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Root Canal Shaping in Endodontics: Fundamental Principles and Clinical Approaches: A Narrative Review

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ABSTRACT: Root canal shaping is a fundamental component of chemomechanical preparation that contributes to reducing the microbial load and creates a canal geometry suitable for irrigation and root canal obturation. This narrative review aimed to explain the biological, mechanical, and technical principles of root canal shaping; evaluate its development from manual instrumentation to contemporary engine-driven nickel-titanium systems; compare different kinematic and instrumentation strategies; and discuss the principal clinical stages of shaping in light of current evidence. English-language studies indexed in PubMed/MEDLINE were searched without a lower publication date restriction. The reference lists of relevant narrative reviews, systematic reviews, clinical practice guidelines, and original studies were also examined. Advances in nickel-titanium alloys, heat-treatment technologies, and instrument design have enabled the development of different shaping systems employing continuous rotation, reciprocation, and adaptive motion. However, current evidence does not demonstrate that a specific kinematic approach or instrument system is superior under all clinical conditions. A safe shaping protocol requires the maintenance of canal patency, creation of a reproducible glide path, accurate determination of the working length, and selection of an apical size and taper appropriate for the individual case. Although larger preparations may increase instrument-wall contact and irrigant delivery, they should be evaluated in relation to additional dentin loss and procedural risks. Consequently, instrument selection and preparation dimensions should be determined on a case-specific basis by considering the balance among root canal anatomy, biological debridement requirements, and dentin preservation.

KEYWORDS: Endodontics; root canal preparation; nickel-titanium; continuous rotation; reciprocation; glide path; apical enlargement.

1. INTRODUCTION

The primary objectives of root canal treatment are to reduce the microbial load within the root canal system, remove infected or necrotic tissues, and establish appropriate conditions for preventing recontamination. Root canal shaping is one of the fundamental components of chemomechanical preparation performed in conjunction with irrigation and root canal obturation to achieve these objectives. In addition to contributing to the removal of root canal contents, shaping should facilitate the delivery of irrigating solutions to the apical region, create a canal geometry suitable for root canal obturation, and preserve the original canal anatomy as much as possible without causing procedural errors [1–3].

The root canal system has a complex anatomical structure that may include oval extensions, isthmuses, recesses, lateral canals, and irregular surfaces. Consequently, mechanical instrumentation cannot directly contact all surfaces of the root canal system. In a micro-computed tomographic study conducted by Peters et al., at least 35% of the canal surface area remained unaffected by instrumentation with each of the four nickel-titanium shaping techniques evaluated. The same study demonstrated that the initial canal anatomy was one of the principal factors determining the shaping outcome, irrespective of the instrument used [4]. These findings indicate that root canal shaping alone cannot achieve complete debridement and that mechanical preparation should be combined with an effective irrigation protocol.

The introduction of nickel-titanium alloys into the manufacture of endodontic instruments represented a major advance, particularly in the shaping of curved root canals. Walia et al. demonstrated that the first endodontic files manufactured from nickel-titanium exhibited greater elastic flexibility than similarly sized stainless-steel files [5]. Subsequently, the alloy properties, heat treatments, surface technologies, cross-sectional designs, tapers, and movement kinematics of instruments were further developed, and various systems employing continuous rotation, reciprocation, and adaptive motion were introduced into clinical practice [6,7].

The current European Society of Endodontology S3-level clinical practice guideline recommends the use of contemporary engine-driven nickel-titanium instruments for root canal preparation in teeth with apical periodontitis. However, the guideline also states that comparative clinical evidence does not demonstrate the superiority of any specific tested nickel-titanium system over others [8]. Therefore, advantages observed in laboratory studies, such as increased flexibility, fatigue resistance, centering ability, or shaping efficiency, should not be assumed to translate directly into greater clinical success [7,8].

The contemporary concept of root canal shaping is not based solely on creating a wider or more tapered canal preparation. Although the preparation should contribute adequately to biological debridement, unnecessary removal of cervical and radicular dentin should also be avoided. Particularly in curved, narrow, oval, or irregular canals, the balance between creating sufficient space for effective disinfection and preserving the root canal anatomy and root dentin constitutes one of the principal considerations in clinical decision-making [3,7].

This narrative review aimed to explain the biological, mechanical, and technical principles of root canal shaping; evaluate its development from manual instrumentation to contemporary engine-driven nickel-titanium systems; compare different kinematic and instrumentation strategies; and discuss the principal clinical stages of root canal shaping in light of current evidence.

2. METHODOLOGICAL APPROACH OF THE NARRATIVE REVIEW

This study was designed as a narrative review to thematically evaluate the fundamental principles of root canal shaping in endodontics, contemporary instrumentation strategies, clinical procedural steps, and dentin-preserving approaches. In preparing the review, the SANRA framework was considered, which includes key criteria for narrative reviews, such as providing a rationale for the research question, clearly stating the objective, describing the literature search, supporting scientific statements with appropriate references, and acknowledging differences among levels of evidence [9]. In addition, structured literature-search principles aimed at improving the transparency and objectivity of narrative reviews were used in the selection and synthesis of the literature [10].

An electronic literature search was conducted in the PubMed database in July, 2026, without applying any lower publication date restriction. The search was limited to studies published in English. The following core and topic-specific terms were used in multiple Boolean combinations according to the thematic domains of the review:

"root canal preparation" OR "root canal shaping" OR "root canal instrumentation"

were used in various combinations with:

"endodontics", "nickel-titanium", "NiTi", "rotary instrumentation", "continuous rotation", "reciprocating motion", "adaptive motion", "single-file", "multiple-file", "glide path", "working length", "apical enlargement", "curved root canal", "oval root canal", "calcified root canal", "canal transportation", "untouched canal walls", "instrument fracture", "apical debris extrusion", "dentin preservation", and "minimally invasive endodontics".

In addition to the electronic search, the reference lists of reviews, systematic reviews, clinical practice guidelines, and original studies considered fundamental to the topic were examined. The author, title, journal, year, volume, page range, and DOI details of the references were verified using PubMed records and the relevant journal publishers' webpages.

Studies evaluating the biological, mechanical, or technical objectives of root canal shaping; investigations examining instrument alloys, heat treatment, design, and movement kinematics; publications addressing clinical stages such as working length determination, glide path preparation, and apical preparation; micro-computed tomographic studies of shaping effectiveness and safety; systematic reviews; clinical studies; and evidence-based clinical practice guidelines were included. No publication-year restriction was applied to classic studies considered pivotal to the historical development of the field.

Publications not directly related to root canal shaping, sources consisting solely of manufacturer or product promotional material, texts that had not undergone scientific evaluation, case reports, and publications lacking verifiable data relevant to the topic under investigation were excluded. Among studies evaluating the same scientific claim, priority was given to current systematic reviews, clinical practice guidelines, and original investigations providing direct measurements. Findings obtained from laboratory studies were not interpreted as clinical outcomes, and the experimental nature of the evidence was explicitly stated in the text.

Because this study was not designed as a systematic review or meta-analysis, a PRISMA flow diagram was not prepared, quantitative data synthesis was not performed, and no formal risk-of-bias assessment of the included studies was conducted. Findings obtained from the selected publications were narratively synthesized under the predefined themes of fundamental shaping principles, instrument development, movement kinematics, contemporary instrumentation strategies, and clinical procedural steps.

Additional relevant publications, including historically important studies and records not indexed in PubMed, were identified by screening the reference lists of relevant reviews, systematic reviews, clinical practice guidelines, and original studies.

3. FUNDAMENTAL PRİNCİPLES OF ROOT CANAL SHAPİNG

Although the objectives of root canal shaping can be classified as biological, mechanical, and technical, these objectives are not independent of one another in clinical practice. The geometric changes produced by instrumentation influence the penetration of irrigants throughout the root canal system, whereas the selected preparation size and taper may affect both microbial load reduction and the amount of remaining dentin. Therefore, successful shaping requires the establishment of a case-specific balance between the requirements of biological disinfection and the preservation of anatomical and structural integrity, rather than the maximum possible enlargement of the root canal.

3.1. Biological Objectives

The primary biological objective of root canal shaping is to contribute to the removal of infected or necrotic tissues, microorganisms, and microbial products from the root canal system, thereby establishing conditions conducive to the healing of periradicular tissues. However, this objective cannot be achieved solely through the mechanical action of instruments on the dentinal walls. The combined use of mechanical preparation and irrigation is essential for removing canal contents, disrupting microbial biofilms, and facilitating the penetration of irrigating solutions into the apical region and anatomical irregularities. Therefore, shaping should be regarded not as biological cleaning itself but as a component of a more comprehensive chemomechanical disinfection process [11].

The anatomical complexity of the root canal system is one of the principal limitations to complete mechanical cleaning. Isthmuses, lateral ramifications, apical deltas, dentinal tubules, oval canal extensions, and C-shaped canal spaces may remain beyond the direct contact of instruments. Evidence from micro-computed tomographic studies indicates that, particularly in oval and irregular canals, a proportion of the canal walls may remain unprepared after instrumentation [11]. Consequently, achieving a specific apical diameter or taper does not indicate that all canal surfaces have been mechanically instrumented or that the root canal system has been rendered sterile.

This limitation is also supported by clinical microbiological studies. In a study conducted by Siqueira et al. involving 11 teeth with primary endodontic infections, chemomechanical preparation performed with 2.5% sodium hypochlorite significantly reduced bacterial counts; however, six samples remained culture-positive after preparation [12]. This finding demonstrates that chemomechanical preparation can substantially reduce the microbial load but cannot predictably achieve sterilization when used alone.

Increasing the apical preparation size may promote bacterial reduction by providing greater mechanical contact with the canal walls. In a clinical study investigating previously root canal-treated teeth with apical periodontitis, a further reduction in bacterial load was reported as the preparation diameter was progressively increased; at the largest preparation size, sodium hypochlorite was more effective than saline irrigation [13]. Furthermore, a systematic review evaluating healing outcomes concluded that the available clinical evidence was limited; nevertheless, larger apical preparations may improve clinical and radiographic healing in teeth with necrotic pulps and periapical lesions [14].

When these findings are considered collectively, the biological objective should not be defined as achieving the “largest possible apical preparation.” Instead, the objective is to create a preparation that enables adequate irrigation and disinfection while considering the anatomical conditions, initial canal diameter, irrigation protocol, and amount of remaining dentin. The potential biological benefit of apical enlargement should be evaluated in conjunction with the mechanical cost associated with additional dentin removal in each case.

3.2. Mechanical Objectives

The mechanical objective of shaping is to create a canal geometry that preserves the original course and curvature of the root canal as much as possible, tapers progressively toward the apical region in a controlled manner, and facilitates subsequent irrigation and root canal obturation procedures. During this process, procedural complications such as canal transportation, ledge formation, perforation, apical zipping, loss of working length, and excessive dentin removal should be minimized. However, mechanical success should not be assessed solely in terms of centering ability or an increase in canal volume; untouched canal surfaces and the amount of remaining dentin should also be considered.

The trade-off between apical enlargement and dentin preservation has been demonstrated in micro-computed tomographic studies. Pérez et al. reported that each incremental increase in preparation size in mandibular incisors reduced the proportion of untouched canal surfaces but also significantly reduced the amount of remaining dentin [15]. The finding that more than 1 mm of root dentin remained in certain regions even after the largest preparation was specific to the sample group investigated and should not be directly generalized to different root anatomies. Nevertheless, the study clearly demonstrates that although larger preparations increase the surface area accessible from a biological perspective, they impose a structural cost in terms of dentin removal.

Evidence regarding the effect of instrument kinematics on canal centering and preservation of the original anatomy is not entirely consistent. In the systematic review by Nagendrababu and Ahmed evaluating micro-computed tomographic studies, no clear overall superiority could be demonstrated between continuous rotation and reciprocating kinematics in terms of canal transportation, centering ability, or changes in surface area and volume. Findings concerning untouched canal walls and accumulated hard-tissue debris were reported to vary among studies [16].

In contrast, a more recent systematic review indicated that continuous rotation may offer certain advantages in terms of centering ability in moderately and severely curved canals and apical transportation in severely curved canals. Nevertheless, it was concluded that none of the kinematic approaches investigated could instrument the entire canal wall surface [17]. The differences between the two systematic reviews may be associated with heterogeneity in the instrument systems, canal anatomies, degrees of curvature, and experimental measurement methods investigated. This interpretation represents an inference drawn from the findings of the reviews and should not be regarded as evidence of clinical superiority.

Although preparations with lower tapers are considered capable of preserving cervical and radicular dentin, a direct clinical relationship between dentin preservation and long-term root fracture resistance has not yet been demonstrated. A systematic review evaluating low-taper preparations reported that the evidence regarding the effects of different tapers on root fracture resistance was inconclusive and that no long-term randomized clinical trials were available [18]. Therefore, although low-taper shaping may offer a theoretical advantage in terms of dentin preservation, it would be inappropriate to conclude from the available in vitro findings that it reduces the clinical risk of fracture.

Thus, the mechanical objective is not to obtain the greatest possible canal volume but to preserve the original canal position and functional dentin thickness as much as possible while preparing the canal sufficiently to meet biological requirements.

3.3. Technical Objectives

Technical objectives encompass the performance of biological and mechanical goals through a safe and reproducible clinical sequence. This process includes identifying the canal orifices, initial canal negotiation, controlled removal of coronal interferences, establishing a reproducible glide path, determining the working length, and advancing shaping instruments within the canal in a controlled manner.

A systematic review evaluating the concepts of canal negotiation, glide path preparation, and coronal preflaring indicated that these procedures represent fundamental preparatory stages before mechanized shaping. Glide path preparation was reported to reduce canal transportation and apical debris extrusion and improve preservation of the original canal anatomy, whereas coronal preflaring could contribute to the accuracy of working length determination [19]. However, the review emphasized that terminology and clinical protocols were not fully standardized across studies and that further randomized clinical trials were required.

Accurate working length determination is of central importance for maintaining preparation within the boundaries of the root canal. An insufficient working length may result in inadequate cleaning of the apical canal segment, whereas exceeding the apical limit may increase the risk of instrumentation of the periapical tissues and debris extrusion. A systematic review investigating the clinical effectiveness of electronic apex locators reported that these devices could reduce the need for radiographs during working length determination and could provide better results than radiographic methods under certain conditions. However, because of the methodological limitations of the evidence, electronic measurement was recommended for use in conjunction with at least one radiographic verification to detect potential errors [20].

Another technical function of the glide path is to provide a smooth pathway through which larger and less flexible shaping instruments can advance into the canal in a controlled manner. In a study conducted in the canals of extracted molar teeth, glide path preparation with stainless steel hand files before rotary nickel-titanium instrumentation was associated with a lower rate of instrument separation [21]. However, because of the ex vivo study design and the use of earlier-generation instruments, this finding should not be directly generalized to all contemporary systems.

In conclusion, technical success depends less on the use of a specific commercial file system or a particular number of instruments than on establishing a procedural sequence that is appropriate for the initial canal anatomy, maintains the working length, and limits mechanical stress on the instrument. Canal negotiation, glide path preparation, working length control, and progressive instrument advancement are fundamental components of safe preparation, irrespective of the final shaping technique.

4. EVOLUTİON OF ROOT CANAL SHAPİNG APPROACHES

The evolution of root canal shaping methods has involved more than merely replacing manual files with engine-driven instruments. This process has encompassed the dimensional standardization of instruments, the transition from stainless steel to nickel-titanium alloys, the development of different movement kinematics, modification of the thermomechanical properties of the alloy, and redesign of the cutting portion. Although each advance has provided specific mechanical advantages, it has also introduced different risks, such as instrument fracture or excessive dentin removal.

4.1. Transition from Manual Instrumentation to Mechanized Systems

One of the first major stages in the development of root canal instruments was the standardization of instrument sizes and tapers. According to Weine, before 1958, there was no accepted standardization of the sizes and geometries of successive endodontic instruments. The standardization of size numbering and the diameters of successive instruments provided a basis for clinicians to establish more predictable preparation sequences [22].

Stainless steel hand files were used as the principal instruments for root canal preparation for many years. However, the rigidity of the material may make preservation of the original canal path more difficult in curved canals, particularly as instrument diameter increases. In a computed tomographic study by Gambill et al., hand-operated NiTi files resulted in less canal transportation, less dentin removal, shorter preparation times, and better-centered canal preparations than stainless steel K-Flex files [23]. These results demonstrated that shaping behavior is determined not only by mechanization but also by the alloy from which the instrument is manufactured.

The introduction of engine-driven NiTi systems accelerated the transition from preparation approaches involving the sequential use of numerous hand files to more standardized rotary instrumentation sequences. In a study performed by novice operators in extracted mandibular molars, rotary NiTi instruments provided faster preparation, produced less transportation in the middle root region, and preserved more tooth structure than stainless steel hand files. However, the fracture of two rotary NiTi instruments in the same study demonstrated that mechanization may introduce a different procedural risk in addition to its shaping advantages [24].

When the differences between manual and mechanized instrumentation are considered within a broader evidence framework, engine-driven NiTi systems cannot be regarded as superior in terms of all clinical outcomes. In the systematic review and meta-analysis by Del Fabbro et al., rotary NiTi instruments were associated with less canal transportation and apical extrusion than stainless steel hand files; however, the groups produced similar results in terms of treatment success, residual bacteria, and canal cleanliness. The authors emphasized that these findings should be interpreted cautiously because of the limited number of clinical studies included in the review and the overall insufficient quality of the evidence [25].

Therefore, the transition from manual instrumentation to mechanized systems should not be interpreted as a direct improvement in clinical success but as a technological development aimed at improving preparation time, preservation of canal geometry, and procedural standardization.

4.2. Development of Nickel-Titanium Instruments

The use of NiTi alloys in endodontic instruments was based on material properties such as a lower modulus of elasticity and superelastic behavior compared with stainless steel. Superelastic NiTi can return to its original geometry after the load causing deformation has been removed. This property allows the instrument to advance through a curved canal with less permanent deformation than stainless steel instruments [26].

Following the introduction of NiTi instruments into endodontics, their development progressed from hand files to engine-driven rotary systems. Subsequent innovations were not limited to the mechanization of files; the geometry of the cutting portion, surface treatments, manufacturing methods, phase composition of the alloy, and movement kinematics were also modified [27]. Thus, the development of NiTi systems has become a process involving successive material and design modifications rather than a single technological innovation.

The flexibility of rotary NiTi instruments may contribute to preserving the original course of curved canals. In the study by Gluskin et al., rotary NiTi instruments produced less canal transportation, greater preservation of coronal tooth structure, and shorter preparation times than conventional stainless steel hand instrumentation [24]. However, these advantages are not independent of the risk of NiTi instrument fracture.

Rotary NiTi instruments may fracture as a result of cyclic flexural fatigue, torsional overload, or the combined effects of these mechanisms. In addition to instrument design and manufacturing methods, canal anatomy, the technique of use, and operator experience may also influence instrument fracture. Parashos and Messer stated that advances aimed at preventing instrument fracture cannot be reduced solely to material or design modifications and that factors related to the operating protocol and clinician should also be considered [28].

Therefore, the development of NiTi instruments should not be regarded as a linear progression that has eliminated all the limitations of stainless steel. Although the flexibility of NiTi offers the potential to reduce canal transportation, its mechanized use has introduced a new safety consideration requiring the control of cyclic and torsional stresses.

4.3. Advances in Alloy and Heat-Treatment Technologies

Most early mechanized NiTi instruments were manufactured from conventional superelastic NiTi alloy. Subsequent developments focused less on changing the chemical composition of the alloy than on modifying its phase-transformation behavior through mechanical and thermal processes applied during manufacturing. Heat treatment can influence instrument flexibility, shape-memory behavior, and fracture resistance by altering the proportions of austenite, R-phase, and martensite, as well as the transformation temperatures between these phases [29].

Thermomechanically treated NiTi alloys are generally classified as conventional NiTi and M-Wire materials, in which austenitic behavior predominates, and controlled-memory, Gold heat-treated, and Blue heat-treated materials, in which martensitic behavior is more pronounced. Instruments with a more pronounced martensitic character are generally more readily deformable and may exhibit greater flexibility and cyclic fatigue resistance than conventional austenitic NiTi instruments [29]. However, this classification does not imply that instrument behavior can be explained solely by the commercially designated alloy group; phase composition depends on temperature and the manufacturing protocol applied.

Yahata et al. demonstrated that different heat treatments altered the transformation temperatures of NiTi instruments and that certain heat-treatment conditions reduced the bending load. The researchers concluded that heat-treatment-induced changes in phase transformation could be used to increase instrument flexibility [30].

However, thermomechanical treatment does not simultaneously improve all mechanical properties to the same extent. In the study by Shim et al. comparing different groups of NiTi alloys, controlled-memory and R-phase instruments exhibited lower moduli of elasticity and greater angular deformation at fracture. Thermomechanically treated instruments demonstrated greater cyclic fatigue resistance; however, the maximum torque values of controlled-memory and R-phase instruments were lower than those of conventional NiTi instruments [31]. This finding indicates that increased flexibility and cyclic fatigue resistance do not necessarily correspond to a similar increase in torsional resistance.

A recent experimental study compared reciprocating instruments with different heat treatments and cross-sectional characteristics and reported that the newly applied heat treatment increased flexibility, ultimate strength, toughness, and cyclic fatigue resistance. The same study indicated that the effect of heat treatment on flexibility was more pronounced than that of cross-sectional area [32]. However, this result is limited to the specific instruments and experimental conditions investigated and should not be directly generalized to all heat-treated systems.

Therefore, the primary objective of advances in alloy technology is not merely to achieve greater fracture resistance but to establish an appropriate mechanical balance among flexibility, cyclic fatigue resistance, torsional resistance, and controlled deformation.

4.4. Effect of Instrument Design on Shaping

The behavior of a root canal instrument does not depend solely on the alloy from which it is manufactured. Cross-sectional geometry, metal core volume, taper, number of cutting edges, distance between cutting edges, helix angle, radial lands, and tip design may influence the instrument’s cutting efficiency, flexibility, pattern of contact with the canal wall, and distribution of mechanical stresses [27].

The effects of cross-sectional area and geometry on torsional behavior have been demonstrated in finite element analyses. Baek et al. reported that models with larger cross-sectional areas exhibited greater torsional stiffness. Even with the same cross-sectional area, models with rectangular cross-sections demonstrated greater torsional stiffness than those with triangular cross-sections. The study also showed that a greater number of cutting flutes within the working portion could increase torsional stiffness [33].

Conversely, geometric features that increase torsional stiffness may reduce the instrument’s flexural flexibility. In the finite element study by Versluis et al., models with larger cross-sectional and central core areas exhibited greater flexural stiffness and internal stress. The thin rectangular model with the smallest central core area demonstrated the lowest stiffness and stress values. The same study reported that increasing the pitch increased flexural stiffness and stress within the instrument [34].

These findings demonstrate the presence of opposing mechanical relationships in instrument design. A larger metal mass may increase resistance to torsional loads while reducing the instrument’s ability to conform to curved canals. A smaller core area may increase flexibility but limit torsional load-bearing capacity. Similarly, the arrangement of cutting edges and radial lands may create different balances among cutting efficiency, advancement within the canal, and the forces exerted on dentinal walls [27,33,34].

Therefore, it is inappropriate to conclude that any single cross-sectional shape or design feature is inherently superior. The clinical shaping behavior of an instrument is determined by the combined effects of its cross-sectional geometry, metal mass, taper, alloy phase, applied movement kinematics, and canal anatomy [27].

5. CONTEMPORARY ROOT CANAL INSTRUMENTATİON STRATEGİES

Contemporary root canal instrumentation strategies comprise interrelated variables, including instrument kinematics, the number and sequence of files used, instrument geometry, alloy properties, and motor torque control. Therefore, attributing outcomes obtained with continuous rotation, reciprocation, or adaptive motion solely to the type of movement may be methodologically misleading. Because instruments operating with the same kinematics may differ in cross-sectional geometry, tip diameter, taper, helix angle, and thermomechanical properties, outcomes reported in comparative studies should be evaluated in conjunction with all characteristics of the systems used [35,36].

5.1. Continuous Rotation

In continuous rotation, the nickel-titanium instrument completes a 360° rotation in the same direction within predetermined speed and torque limits. Although this movement is most commonly associated with multiple-file systems in which instruments with different tip diameters or tapers are used in a specific sequence, single-file continuous-rotation systems are also available. Therefore, continuous rotation is a kinematic concept independent of the number of files used [35].

The principal mechanical limitations of continuous rotation are cyclic fatigue resulting from repeated tensile-compressive cycles in curved canals and torsional loading that may occur when part of the instrument becomes locked in dentin. However, the risk of fracture does not depend solely on the type of movement; canal curvature, instrument alloy and heat treatment, cross-sectional geometry, diameter, surface characteristics, and method of clinical use also influence fatigue behavior [35].

In the systematic review by Ahn et al. that included in vitro studies, instruments used in reciprocation demonstrated greater cyclic fatigue resistance than those used in continuous rotation in most experimental settings. The same review found that canal transportation was lower with reciprocation in some studies, whereas findings concerning debris extrusion and dentinal defect formation were inconsistent [36]. These findings do not demonstrate that continuous rotation is systematically inadequate across all shaping outcomes. Furthermore, because the studies included in the review were conducted under laboratory conditions, their findings cannot be directly equated with clinical instrument fracture or treatment success.

The effects of kinematic differences on patient-reported outcomes also appear to be limited. A systematic review and meta-analysis evaluating randomized clinical trials found no significant differences between continuous rotation and reciprocation in the incidence of postoperative pain or analgesic use at 12, 24, and 48 hours [37]. Therefore, the clinical suitability of continuous rotation should be evaluated not solely according to theoretical fatigue resistance but in conjunction with root canal anatomy, glide path quality, selected apical preparation size, irrigation protocol, and operator control.

5.2. Reciprocating Motion

Reciprocation is a kinematic pattern in which the instrument moves sequentially in opposite directions, usually through unequal angles. The movement through the larger angle determines the cutting and advancement direction of the instrument, whereas the smaller reverse angular movement serves as a disengaging movement intended to reduce instrument binding. The angular difference generated at the end of each movement cycle enables the instrument to advance progressively within the canal [35].

The technique described by Yared represented an important stage in the conceptual development of the single-file reciprocating approach. In this technique, after the working length had been reached with a size #08 hand file, completion of canal shaping using a single F2 instrument in reciprocating motion was proposed. However, the author explicitly stated that additional hand files might be required for apical enlargement in wider canals [38]. Furthermore, this publication was not a comparative clinical study but a technical report presenting "preliminary observations." Therefore, it should not be regarded as independent evidence of the clinical effectiveness of contemporary single-file reciprocating systems.

The most consistently reported mechanical advantage of reciprocation is its cyclic fatigue resistance. Most of the 12 cyclic fatigue studies included in the systematic review by Ahn et al. produced results favoring reciprocation. Some studies evaluating canal shaping also reported less transportation with reciprocation [36]. However, these findings should be interpreted by distinguishing studies in which the same instrument was tested with identical characteristics under continuous rotation and reciprocation from those comparing commercial systems with entirely different designs.

The superiority of reciprocation in terms of apical debris extrusion has not been demonstrated. Although a synthesis of laboratory studies reported a tendency toward greater debris extrusion with reciprocation, the findings were described as heterogeneous and conflicting [36]. At the clinical level, the absence of a significant difference in postoperative pain between rotation and reciprocation suggests that the amount of debris measured in laboratory settings does not translate linearly into symptomatic outcomes [37]. Therefore, the advantage of reciprocation in terms of fatigue resistance does not imply more effective biological cleaning or a greater probability of periapical healing.

5.3. Adaptive and Combined Motion Systems

In adaptive and combined motion systems, the motor can modify the movement pattern according to the load or torque exerted on the instrument. Under low-load conditions, a movement resembling continuous rotation is applied, whereas reverse angular movements may be activated as the torsional load increases. In some systems, the instrument rotates continuously until a predetermined torque threshold is reached; once this threshold is exceeded, it performs a partial reverse rotation in an attempt to disengage [35]. The common objective of these approaches is to limit the torsional stress accumulated within the instrument while maintaining cutting efficiency.

In an ex vivo study conducted by Lee et al. using extracted teeth, adaptive motion was reported to reduce the torsional stresses generated in the nickel-titanium instrument and root dentin compared with continuous rotation [39]. However, an experimental reduction in torsional stress alone does not demonstrate that the incidence of clinical instrument fracture or dentinal cracking will decrease to the same extent.

Similarly, Pedullà et al. demonstrated that torque-triggered reverse motion increased the time to fracture compared with continuous rotation in all five instrument groups tested in artificial curved canals. Nevertheless, differences in fatigue resistance among the instrument groups persisted after the movement pattern had been changed [40]. This finding indicates that kinematics can modify fatigue behavior but do not operate independently of alloy properties and instrument design.

A clear superiority of adaptive motion in terms of shaping accuracy has not yet been established. In a study by Duarte et al. evaluating the mesiobuccal canals of maxillary molars using micro-computed tomography, canal transportation was similar among the groups at levels 3 and 9 mm from the apex, and no significant difference in centering ability was identified irrespective of the system or kinematics used. However, at the 6-mm level, the Twisted File Adaptive group operated in continuous rotation exhibited greater transportation than some of the comparison groups, and changes in canal volume were found to vary according to the instrument–kinematic combination [41]. These findings demonstrate that shaping outcomes cannot be explained solely by the use of adaptive or continuous motion.

5.4. Single-File and Multiple-File Approaches

The concepts of single-file and multiple-file instrumentation refer primarily to the number of mechanized instruments used for root canal shaping rather than to the movement of the instrument. A single-file system may operate in continuous rotation or reciprocation, whereas multiple-file sequences may also be used with different movement patterns. Therefore, in comparisons between single-file and multiple-file approaches, kinematics, cross-sectional geometry, apical diameter, taper, alloy properties, and the shaping protocol applied should be controlled in addition to the number of files [35,38].

In a micro-computed tomographic study by Yuan and Yang evaluating severely curved canals, both the single-file and multiple-file systems compared were reported to preserve the overall external outline of the canal and produce a regular taper. However, greater transportation was observed in the apical third with the single-file system, whereas the multiple-file system demonstrated better centering ability. Approximately 29–34% of the canal walls remained untouched in both groups, with no significant difference between the groups in this respect [42]. This study demonstrates that the number of files does not guarantee mechanical contact with all canal surfaces.

In the systematic review and meta-analysis by Caviedes-Bucheli et al., the pooled findings of four laboratory studies indicated greater apical debris extrusion with single-file techniques than with multiple-file systems. However, the authors emphasized that the observed biological response could not be explained solely by the number of files and that movement kinematics and instrument design might also be determining factors [43]. The limited number of included studies and the design differences among the systems restrict a general causal inference that “single-file systems extrude more debris.”

A multicenter study involving 599 patients treated under routine general dental practice conditions reported that single-file and multiple-file methods produced similar outcomes in terms of pain reduction and improvement in oral health-related quality of life [44]. However, because the study did not evaluate long-term periapical healing, these findings do not demonstrate that the two approaches are equivalent in terms of biological success.

In conclusion, the choice between single-file and multiple-file approaches should not be based solely on the number of instruments. Single-file use may simplify the clinical workflow; however, this characteristic does not guarantee a greater proportion of cleaned canal walls, reduced apical debris extrusion, or improved treatment success. Similarly, multiple-file use does not independently provide superior anatomical preservation. The appropriate strategy should be selected by jointly considering canal curvature and initial canal width, the established glide path, the intended apical diameter and taper, the design and metallurgical properties of the instrument, and the requirements of concomitant irrigation.

6. CLİNİCAL STAGES OF ROOT CANAL SHAPİNG

Root canal shaping is a comprehensive process in which each stage influences the safety and accuracy of the subsequent stage, rather than merely a sequence of independent procedures. The geometry of the access cavity determines coronal access; coronal preflaring influences glide path preparation and assessment of the apical diameter; and the working length establishes the apical limit of shaping. Therefore, the clinical protocol should be regarded as a stepwise approach that is reassessed according to canal anatomy rather than as the application of a fixed instrument sequence [45,46].

6.1. Access Cavity and Coronal Preflaring

The primary function of the access cavity is to facilitate the identification of canal orifices and the controlled introduction of instruments into the root canals. Although preservation of coronal dentin is important during cavity design, dentin conservation should not compromise the location of canal orifices or the controlled performance of root canal procedures.

In a laboratory study conducted by Barbosa et al. using extracted mandibular molars, traditional, conservative, and truss access cavities were compared in terms of canal instrumentation, microbial reduction, root canal obturation, and fracture resistance. Conservative access cavities provided no advantage over traditional access cavities for any of the parameters investigated and were also associated with a greater proportion of unprepared canal surfaces and more residual root canal filling material in the pulp chamber [45]. Although these findings cannot be directly generalized to long-term clinical outcomes because they were obtained from extracted teeth, they demonstrate that access cavities should not be evaluated solely according to the amount of dentin removed.

Coronal preflaring involves reducing dentinal interferences in the cervical and middle regions of the canal. This procedure may facilitate the controlled advancement of small hand files and subsequent mechanized instruments into the more apical portions of the canal. However, the extent of preflaring should be determined by considering the initial canal diameter, degree of curvature, and thickness of the root dentin [46].

Schroeder et al. demonstrated that straight-line access and coronal enlargement produced a mean reduction of 0.17 mm in canal length in 86 canals of extracted premolars and molars, with the change being statistically greater in severely curved canals [47]. Although the mean difference was small, this finding demonstrates that removing coronal interferences and partially straightening the canal curvature may alter the measured canal length. Therefore, determining the working length after coronal preflaring or reassessing it after a substantial geometric change appears reasonable.

Coronal preflaring may also affect the assessment of the initial apical instrument size. In a study conducted by Pécora et al. using extracted teeth, preflaring of the cervical and middle thirds increased the size of the instrument that bound at the working length and improved determination of the apical anatomical diameter. The preflaring instrument used was also shown to affect the resulting measurement [48]. Therefore, the first binding file identified after preflaring does not have the same anatomical meaning as a file identified without prior preflaring.

6.2. Establishing Canal Patency and Creating a Glide Path

Initial canal negotiation involves exploring the canal path with small, flexible hand files and identifying a route through which the instrument can advance toward the apical region. A glide path is defined as a smooth and reproducible passage extending from the canal orifice to the apical terminus, along which subsequent shaping instruments can advance [46,49]. Establishing a glide path should not be regarded as equivalent to merely negotiating the canal to the working length with a small file.

In the systematic review by Hartmann et al., which included 18 studies, mechanized glide path preparation produced results similar to manual preparation in most studies and superior results in some studies regarding apical transportation and centering ability. Final shaping performed after glide path preparation was reported to be associated with similar or less apical transportation than shaping performed in canals without prior glide path preparation [49]. However, because most of the studies included in the review were laboratory investigations and different instrument systems were used, no definitive conclusion can be drawn regarding the clinical superiority of glide path preparation.

Apical patency is a procedure intended to prevent debris accumulation and blockage in the apical region by passively passing a small, flexible file through the apical foramen. Maintaining apical patency is not synonymous with mechanically enlarging the apical foramen. The use of a patency file without binding or causing unnecessary mechanical intervention in the apical tissues forms the basis of this distinction.

In a systematic review of randomized controlled trials by Yaylali et al., maintaining apical patency was reported not to increase postoperative pain in teeth with vital or necrotic pulps. Furthermore, no adverse effect of patency procedures on flare-ups or analgesic use was demonstrated. However, the quality of evidence was rated as low to moderate, depending on the outcome investigated [50]. Although these findings support that apical patency does not increase postoperative symptoms, they do not demonstrate that the procedure contributes to long-term periapical healing.

Clinically, canal patency and glide path preparation are complementary procedures with different objectives. Whereas patency aims to prevent blockage of the apical region by debris, the glide path is intended to establish a controlled pathway that subsequent shaping instruments can follow within the canal. In both procedures, avoiding excessive apical force and maintaining the passive advancement of the instrument within the canal are important.

6.3. Working Length Determination

Working length refers to the distance from a coronal reference point to the apical point at which root canal shaping and obturation are planned to terminate. Incorrect determination of this length may cause shaping to terminate short of the apical canal segment or extend beyond the designated apical limit. To ensure measurement reproducibility, the coronal reference point should remain constant throughout treatment.

In a randomized clinical trial by Ravanshad et al. comparing electronic apex locators with radiographic methods in 84 patients and 188 canals, no significant difference was detected between the two methods in the rates of acceptable working lengths or short measurements. On the master cone radiograph, the rate of long measurements was reported to be 10.7% in the radiographic group and 1% in the electronic apex locator group; however, no significant difference was found between the groups in the length of the final root canal fillings [51]. Although these findings demonstrate that electronic measurements are clinically applicable, they cannot be generalized to all electronic apex locators or anatomical conditions.

The 2024 systematic review and meta-analysis by Kaur et al. evaluated 11 randomized controlled trials, eight of which were included in the quantitative synthesis. In the meta-analysis, the radiographic method produced better results in terms of measurement accuracy, whereas the electronic apex locator group demonstrated 10% greater working length adequacy. No significant difference was detected between the methods in postoperative pain. However, because five of the included studies had a high risk of bias and the remaining six had an unclear risk of bias, the certainty of the evidence was rated as very low, and no definitive conclusion could be reached regarding the superiority of either method [52].

These data support considering electronic apex locators and radiography as methods that provide different types of information rather than as direct alternatives to one another. Electronic measurements provide information about the apical terminus, whereas radiographic images demonstrate root curvature, canal direction, and the relationship of the instrument to the radiographic apex. Nevertheless, neither method should be regarded as entirely error-free; measurements should be interpreted in conjunction with clinical findings and a reproducible coronal reference point.

Because partial straightening of the canal curvature during coronal preflaring or shaping may alter the measured length, the working length may need to be reassessed throughout the procedure, particularly in curved canals [47]. This may prevent an initially accurate measurement from extending beyond the apical limit after changes in canal geometry.

6.4. Selection of Apical Size and Taper

Apical size refers to the final instrument diameter at the working length, whereas taper refers to the rate at which the canal diameter increases from the apical to the coronal direction. These two variables are not independent of one another. Two preparations with the same apical diameter may have different tapers, resulting in differences in the amount of dentin removed and the canal volume created for irrigation.

Although using the first file that binds at the working length is a traditional approach to determining the apical preparation diameter, this instrument has not been shown to accurately represent the actual apical canal diameter. In a study by Wu et al. involving curved mandibular premolar canals, the first binding instrument contacted only one side of the canal wall in 75% of the canals and did not contact the canal wall in 25%. In 90% of the canals, the instrument diameter was smaller than the short diameter of the canal [53]. Therefore, adding a fixed number of instrument sizes to the diameter of the first binding file does not provide the same anatomical enlargement in all canals.

Coronal preflaring may improve estimation of the apical diameter by reducing false binding caused by cervical interferences [48]. However, even a file identified after preflaring may contact only part of an oval or irregular apical cross-section. The apical size should be selected by considering the first binding file together with the tooth type, initial canal diameter, degree of curvature, and preservation of root dentin.

Increasing the apical preparation size may influence irrigant penetration into the apical region. In a laboratory study by Khademi et al. involving the mesiobuccal canals of mandibular first molars, the minimum preparation size required for irrigant penetration and debris removal in the apical third was reported to be size 30 [54]. However, because this finding was obtained under a specific tooth group, irrigation method, and experimental model, it should not be interpreted as indicating that size 30 represents a universal minimum diameter for all root canals.

Using negative-pressure irrigation in extracted single-rooted teeth, Brunson et al. demonstrated that the volume of irrigant delivered to the working length increased significantly as the apical size and taper increased. Increasing the apical size from 35 to 40 produced a marked increase in irrigant volume, whereas increasing it from 40 to 45 provided a more limited additional contribution. Increasing the taper also increased the volume of irrigant delivered to the working length [55]. However, these findings are specific to a negative-pressure irrigation system and a laboratory model comprising straight, single-rooted teeth.

Therefore, no single apical diameter or taper can be specified for all cases. A wider or more tapered preparation may create more space for irrigation; however, the apical target should be evaluated in conjunction with the anatomical boundaries of the root and the amount of dentin that should be preserved.

6.5. Final Apical Shaping

Final apical shaping involves preparing the apical canal segment to the planned size after the working length and intended apical diameter have been determined. This procedure should not be regarded solely as advancing the final file to the working length; the compatibility of the resulting apical preparation with the canal anatomy and irrigation requirements should also be considered.

Fornari et al. enlarged the curved mesiobuccal canals of maxillary molars to sizes 30/.02, 35/.02, 40/.02, and 45/.02 and examined the apical thirds histologically. The proportions of unprepared dentin surfaces and residual debris were lower in the 40/.02 and 45/.02 groups than in the 30/.02 and 35/.02 groups. However, none of the apical enlargement sizes resulted in complete instrumentation of the canal walls [56]. This finding indicates that apical enlargement may improve cleaning effectiveness but does not completely eliminate anatomical irregularities.

In a clinical microbiological study conducted by Rodrigues et al. involving 43 teeth with post-treatment apical periodontitis, enlarging the apical preparation from the first instrument used to the third instrument in the sequence resulted in a greater reduction in bacterial counts. Sodium hypochlorite was also found to be more effective than saline after use of the largest instrument [13]. This finding demonstrates that apical size may influence microbial reduction but that its effectiveness is not independent of the irrigating solution used.

The effect of apical preparation size on healing was evaluated in a randomized controlled trial by Saini et al. involving mandibular first molars. The canals were prepared to two, three, four, five, or six sizes larger than the first apical binding file. At the 12-month follow-up, healing was lower in the group enlarged by two sizes, whereas no significant differences were detected among the groups enlarged by three to six sizes. The researchers concluded that, under the conditions of this study, preparation to three sizes larger than the first binding file was sufficient [57]. However, this finding applies only to the mandibular molars and protocol evaluated in the study and should not be regarded as an invariable enlargement rule for all canals.

It cannot be concluded that larger diameters are automatically superior in final apical shaping. Available studies indicate that apical enlargement may improve mechanical contact with the canal walls, debris removal, irrigant delivery, and microbial reduction [13,54–56]. However, no preparation size guarantees instrumentation of all canal surfaces, and it has not been demonstrated that the clinical benefit continues to increase beyond a specific size [57]. Therefore, the final apical size should be determined by jointly considering the anatomical diameter, canal curvature, root dentin thickness, and the irrigation protocol to be applied.

7.CONCLUSION

Root canal shaping is a fundamental component of chemomechanical preparation that contributes to reducing the microbial load within the root canal system and creates a canal geometry suitable for irrigation and root canal obturation. Although advances in nickel-titanium alloys, heat-treatment technologies, instrument designs, and movement kinematics have increased the effectiveness and safety of shaping procedures, the available evidence does not demonstrate that a specific instrument system is superior under all clinical conditions. Therefore, the instrumentation strategy should be determined on a case-specific basis by considering root canal anatomy, canal curvature, initial canal diameter, and the amount of dentin that should be preserved. Establishing canal patency, creating a reproducible glide path, accurately determining the working length, and selecting an appropriate apical size and taper are fundamental stages of safe shaping. The potential benefits of wider preparations in increasing irrigation and mechanical contact should be evaluated together with the risks of additional dentin loss and procedural errors. Ultimately, successful root canal shaping depends not on creating the largest preparation or using a specific commercial system, but on establishing a balanced approach between the requirements of biological cleaning and the preservation of the original canal anatomy and root dentin.

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