produced after GPP by K-files resulted in more colony forming units than the engine-driven glide path groups.

These studies showed that manual GPP resulted in more apically extruded debris compared with engine-driven GPP, both after GPP and after final shaping.

Postoperative pain

Postoperative pain is the only clinical outcome of engine-driven GPP that has been investigated. Apically extruded debris is a contributing factor for the occurrence of postoperative pain (36, 37).

There are only two studies (Table 6) investigating this issue (45, 46). Pasqualini et al. (45) divided 280 patients randomly into two equal groups, one where glide paths were prepared using the PathFile system (Dentsply Sirona) and other using K-files; final shaping was not carried out. Apart from GPP, the treatment protocol was standardised and procedures were carried out by 21 'expert operators'. After treatment the patients were given a 5-level pain scale to complete twice a day for a week and a prescription for analgesics. Results revealed faster reduction in pain intensity and less days for complete pain resolution for patients in the PathFile (Dentsply Sirona) group whereas patients in the K-file group reported a higher mean intake of analgesics.

Measuring postoperative pain intensity and incidence, Keskin et al. (46) divided 240 patients randomly into three equal groups. The glide path was prepared with K-files, the

TABLE 5. Main characteristics of the studies assessing apical extrusion of debris

Authors	Groups (ISO tip)	Teeth	Assessment	Results
Ha et al. 2016 (38)	ProGlider (16) One G (14) ScoutRace (15) K-file (15)	40 mandibular incisors, curvature less than 10°	Apical debris collected in Eppendorf tubes	ProGlider extruded less debris than all other groups, ScoutRace and One G extruded less debris than K-file
Abdallah et al. 2017 (39)	G-file (12,17) ProGlider (16) K-file (10,15,20) Final Shaping: One Shape	30 mesial roots of mandibular molars, 25-35° curvature	Apical debris collected in Eppendorf tubes	ProGlider extruded less debris than all other groups
Dagna et al. 2017 (44)	ProGlider (16) One G (14) PathFile (13,16,19) G-file (12,17) K-file (10,15,20)	60 mandibular molars, 10-20° curvature	Number of colony forming units from the extruded debris	K-files produced more colony forming units than all other groups, no difference between other groups
Gunes & Yeter 2018 (40)	G File (12,17) One G (14) ProGlider (16) PathFile (13,16) K-File (10,15) No glide path Final shaping: WaveOne Gold primary	60 mesial roots of mandibular molars, 25-35° curvature	Apical debris collected in Eppendorf tubes	K-Files caused more apical extruded debris than One G files, no difference between any other groups
Zheng et al. 2018 (23)	PathFile (13,16,19) ProGlider (16) K-Files (15,20) Final shaping: WaveOne primary	60 mesial canals of mandibular molars, 25-40° curvature	Apical debris collected in Eppendorf tubes	ProGlider and PathFiles produced less apical extruded debris than K- files
Yahya et al. 2019 (41)	ProGlider (16) K-file (20) Final shaping: WaveOne Primary and One Shape	40 mandibular incisors, curvature less than 8°	Apical debris collected in Eppendorf tubes	ProGlider extruded less debris than K-files
Keskin et al. 2020 (42)	ProGlider (16) R-Pilot (12.5) WaveOne Gold Glider (15) K-file (10,15) Final shaping: Recipro Blue R25	80 mesial roots of mandibular molars, 25-35° curvature	Apical debris collected in Eppendorf tubes	K-files caused more extruded debris than all other groups, no difference between other groups
Anshida et al. 2021 (43)	ProGlider (16) WaveOne Gold Glider (15) K-file (15)	75 mandibular incisors, curvature less than 10°	Apical debris collected in Eppendorf tubes	ProGlider extruded the least debris, no difference between other groups

ISO: International Organisation for Standardisation

TABLE 6. Main characteristics of the studies assessing postoperative pain

Authors	Groups (ISO tip)	Teeth	Investigation	Measurement	Results
Pasqualini et al. 2012b (45)	PathFile (13,16,19) K-file (10,12,15,17,20)	280 patients Irreversible pulpitis (asymptomatic or symptomatic) Pulp necrosis with or without apical periodontitis	Incidence and intensity of postoperative pain, frequency of postoperative analgesics intake	5-level pain scale bidaily for one week	PathFile group showed faster reduction in pain intensity, less days till complete pain resolution and less mean intake of analgesics per patient
Keskin et al. 2019 (46)	ProGlider (16) R-Pilot (12.5) K-files (08,10,15) Final shaping: ProTaper Next up to X3	240 patients Irreversible pulpitis (asymptomatic or symptomatic) Apical periodontitis (asymptomatic or symptomatic)	Incidence and intensity of postoperative pain	0-10 visual analogue scale at six intervals (6h, 12h, 18h, 24h, 48h, 72h)	Less incidence and intensity of pain in R-Pilot and ProGlider groups No difference between R-Pilot and ProGlider groups

ISO: International Organisation for Standardisation

R-Pilot file (VDW) or the ProGlider file (Dentsply Sirona), this was followed by final shaping with the ProTaper Next system (Dentsply Sirona). Treatment was carried out by four clinicians with a standardised protocol excluding the GPP. Patients in the groups prepared with engine-driven glide path files experienced a lower incidence and intensity of pain at all postoperative time intervals (6, 12, 18, 24, 48, and 72 hours) compared with the K-file preparation group. None of the 240 patients used any analgesic drugs postoperatively.

The results from these studies showed that GPP using engine-driven files can lead to less postoperative pain compared with manual GPP.

DISCUSSION

Many studies have been published demonstrating the benefits of engine-driven GPP compared with manual GPP (Tables 2-6). The use of engine-driven glide path files can lead to a root canal shape that conforms more accurately to the original root canal anatomy and help reduce postoperative pain experienced by patients. However, there are limitations with these studies and the results may not necessarily be clinically applicable.

Limitations of study design

A randomised control trial is the most effective study design when comparing different methods. Randomly allocating samples, for example, if human teeth were used, will reduce potential bias caused by differences in the dentine substrate, the root canal curvature or width. Postoperative pain is a subjective sensation and dependent on various factors such as patients' pain threshold, host response, microbial virulence and the operators' technique. Attempting to extrapolate an objective finding from subjective results to achieve a meaningful conclusion is challenging so randomisation to reduce the interference of these variables (45, 46) is necessary.

To improve external validity, inclusion and exclusion criteria should indicate the population groups applicable. For example, some studies did not set inclusion/exclusion criteria regarding tooth type, root canal curvature and width (45, 46). Furthermore, the inclusion criteria of these studies (45, 46) allowed the inclusion of teeth from different diagnostic classifications, which may lead to differences; for example, an infected non-vital tooth may cause more postoperative pain than a non-infected vital tooth. Both studies (45, 46) overcame this potential bias using statistical analysis to ensure even distribution of teeth between the groups.

To be confident that the differences in results are statistically significant and not due to chance, a sample size calculation should be carried out to ensure sample sizes are adequate. Unfortunately, sample size calculations were absent from certain studies (17, 19, 20, 25, 26, 34, 38-41, 43, 44). This is a compounding factor and a recent study reported low incidence of *a priori* sample size calculations being carried out (47).

The results of studies may be inaccurate if the experimental methods are not suitable. Digital radiographs were used to assess root canal transportation (12, 13, 25) which is not as sensitive as CBCT or micro-CT imaging. Furthermore, digital radiographs only provide two-dimensional measurements

and root canal transportation may not be seen in the plane of the radiograph. To overcome this problem, digital radiographs can be taken at multiple angles; however, this was not always used (12, 13, 18). Alovisei et al. (22) stated that the preparation time was measured for glide path and shaping but it was unclear what the time duration included (irrigation, cleaning files, changing files); also, the time for manual GPP was not recorded. Alves et al. (12) measured the occurrence but not the degree of apical transportation, which may miss important differences between the study groups.

Furthermore, the method of preparation itself can negatively affect the accuracy of results if not standardised. For example, Pasqualini et al. (45) had 21 operators treating the 280 participating patients. A larger number of operators may introduce more variance even if attempts were made to standardise the protocol. A single operator using a standardised protocol will reduce any differences in the preparation method to a minimum even though there still may be a degree of intra-operator variance.

Accuracy of information is lacking in several studies. Pasqualini et al. (26) stated that when the PathFile (Dentsply Sirona) system was used, the centring ability and the changes in root canal area meant that canal modifications were statistically significantly reduced. However, from the results presented in their graphs, there was less change in root canal area when K-files were used at the apical level, and the difference was significant for severe curvatures.

Two studies reported results which were not part of their study's aims and there were no descriptions of the assessment methods. Alves et al. (12) presented results on central axis (centring ability); however, the aims of their study were to investigate the change in root canal curvature, occurrence of apical transportation and root canal aberrations. Likewise, Keskkin et al. (46) stated 'none of the patients reported analgesic intake' while their stated aims were to only investigate the incidence and intensity of postoperative pain.

Dagna et al. (44) did not present the results from their two control groups. The results would have helped to prove whether the differences between the experimental groups were due purely to the investigated variable.

Finally, engine-driven glide path files are commercial products. A number of studies benefitted from files being provided by manufacturers (4, 14, 15, 21, 24, 31, 32) and a contributing author acknowledged receiving payment from a manufacturer (22).

Clinical relevance

Although statistical analysis is carried out to demonstrate any significant differences, it does not necessarily indicate a clinically relevant effect. For example, a statistically significant difference can be demonstrated between engine-driven and manual GPP in terms of maintaining the original root canal anatomy; however, there may be no significant difference in treatment outcomes as this is a measure of a technical, not biological, aspect of root canal treatment.

Wu et al. (48) investigated the clinical significance of apical transportation by measuring the movement of the tip of a

file placed in the root canal at length. Movement greater than 0.3 mm was shown to cause more apical leakage post-obturation but measurements may not be clinically relevant (49). Nonetheless, it is not clear whether the statistically significant difference seen regarding the changes in root canal anatomy correspond to a significant difference in treatment outcome. Furthermore, the mean apical transportation measurements described in the relevant studies are all below the 0.3 mm threshold (12-14, 18, 25).

A reduction in preparation time can provide more time for canal disinfection. However, when comparing manual with engine-driven GPP the difference in preparation time was measured in seconds; therefore, its benefit in terms of extra time for disinfection is negligible. The main benefit in this regard will be the reduction in operator fatigue.

The clinical significance of increased apical debris produced when creating a manual glide path was not proven (23, 38-44). It is assumed the increased debris will lead to a more severe inflammatory reaction and therefore, increased postoperative pain (36, 37). This can be seen in the postoperative pain studies (45, 46) which have demonstrated an increased incidence and intensity of postoperative pain which takes longer to subside when a manual glide path was created.

The extrusion of debris from a tooth with an infected pulp may introduce infected dentine chips/bacteria into the periapical area, potentially causing persistent apical periodontitis due to extra-radicular infection (50-52). It has been reported that *Actinomyces israelii* and *Propionibacterium propionicum* can build cohesive colonies which enable them to avoid the host's immune response (52). Since engine-driven GPP extruded less debris apically, it may reduce the risk of causing an extra-radicular infection compared with manual GPP.

Due to its antimicrobial and tissue-dissolving properties, sodium hypochlorite (NaOCl) is the irrigant of choice (29) and the most widely used in clinical practice (53, 54). When investigating apical extrusion of bacteria, Dagna et al. (44) standardised their irrigation solution to 6 mL of 0.9% sodium chloride (NaCl) per root canal; using NaCl instead of NaOCl may render the results less clinically relevant. NaOCl may reduce bacterial counts regardless of the extent of apical debris extrusion.

Furthermore, a common problem with all apical extrusion studies was the absence of pressure from the periapical tissues. Clinically, this pressure will act to prevent extrusion of debris; therefore, the amount of debris extruded will be less and possibly insignificant. The use of 1.5% agar gel to replicate apical pressure has been shown to reduce apical extrusion (55).

Only three studies were *in vivo* experiments (35, 45, 46). The vast majority of experiments were *in vitro*; the advantage is the ability to standardise many of the variables. Furthermore, some assessments are not possible *in vivo*. Due to the radiation dose of digital radiographs, CBCT and micro-CT, it is not ethical to assess changes in root canal anatomy *in vivo*. However, aspects of the clinical environment may be lost, which may have an influence on the significance of the results.

Five studies used AETB (4, 20, 27, 30, 34), which allowed the standardisation of canal anatomy (length, width and curvature). However, the difference in hardness between acrylic and dentine may make the results non-transferable to human teeth.

With two studies, a specific issue which may affect clinical relevance was the restriction to only using the first two files of the PathFile system (Dentsply Sirona) (22, 40). The reason for this restriction was to achieve a glide path of similar apical size for all groups. However, in a clinical setting the full sequence of files of the PathFile system (Dentsply Sirona) will be used; therefore, this is not representative of the clinical scenario.

A case for no glide path

A suggested alternative method to overcome the potential procedural errors associated with engine-driven rotary instruments is to operate them in a reciprocating motion. The manufacturer of Reciproc (VDW) claimed their files can be used safely without a prior glide path. The angles of clockwise and counter-clockwise rotation are 'significantly lower than the angles at which a Reciproc (VDW) instrument would fracture (if bound)' suggesting that the file will not experience torsional failure (56). The manufacturer advises no glide path establishment if an ISO size 10 hand file reaches the working length without being pre-curved. However, when an ISO size 10 hand file has to be pre-curved to reach the working length the creation of a glide path up to an ISO size 15 hand file is recommended, and a Reciproc file (VDW) should only be used when the hand file reaches the working length without being pre-curved. Where hand files still need to be pre-curved to reach the working length, the manufacturer suggested finishing the preparation with hand files (57).

Reciproc instruments (VDW) have been shown to be able to reach the full working length in over 90% of cases (33, 58-60). Furthermore, Plotino et al. (61) demonstrated a very low rate of file separation or deformation, 0.47% and 0.35% respectively from 1696 Reciproc files (VDW). Finally, Saber & Schäfer (62) found no difference in dentinal defects after Reciproc R25 (VDW) use with or without prior glide path creation.

Although preparation of the root canal system using Reciproc instruments (VDW) can be achieved without the need for glide path files, this requires careful case selection and is dictated by the root canal morphology.

Future direction of research

Currently micro-CT imaging is a highly sensitive method of assessing changes to the root canal anatomy and should be the standard modality going forward. Future research should have experimental models that more closely replicate the clinical scenario or directly assess a biological aspect; for example, bacterial presence or postoperative pain, in order to provide results which will have a stronger bearing on clinical relevance.

The only clinical outcome investigated is postoperative pain (45, 46); this is important as it relates to patients' experience of treatment and quality of life. Equally important is treatment outcome, whether engine-driven GPP will increase the chances success. Well-designed prospective randomised control trials focused on clinical outcomes will help to determine the clinical effectiveness of engine-driven GPP.

Only Berutti et al. (4) investigated the difference between expert (endodontist) and inexperienced clinicians when using the PathFile system (Dentsply Sirona) or K-files to prepare the glide path. Inexperienced clinicians were reported to be able to produce glide paths with less variation in root canal curvature using the PathFile system (Dentsply Sirona) compared to endodontists using K-files. An interesting result which suggests inexperienced clinicians would benefit most from the use of engine-driven files to create glide paths. However, since this is the only study, more are needed.

CONCLUSION

Based on this literature review, it may be concluded that engine-driven GPP maintains the original root canal anatomy as good as or better than manual GPP. Engine-driven glide paths allow for final shaping of the root canal which conforms to the original root canal anatomy to the same degree or better than a prior manual glide path. The glide path can be prepared faster with engine-driven glide path files compared with manual K-files. Engine-driven glide paths allow for decreased or comparable preparation times of final shaping compared with manual glide paths. Engine-driven and manual glide paths have similar effects on shaping files. Less apically extruded debris is caused by engine-driven GPP compared with manual GPP. Engine-driven GPP causes a reduction in incidence and intensity of postoperative pain compared to manual GPP.

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