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Paper Accepted[1]

ISSN Online 2406-0895

Review Article / Прегледни рад

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Manual instruments for root canal negotiation and glide path preparation – contemporary aspects

Ручни ендодонтски инструменти за успостављање иницијалне проходности и формирање инструментационе путање – савремени приступ

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Received: March 26, 2026
Revised: August 25, 2026
Accepted: August 28, 2026
Online First: September 1, 2026
DOI: https://doi.org/10.2298/SARH260326065J

[1]**Accepted papers** are articles in press that have gone through due peer review process and have been accepted for publication by the Editorial Board of the *Serbian Archives of Medicine*. They have not yet been copy-edited and/or formatted in the publication house style, and the text may be changed before the final publication.
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SUMMARY

Root canal negotiation that establishes a full working-length canal and creates a glide path (GP) prior to mechanical root canal instrumentation reduces the risk of procedural errors and significantly contributes to the success of endodontic therapy. The aim of this narrative review was to critically analyze currently available stainless-steel manual instruments used for root canal negotiation and glide path preparation, with an emphasis on their design characteristics, mechanical behavior, and clinical applicability. The manuscript describes instruments manufactured from conventional stainless steel and stainless-steel alloys modified by specific heat treatments to improve their mechanical properties. The cross-sectional and tip design of the instruments were analyzed to provide more profound insight into the effect of these parameters on apical patency and overall instrument reliability during clinical use. The potential advantages and limitations of the analyzed instruments are discussed, along with recommendations for their selection in specific clinical situations, depending on the complexity of the root canal system.

Keywords: manual stainless-steel instruments; initial canal negotiation; glide path; endodontics

САЖЕТАК

Успостављање иницијалне проходности канала до пуне радне дужине и формирање инструментационе путање пре машинске инструментације канала корена зуба смањује ризик од настанка процедуралних грешака и значајно доприноси успеху ендодонтске терапије. Овај наративни преглед критички анализира тренутно доступне ручне инструменте од нерђајућег челика који се користе за успостављање иницијалне проходности и припрему инструментационе путање, са посебним нагласком на њихове дизајнерске карактеристике, механичко понашање и клиничку примену. У раду су описани инструменти израђени од конвенционалне легуре нерђајућег челика, као и инструменти чија су својства побољшана применом специфичне термичке обраде ради унапређења њихових механичких карактеристика. Анализирани су попречни пресек и дизајн врха инструмената, и утицај ових параметара на поузданост инструмената током њихове примене.

Такође су разматране потенцијалне предности и ограничења анализираних инструмената, као и критеријуми за њихов избор у специфичним клиничким ситуацијама, у зависности од сложености система коренских канала.

Кључне речи: ручни инструменти; иницијална проходност; инструментациона путања; ендодонција

INTRODUCTION

The introduction of engine-driven nickel-titanium (NiTi) instruments has significantly improved the predictability, efficiency, and overall quality of root canal instrumentation, enabling adequate hermetic obturation, particularly in canal systems with complex anatomy [1, 2]. Since clinical success remains highly technique-sensitive, the improper use of NiTi systems is frequently associated with procedural complications, most notably instrument fracture, especially in narrow, curved, or calcified canals [1, 3]. These complications are primarily attributed to cyclic fatigue, torsional overload, and the simultaneous effect of both contributing factors [4. 5, 6].

Preliminary procedures such as canal negotiation (CN) and glide path (GP) preparation are recommended prior to engine-driven instrumentation in order to reduce the biomechanical stress on NiTi instruments [4–8]. Canal negotiation refers to the initial exploration and identification of the root canal pathway using small-sized manual instruments, with the aim of reaching the desired working length while maintaining the original canal trajectory. Canal patency refers to the maintenance or confirmation of an unobstructed pathway through the apical portion of the canal using a small, flexible instrument, without intentional enlargement beyond the apical foramen. A glide path is defined as a smooth, reproducible, and continuous pathway extending from the canal orifice to the established working length, which facilitates the safe progression of subsequent shaping instruments (Figure 1). The importance of an adequate glide path in reducing torsional stress, cyclic fatigue, and iatrogenic errors has led to the development of numerous mechanical glide path systems [9].

Consequently, stainless-steel manual instruments have maintained an important role in contemporary endodontic practice due to their simplicity, cost-effectiveness, tactile feedback, and continuous technological improvements in design and manufacturing [10]. Unlike engine-driven instruments, manual files provide enhanced tactile control and sensory perception, particularly in challenging clinical situations such as severe canal curvature, canal calcification, and retreatment cases. Consequently, manual instruments should not be considered obsolete, but rather as an essential component of a safe and biologically sound instrumentation strategy.

Contemporary manual endodontic instruments are predominantly manufactured from stainless steel, whereas the utilization of carbon steel has markedly declined due to its inferior flexibility and reduced resistance to corrosion [11, 12]. In recent years, manufacturers have introduced modifications to instrument geometry, tip design, surface treatment, and thermal processing, with the aim of improving mechanical performance and reducing the risk of procedural errors associated with manual instrumentation [8].

The aforementioned has emphasized the need to provide a critical analysis of contemporary stainless-steel manual instruments used for canal negotiation and glide path preparation, with particular emphasis on how design influences mechanical behaviour and clinical applicability, in order to support informed instrument selection in clinically demanding situations.

METHODOLOGY

This narrative review was based on a literature search conducted via PubMed, Scopus, and Google Scholar databases using the keywords “manual endodontic instruments,” “glide path,” “canal negotiation,” and “stainless-steel files.” The literature search was conducted between January and March 2025. Particular emphasis was placed on peer-reviewed publications addressing the mechanical properties, design characteristics, clinical applications, and performance of manual instruments used for root canal negotiation and glide path preparation. Articles published in English between 1990 and 2025 were included. Additional references were identified through manual searches of relevant journals and reference lists.

Manufacturer-provided information was used primarily to describe instrument-specific technical characteristics, including dimensions, taper, cross-sectional design, material composition, and recommended use, whereas statements concerning mechanical properties, clinical performance, advantages, and limitations were based preferentially on independently published scientific evidence.

TYPES AND CHARACTERISTICS OF MANUAL INSTRUMENTS – OVERVIEW FOR CANAL NEGOTIATION AND GLIDE PATH PREPARATION

Manual instruments remain essential for initial CN and GP preparation, particularly in complex, narrow, or calcified root canals. Their design features, including cross-sectional geometry, tip configuration, and taper, significantly influence mechanical performance, tactile feedback, and clinical safety (Table 1) [13–28].

Critical comparison of manual endodontic instruments – mechanical behavior, handling, and clinical implications

Despite the revolutionary impact of nickel-titanium (NiTi) instruments on contemporary endodontic practice, stainless-steel (SS) hand instruments remain indispensable, particularly during the most critical initial phases of endodontic treatment, establishing initial canal patency and creating the glide path. Their enduring clinical relevance stems from their distinct mechanical behavior, which fundamentally differs from that of NiTi alloys and provides both unique advantages and inherent limitations.

From a mechanical perspective, the behavior of manual endodontic instruments is determined not only by the properties of the alloy from which they are manufactured but also by several interrelated design and manufacturing factors, including instrument size, cross-sectional geometry, taper, tip configuration, manufacturing process, and, where applicable, thermal treatment. These variables collectively influence the balance between rigidity, flexibility, buckling resistance, torsional behavior, and tactile feedback [13–28].

From a mechanical perspective, stainless-steel instruments exhibit a significantly higher modulus of elasticity (stainless steel ≈ 190–210 GPa, NiTi alloy ≈ 30–50 GPa) and, consequently, greater hardness in comparison with NiTi instruments [12]. This results in increased resistance to torsional stress and buckling under axial load, as well as a more pronounced plastic deformation prior to fracture, manifested as visible unwinding of SS instruments before failure [11, 12]. These mechanical properties represent a key advantage during the negotiation of narrow and calcified canals, since the application of apically directed force is often required to overcome anatomical obstacles while preserving tactile control.

However, the increased rigidity of SS instruments represents a double-edged sword. A higher modulus of elasticity implies reduced flexibility, and although enhanced resistance to buckling facilitates apical penetration, excessive stiffness may compromise the instrument's ability to conform to canal curvature. Consequently, the risk of iatrogenic errors, such as canal transportation, ledge formation, or even perforation, may increase during the establishment of initial patency [11, 12]. These opposing effects highlight the importance of achieving a balanced mechanical profile rather than pursuing maximal rigidity at all costs.

Buckling resistance – advantage or potential risk?

Resistance to buckling is often cited as a key determinant of the clinical performance of instruments used to establish initial canal patency; however, its clinical relevance requires careful and critical interpretation [18, 29, 30]. Instruments with insufficient buckling resistance, such as small-sized conventional K-files (ISO 06 and 08), are prone to early deformation when encountering apical resistance, limiting their ability to advance in narrow or calcified canals [8]. This deformation, whether in the form of elastic bending or permanent plastic deformation, compromises tactile sensation, reduces cutting efficiency, and increases operator fatigue and frustration.

Conversely, instruments with very high buckling resistance, primarily C+ files, exhibit superior apical penetration capacity and increased resistance to deformation under axial load [29, 30, 31]. Numerous independent studies consistently rank C+ files as instruments with the highest buckling and torsional resistance compared with conventional K-files, C-PILOT files, and various NiTi GP instruments [32–35]. These mechanical properties make C+ files particularly suitable for negotiating severely narrowed or calcified canals, where the application of apical force is often unavoidable.

However, high buckling resistance should not be interpreted as an unequivocal clinical advantage, as these mechanical properties may also represent a clinical risk. The same characteristics that provide increased axial strength can predispose highly rigid instruments to iatrogenic complications. Reduced flexibility limits the instrument's ability to follow canal curvatures, increasing the likelihood of deviation from the original anatomy. Dias et al. [29] warned that increased rigidity of C+ files may increase the risk of iatrogenic errors when instruments are used without adequate pre-bending and careful tactile control. Canal transportation studies indicate that excessively rigid instruments, especially those with active cutting tips, can increase the frequency of canal aberrations if used aggressively or without proper pre-bending and tactile guidance [13, 35].

In this context, C-PILOT files have been proposed as a more conservative alternative. By combining thermally modified stainless steel with a passive, guided tip, these instruments provide a balanced compromise between mechanical strength and preservation of canal anatomy, enabling more predictable negotiation and reducing the risk of procedural errors [29, 33].

In the study by Yörel et al., which investigated the preparation of curved and narrow root canals in primary molars, it was shown that K-files produced less apical transportation compared with OneShape (MicroMega, Besancon, France) and pediatric rotary EndoArt Pedo Blue files (İnci Dental, Istanbul, Turkey). While the results confirm that the use of rotary instrumentation in primary teeth is safe, K-files provide enhanced tactile sensation and facilitate the formation of an apical matrix, representing an important clinical factor in reducing the risk of material extrusion toward the permanent tooth germs during instrumentation [36].

Although laboratory measurements of buckling resistance provide valuable information regarding the mechanical behavior of endodontic instruments, these findings should not be interpreted as direct predictors of clinical treatment outcomes.

Influence of manufacturing quality and metallurgy

A critical comparison of manual endodontic instruments must also consider manufacturing quality and metallurgical consistency. Buckling resistance and overall mechanical performance depend not only on instrument design or alloy type but are also significantly influenced by the manufacturing process [30]. Izadi et al. [37] reported a higher incidence of surface defects and irregularities in certain SS instruments, including Mani K-files, which may act as stress concentrators and negatively affect mechanical durability. These findings were corroborated by Nair et al. [38], who demonstrated that Mani K-files exhibited the lowest buckling resistance among the tested path-finding instruments. These results clearly indicate that not all SS instruments perform equally, and alloy selection alone does not guarantee optimal mechanical behavior.

Thermal treatment of stainless steel has proven to be a decisive factor in improving mechanical properties. Thermally modified SS instruments, such as C-files, C+ files, and C-PILOT files, consistently demonstrate higher buckling resistance compared with conventional SS instruments, and even outperform rotary NiTi glide path systems such as PathFile (Dentsply Maillefer, OK, USA) [29–32]. In contrast, carbon steel instruments, such as the Pathfinder CS, offer excellent initial cutting efficiency and high rigidity, but are limited by increased susceptibility to corrosion in the presence of sodium hypochlorite and progressive degradation after repeated sterilization cycles, reducing their long-term clinical reliability [39].

Comparative studies by Kwak et al. and Gupta et al. further confirm these findings, providing strong evidence that advanced, thermally treated SS instruments exhibit significantly greater buckling resistance compared to NiTi GP instruments [18, 40]. Recent research consistently shows that C+ files display the highest buckling resistance among both manual and engine-driven glide path instruments. Although Hamid et al. [41] primarily investigated the metallurgical behavior of thermally treated NiTi instruments, their results further emphasize the importance of alloy processing and phase transformations in mechanical properties determination, highlighting the broader relevance of metallurgical optimization in endodontic instrument design.

Design trade-offs – flexibility *vs.* control

Instrument design plays a key role in modulating the balance between rigidity, flexibility, and tactile perception during manual canal negotiation [42]. The instrument's cross-sectional geometry is one of the main determinants of its mechanical behavior. Square and pentagonal cross-sections increase the amount of metal and core diameter, enhancing buckling resistance and tactile feedback, but at the cost of reduced flexibility [13, 30]. Such designs provide better control in narrow or calcified canals but are less tolerant in curved anatomies.

In contrast, D-shaped and S-shaped cross-sections, characteristic of instruments such as D-Finder and S-Finder, reduce the metal mass and core stiffness, resulting in greater flexibility and improved adaptation to canal curvature. Although this design may help preserve the original canal anatomy, the reduced core mass is associated with lower buckling resistance. Therefore, these instruments may be less efficient in severely narrowed canals unless used with careful pre-bending, gentle apical pressure, and controlled manual technique [13, 30].

Tip design represents another crucial variable influencing the clinical behavior of the instrument. Active, pyramidal tips facilitate penetration through calcified obstructions but inherently increase the risk of canal deviation or ledge formation if excessive axial force is applied [22]. Conversely, passive, conical tips offer a safer and more anatomically respectful approach but may be less efficient in penetrating dense calcifications. Das et al. [30] emphasize that although C+ files offer clear advantages in negotiating narrow canals, their increased rigidity and active cutting tip require cautious use to minimize iatrogenic risk. In contrast, C-PILOT instruments have demonstrated more predictable canal tracking due to their guided-tip design, reducing the likelihood of canal aberrations. Thus, instrument selection should not rely solely on canal anatomy but also consider tactile sensitivity, operator experience, and the ability to precisely control applied force.

Manual *vs.* engine-driven glide path preparation – a complementary relationship

A glide path can be prepared using stainless-steel hand files or engine-driven NiTi instruments. Although numerous studies have reported potential advantages of engine-driven NiTi glide path systems, including reduced instrumentation time, improved centering ability, preservation of the original canal morphology, and decreased extrusion of dentin debris [4, 42–48], their clinical performance may vary according to the specific instrument design, dimensions, alloy characteristics, kinematics, root canal anatomy, and clinical situation. Therefore, the choice between manual and engine-driven glide path preparation should be individualized rather than based on the assumption that one approach is universally superior.

In many clinical situations, successful manual canal negotiation provides an important foundation for subsequent engine-driven glide path preparation, particularly in narrow, curved, calcified, or anatomically complex canals. However, the extent of prior manual preparation required may vary depending on the specific NiTi system and the clinical conditions. NiTi glide path instruments are generally designed to follow an established canal pathway and may be less suitable for initial exploration of severely calcified or obstructed canals without prior manual negotiation [8, 28]. The advantages and disadvantages of manual and engine-driven instruments for glide path preparation are summarized in Table 2.

Although certain instruments, such as the ProTaper Ultimate Slyder (Dentsply Sirona, USA), reportedly achieve initial canal patency in a substantial number of cases (approximately 63%) without prior use of hand instruments, this approach remains a matter of professional debate [19]. In complex canal systems, the prior use of stainless-steel hand instruments is considered a safer and more predictable approach for ensuring canal patency, compared with applying increased apical pressure to the tip of an engine-driven instrument [4].

Accordingly, manual SS instruments remain the cornerstone of initial canal negotiation. Their superior tactile feedback enables the clinician to detect subtle anatomical variations, recognize curvatures or obstructions, and adjust the instrumentation strategy in real time [49]. However, the clinical performance of manual instruments is highly operator-dependent. Technique, experience, and tactile skill play a decisive role in treatment outcomes. This concept is supported by the findings of Allen et al. [13], who observed file deformation in only a subset of operators during simulated use, suggesting that operator-related factors may be as significant as instrument design.

Overall, manual stainless-steel and engine-driven NiTi instruments should be regarded as complementary rather than competing approaches to canal negotiation and glide path preparation. Their appropriate use should be determined by the instrument's specific characteristics and the clinical situation, including root canal anatomy, degree of calcification, canal curvature, and procedural complexity.

CLINICAL IMPLICATIONS

In general, the available evidence indicates that no single manual instrument design represents a universal solution for all clinical situations. Instruments with high buckling resistance are particularly useful for negotiating calcified or severely narrowed canals but require careful use to minimize the risk of iatrogenic damage. Conversely, more flexible designs better preserve canal anatomy in curved canals but may lack the mechanical strength needed to overcome dense obstructions [12].

In addition to instrument-related characteristics, the clinical behavior of manual instruments is strongly influenced by operator-related factors. Operator experience and tactile control are particularly important during canal negotiation, while appropriate pre-curving of the instrument may facilitate its adaptation to canal curvature and reduce the risk of deviation from the original canal path. Furthermore, the magnitude and direction of the applied apical force should be carefully controlled, as excessive force may increase the risk of instrument deformation and iatrogenic errors [49].

Therefore, contemporary endodontic practice should favor a selective and sequential approach to instrument use, combining manual SS instruments for initial canal negotiation with engine-driven NiTi systems for glide path enlargement and further preparation. This staged, hybrid approach reflects a balance between mechanical efficiency and biological safety, aligning instrument selection with canal anatomy, clinical objectives, instrument characteristics, and operator-related factors, including clinical experience and tactile control [4, 8].

Selection of manual endodontic instruments according to clinical conditions

The selection of appropriate instruments may significantly influence the course and outcome of treatment. During initial canal negotiation and glide path preparation, the clinical scenario helps determine which instrument may be the most appropriate and safe to use. The manual instruments analyzed in this review possess distinct characteristics that may make them suitable for different clinical conditions. The recommendations presented in Table 3 should be regarded as an evidence-informed clinical framework rather than a rigid protocol, and should be adapted individually to root canal anatomy, case complexity, and operator experience.

CONCLUSION

The integration of an individualized approach to canal preparation and instrumentation, together with the adoption of new technological solutions, enables successful and predictable endodontic procedures. NiTi systems may offer advantages in terms of flexibility, efficiency, and preservation of canal morphology when an adequate initial canal pathway has been established. Nevertheless, manual instruments remain indispensable during the canal negotiation phase. Their adequate mechanical properties, availability, cost-effectiveness, and simplicity of use ensure their continued relevance in contemporary endodontic practice, particularly during the initial stages of treatment in cases involving complex canal morphologies and/or calcified root canals.

Ethics: The authors declare that the article was written in accordance with ethical standards of the Serbian Archives of Medicine as well as ethical standards of medical facilities for each author involved.

Conflict of interest: None declared.

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Table 1. Key characteristics of manual instruments for canal negotiation and glide path preparation, with a focus on design, mechanical properties, and clinical applications

Instrument	Material-treatment	Cross-section	Taper	Sizes (ISO)	Key features	Clinical advantages	Limitations
K-File Kerr Manufacturing Co. (Romulus, MI, USA)	Stainless steel	Square	2%	06, 08, 10, 15, 20;	Twisted design; reliable torsional resistance	Effective in straight/moderately curved canals; basic CN & GP	Risk of ledging in severe curvature; debris accumulation
K-Reamer Kerr Manufacturing Co. (Romulus, MI, USA)	Stainless steel	Triangular	2%	06, 08, 10, 15, 20;	Longer flutes; flexible	Efficient debris removal; flexible for initial GP	Aggressive tip increases risk of zipping/transportation
C-File Dentsply (Maillefer, OK, USA)	Heat-treated stainless steel	Square	2%	06, 08, 10, 12.5, 15;	Enhanced strength	Negotiation of calcified canals	Less flexible than C+ Files
C+ Files Dentsply (Maillefer, OK, USA)	Thermally treated stainless steel	Square, pyramid typ	2–4% regressive	06, 08, 10, 15;	High apical control; electropolished surface	Safe negotiation of obliterated canals; good tactile feedback	Requires careful handling in narrow canals
D Finders Mani, (Tochigi, Japan)	Stainless steel	D-shaped	2%	06, 08, 10, 12, 15;	Reduced torsional stress	Safe in narrow/curved canals; enhanced tactile control	Pre-curving recommended in calcified canals
Glide Finders Mani, (Tochigi, Japan)	Stainless steel	Square typ, Rectangular shaft	2–3% regressive	08, 10, 12, 15;	Variable cross-section	Effective GP formation; reduced canal transportation	Less suited for extremely tight canals without pre-flaring
Hi-5® Files Integra, Miltex, (USA)	Stainless steel	Pentagonal	2%	06, 08, 10, 15;	Spirally ground flutes; strong	Excellent patency establishment; durable	Limited sizes; careful activation required
Pathfinder CS SybronEndo(CA, USA)	Carbon steel	Square	2%	K1–07, K2–09;	Enhanced cutting strength	Negotiation of tight canals	Corrosion-prone; cannot be autoclaved
S Finders JS Dental, (Sweden)	Stainless steel	Partial circle withflat edges	2%	08;	Small length for access	Suitable for blocked/obliterated canals	Limited flexibility in severely curved canals
C-PILOT Files VDW, (Munich, Germany)	Heat-treated steel	Square	2%	06, 08, 10, 12, 15;	Non-cutting Pilot tip	Guided progression; reduced ledging	Careful handling needed in narrow canals
Ready-Steel FlexoFiles Dentsply (Maillefer, OK, USA)	Stainless steel	Triangulare-square	2%	06, 08, 10, 12.5, 15, 17, 20;	Non-cutting Batt® tip	Safe initial CN & GP; gradual instrumentation	Less efficient in calcified canals
Senseus FlexoFiles Dentsply (Maillefer, OK, USA)	Thermally treated stainless steel	Square	2%	06, 08, 10, 15, 20;	Enhanced flexibility	Better tactile feedback; suitable for complex canals	May require combination with balanced force technique

*Modified table of Jovanović-Medojević et al. [9]

Table 2. Advantages and disadvantages of manual and engine-driven instruments for glide path preparation

Feature-aspect	Manual stainless-steel instruments	Engine-driven NiTi instruments
Efficiency	Slower preparation; more operator fatigue	Faster preparation (40–50% time reduction); less fatigue
Tactile feedback	Excellent; allows sensing canal irregularities and obstacles	Reduced compared to manual; relies on controlled motor settings
Flexibility and canal anatomy preservation	Limited flexibility; risk of canal transportation in narrow or curved canals	Generally greater flexibility; may facilitate preservation of canal morphology depending on instrument design, alloy, dimensions, and clinical conditions
Cutting efficiency	High cutting efficiency in narrow canals; may produce more debris	Efficient cutting; smoother canal shaping; less debris compaction
Mechanical resistance	High torsional and fracture resistance; resistant to corrosion	NiTi more prone to cyclic fatigue and fracture, especially in complex canals
Debris extrusion / apical irritation	Higher risk of debris extrusion and postoperative pain	May reduce apical debris extrusion in some clinical and laboratory conditions, although outcomes depend on instrumentation system and technique
Clinical applicability	Essential for initial canal negotiation, especially in calcified or curved canals; cost-effective	Ideal for creating reproducible glide paths; requires investment in equipment and training
Control/safety	High tactile control; allows pre-curving	Dependent on operator skill and motor settings; less tactile feedback
Limitations	Time-consuming; may alter canal shape; risk of procedural errors in complex canals	Risk of instrument fracture; higher cost; learning curve for safe use

Table 3. Overview of commonly used or recommended manual instruments for canal negotiation and glide path preparation based on case complexity

Case category	Canal characteristics	Recommended instruments
Simple	Straight canal anatomy, no calcifications	K-Files (Kerr Manufacturing Co.) K-Reamers (Kerr Manufacturing Co.) Readi•Steel FlexoFiles (Dentsply)
Moderate	Mild curvature, initial calcification, partially restricted canal patency	Senseus FlexoFiles (Dentsply) Glide Finders (Mani)* D-Finders (Mani) C-PILOT Files (VDW)
Complex	Severe curvature, calcifications, difficult canal negotiation	C+ Files (Dentsply) S-Finders (JS Dental) Hi-5® Files (Integra) Pathfinders CS (SybronEndo) C-Files (Dentsply)

*Instruments primarily designed for glide path preparation

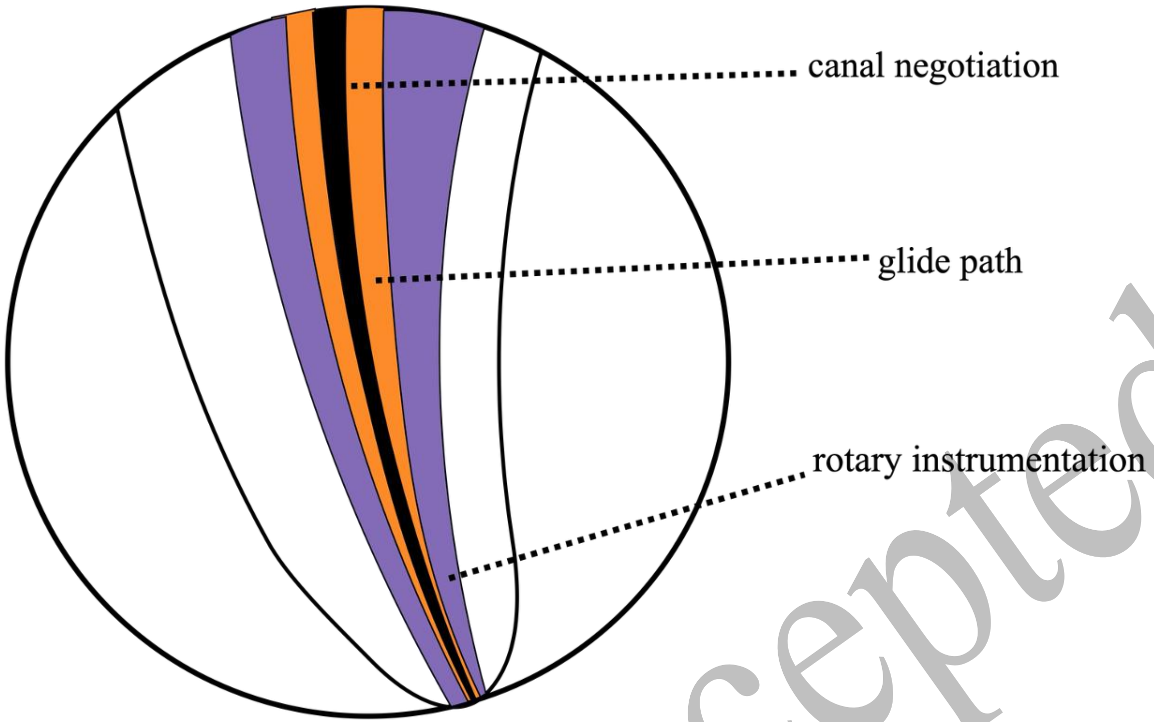

Figure 1. Schematic representation of established initial canal negotiation, prepared glide path, and engine-driven instrumentation