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Endodontic working width: current concepts and techniques

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A clinician's primary concern is to thoroughly cleanse the root canal system during root canal therapy, mechanically and chemically removing microorganisms and their substrates from the canal. Without proper chemomechanical instrumentation, the remaining irritants may reduce the success rate and cause failure of the treatment. In addition, canal surface irregularities require proper instrumentation for adequate root canal filling. Many textbooks and much literature focus on canal instrumentation in terms of filing, reaming, or other instrument motions and usage and always stress the importance of enlarging the canal size. Without solid scientific evidence, however, it is still not clear how large is large enough.

Many studies have demonstrated that widely accepted endodontic cleaning and shaping techniques are inadequate. Haga [1] found that mechanical preparation of root canal to two sizes larger than the original was still not adequate. Gutierrez and Garcia [2] showed that often, canals are improperly cleaned. They attributed this inadequate instrumentation to the fact that the root canal diameter is larger than the instrument caliber used in each particular case. This finding suggests that each canal should be calibrated independently before instrumentation so that proper preparation can be achieved. Walton's [3] histologic study showed that canals that were instrumented to three sizes larger still were not thoroughly cleaned. Recent in vitro investigations [15] concluded that stainless steel and nickel–titanium (NiTi) rotary instruments were not able to clean the root canals satisfactorily.

In the absence of a study that defines what the original width and optimally prepared horizontal dimensions of canals are, clinicians are making treatment decisions without any support of scientific evidence.

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Root canal morphology is a critically important part of conventional and surgical endodontics (root canal therapy). Many in vitro studies have recorded the scales and average sizes of root canals [1,5–7,23], but there have been few clinical attempts to determine the working width (WW). It is difficult to section all levels of the teeth and make the section plane exactly perpendicular to the canal curvature. Therefore, most morphometric studies cannot show the true picture of the horizontal dimensions of the root canal system. Until recently, most investigations have involved counting the number of canals and foramina and categorizing how the canals join or split. Current studies pay more attention to the shape of the canal systems and its clinical implications than to the actual, preoperative size of the canal [4,8,9].

The horizontal dimension of the root canal system is not only more complicated than the vertical dimension (root canal length or working length) but also more difficult to investigate because the horizontal dimension varies greatly at each vertical level of the canal as shown in Figs. 1–3. Routine clinical radiographs may mislead clinicians to make a different plan to clean the root canal system. Unfortunately, this area of critical information has not been investigated thoroughly. Some clinicians may still have the impression that all root canals are round in shape because of such radiographs as shown in Figs. 1 and 2. Recent studies reported a high prevalence of oval root canals in human teeth [4,8,9]. Cross-sections of 90% of the mesiobuccal canals of maxillary first molars were found to be oval or flat [4]. This article provides definitions and perspectives on the current concepts and techniques to handle WW (the horizontal dimension of the root canal system) and its clinical implications.

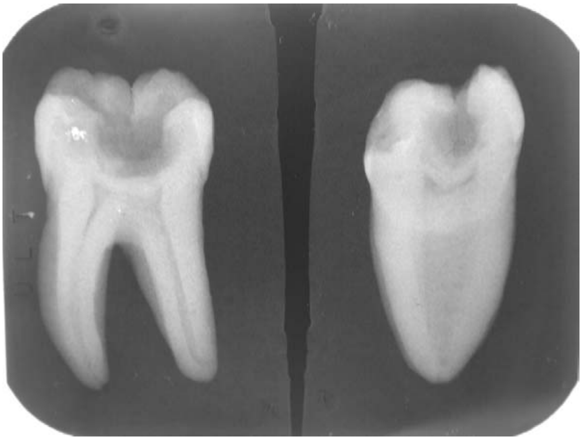

Fig. 1. The mesiodistally directed radiograph indicates a flattened distal root canal in a mandibular first molar. In the same tooth, the faciolingual direction of the routine radiograph gives an impression of a round-shaped distal canal.

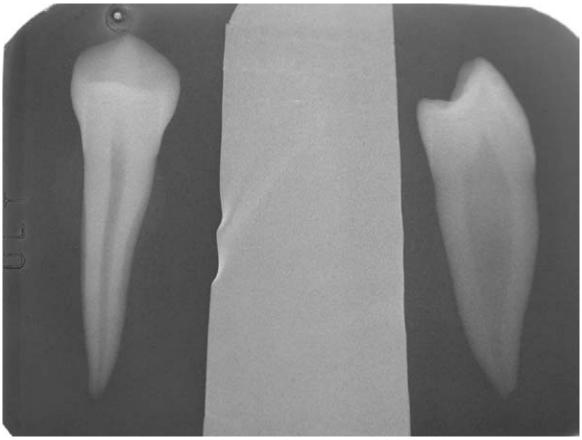

Fig. 2. The faciolingual direction of the routine radiograph gives an impression of round-shaped canal in a mandibular first premolar. The mesiodistally directed radiograph indicates a flattened root canal in the same tooth.

Definition of working width

The initial and postinstrumentation horizontal dimensions of the root canal system at working length and other levels are shown in Box 1. In a relatively round canal, the lesser and the greater initial horizontal

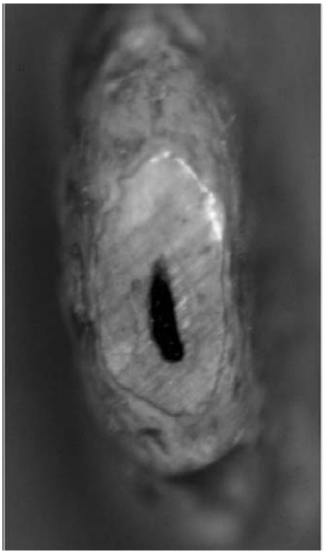

Fig. 3. Cross-section of a mandibular first premolar, indicating a long-oval and irregular root canal. In the same tooth, the faciolingual direction of the routine radiograph may be mistakenly recognized as a round-shaped canal because a mesiodistally directed radiograph is rarely available clinically.

Box 1. Definitions of the working width

MinIWW(N)	Minimal initial horizontal dimension N mm short of working length
MinIWW0	Minimal initial horizontal dimension at working length
MinIWW1	Minimal initial horizontal dimension 1 mm short of working length
MinIWW2	Minimal initial horizontal dimension 2 mm short of working length
MaxIWW(N)	Maximal initial horizontal dimension N mm short of working length
MaxIWW0	Maximal initial horizontal dimension at working length
MaxIWW1	Maximal initial horizontal dimension 1 mm short of working length
MaxIWW2	Maximal initial horizontal dimension 2 mm short of working length
MinFWW(N)	Minimal final horizontal dimension N mm short of working length
MinFWW0	Minimal final horizontal dimension at working length
MinFWW1	Minimal final horizontal dimension 1 mm short of working length
MinFWW2	Minimal final horizontal dimension 2 mm short of working length
MaxFWW(N)	Maximal final horizontal dimension N mm short of working length
MaxFWW0	Maximal final horizontal dimension at working length
MaxFWW1	Maximal final horizontal dimension 1 mm short of working length
MaxFWW2	Maximal final horizontal dimension 2 mm short of working length

dimensions are approximately the same. In an oval, long-oval, or flat canal as shown in Box 2, the maximal initial horizontal dimensions (MaxIWW) may be several times larger than the minimal initial dimension (MinIWW) at different levels of the canal. For example, in a maxillary cuspid, MinIWW at working length (MinIWW0) may be the same as MaxIWW at working length (MaxIWW0). But 12 mm short of working length, its MaxIWW12 is probably three to four times larger than MinIWW12. This is because at that

Box 2. Current descriptions of the horizontal dimensions (cross-sections) of the root canal

1. **Round (circular):** MaxIWW equals MinIWW
2. **Oval:** MaxIWW is greater than MinIWW (up to two times more)
3. **Long oval:** MaxIWW is two or more times greater than MinIWW (up to four times more)
4. **Flattened (flat, ribbon):** MaxIWW is four or more times greater than MinIWW
5. **Irregular:** cannot be defined by 1–4

level, the cross-section of a cuspid very often is a long-oval or flat canal shape. After root canal instrumentation, the minimal final horizontal dimension at working length (MinFWW0) may be no different than the maximal final horizontal dimension at the working length (MaxFWW0) if there was not significant transportation. At the level of 12 mm short of the working length, however, the ratio between MinFWW12 and MaxFWW12 may be altered by the mechanical preparation of the canal. In general, there is a 25% prevalence of long-oval canals in the apical third, and in some groups of teeth, the prevalence is greater than 50% [9]. At the level of 5 mm from the working length in human teeth, it is common to have long-oval canals where the MaxIWW5 is two to four times greater than the MinIWW5 [9].

Determination of initial working width at working length (initial apical file determination—estimation of initial canal diameter)

In the course of cleaning and shaping the root canal system, the clinician must determine three critical parameters. These are the length of the canal, the taper of the preparation, and the horizontal dimension of the preparation at its most apical extent, also referred to as the initial apical file size. One common method of deciding on the size of the apical preparation is to first determine the preoperative canal diameter by passing consecutively larger instruments to the working length until one binds. This initial apical file estimation is referred to as the determination of MinIWW0. In some textbooks, the master apical file size (MaxFWW0) is then suggested to be three International Standards Organization (ISO) file sizes larger than that initial binding file (Table 1). Clinicians and researchers started to question whether the first file to bind corresponds to the apical diameter of the canal. Recent studies suggest that the first K file and the first LightSpeed (LightSpeed Technology, San Antonio, Texas) instrument that bound at the working length did not accurately reflect the diameter of the apical canal [10,11,13,15]. The inaccuracy and discrepancy can come from various

Table 1
Current concepts and guidelines determine the minimal final working width at working length from different publications

	Author and references			
Tooth	Grossman [17]	Tronstad [20]	Glickman and Dumsha [19]	Weine [21]
Maxillary				
Centrals	80–90	70–90	35–60	3 sizes
Laterals	70–80	60–80	25–40	3 sizes
Canines	60–60	50–70	30–50	3 sizes
First premolars	30–40	35–90	25–40	3 sizes
Second premolars	50–55	35–90	25–40	3 sizes
Molars	30–55–50			3 sizes
MB/DB		35–60	25–40	3 sizes
P		80–100	25–50	3 sizes
Mandibular				
Centrals	40–50	35–70	25–40	3 sizes
Laterals	40–50	35–70	25–40	3 sizes
Canines	50–55	50–70	30–50	3 sizes
First premolars	30–40	35–70	30–50	3 sizes
Second premolars	50–55	35–70	30–50	3 sizes
Molars	30–55–50			3 sizes
MB/ML		35–45	25–40	3 sizes
D		40–80	25–50	3 sizes

morphologic and procedural factors such as canal shape, canal length, curvature of the canal, canal content, coronal interference, and the instrument used in estimating or measuring MinIWW0 and MaxIWW0.

Factors affecting the determination of minimal initial working width at working length

Several factors may affect the accuracy of determining the MinIWW0. The canal shape, length, taper, curvature, content, and wall irregularities and the instrument used may all influence the result because each can affect the clinician's tactile sense. The combination of those factors makes correct determination of IWW very difficult, if not impossible. Understanding these factors can minimize the underestimation of the IWW.

Canal shape

The current descriptions of horizontal dimensions of the root canal system are listed in Box 2. The round canal can be measured more easily because the MinIWW and MaxIWW are the same. Other factors, however, make determination of IWW difficult, even in straight canals. The proper instrument and tactile sensation may determine the MinIWW of the oval, long-oval, and flat canals. The determination of MaxIWW, however, cannot easily be realized with current methods.

Canal length

When using an instrument to gauge working length, the longer the canal, the greater the frictional resistance. In a very long canal (>25 mm), the frictional resistance may increase to affect the clinician's tactile sense for determining the IWW correctly. In addition, if the coronal flare is too conservative or limited to the coronal third of the canal, then the shaft of the instrument may engage the canal wall and cause a false/premature conclusion as to the WW.

Canal taper

Any tapering discrepancy between the gauging instrument and canal may lead to an early instrument engagement of the canal wall, causing a false sensation of apical binding. Early coronal flare can increase the taper of the canal and reduce the tapering discrepancy between the gauging instrument and canal wall. The last 3 to 5 mm of the canal can have parallel walls, making correct determination of IWW difficult.

Canal curvature

Curved canals can cause deflection of the gauging instrument and increase the frictional resistance. The curvature of the root canal can be categorized into two-dimensional, three-dimensional, small radius, large radius, and double curvature (S-shaped, bayonet-shaped) and with different degrees of severity. Each of these curvatures has a different effect on a clinician's tactile sense. The combination of these curvatures makes correct determination of IWW extremely difficult, if not impossible. In curved mandibular premolars, the study by Wu et al [13] indicated that the first K file and the first LightSpeed instrument that bound at the working length failed to accurately reflect the diameter of the apical canal.

Canal content

The content of the root canal may be fibrous in nature. Calcified material (calcific metamorphosis) may also be part of the canal content. During determination of IWW, the mixed canal contents can create different degrees of frictional resistance against the gauging instrument. It can eventually affect the clinician's tactile sense. This factor makes correct determination of IWW somewhat more difficult.

Canal wall irregularities

Attached pulp stones, denticles, and reparative dentin can create convexities on the canal wall surface. Resorption can produce concavities on the canal wall surface. These phenomena can serve as an impacting factor that induces a false estimation of the true canal dimension at working length and other levels.

Instrument for determining initial working width

The rigidity, flexibility, and tapering of the instrument used for determining IWW can affect accuracy. As mentioned previously, any tapering discrepancy between the gauging instrument and canal may lead to an early instrument engagement of the canal wall, altering the tactile sensation. In addition, the rigid instrument in a curved canal also can lead to a false tactility. During IWW determination, the combination of those affecting factors can have a great impact on the accuracy. Understanding these factors can minimize the underestimation of the IWW and maximize its accuracy.

Eliminating or minimizing the influence of affecting factors

Being aware of the existence of the affecting factors in IWW determination is the primary step in maximizing the accuracy of the technique. Without knowing these factors, clinicians can repeatedly make the same mistakes in underestimating IWW, which will lead to incomplete cleaning and shaping of the root canal system as shown in Figs. 4–7.

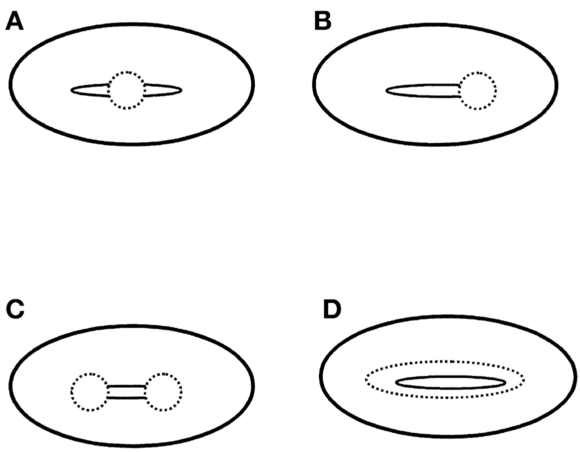

Fig. 4. In a long-oval or flat root canal, reaming and modified reaming actions will result in incomplete debridement of the root canal system. The "keyhole" and "dumbbell" effects (*B*,*C*) are typical pictures that demonstrate the unprepared parts of the root canal. Most NiTi rotary instruments used with continuous reaming and modified reaming actions like the balanced force technique and quarter-turn pull technique will lead to the same misadventures (*A*–*C*). Circumferential instrumentation can conform to the outline of the horizontal dimensions of the root canal at different levels of the canal (*D*).

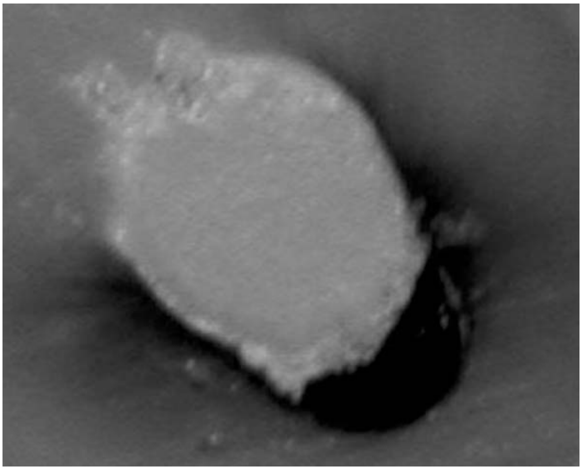

Fig. 5. A cross-section of a NiTi rotary instrument–prepared canal indicates an incomplete instrumentation. The untouched canal walls may lead to a failed root canal treatment.

Before the IWW determination, it is suggested to widen the orifices, to do early coronal flaring and additional canal flaring (crown down, double flaring) to ensure effective irrigation, and to minimize any interferences with tactile sensation. Carefully selecting the adequate instrument of maximal flexibility and minimal taper such as LightSpeed may avoid interference and help to achieve better results.

Ideally, root canal preparation should follow the exact outline of the horizontal dimensions of the root canal at every level of the canal. In this

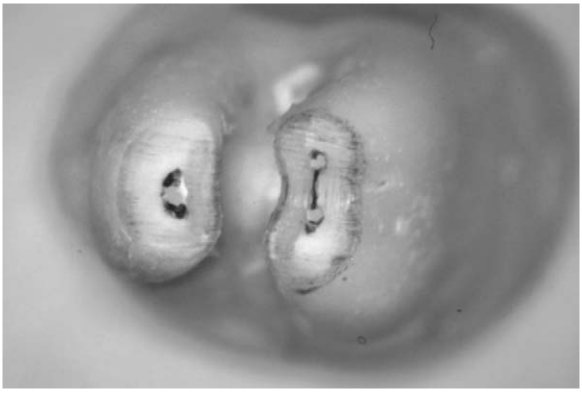

Fig. 6. A cross-section of prepared and filled canals indicates an incomplete instrumentation and may result in a failed root canal treatment. The ‘‘dumbbell’’ effects are typical pictures that demonstrate the unprepared parts of the root canal. This misadventure can come from underestimation of the IWW and the lack of understanding of endodontic WW concepts.

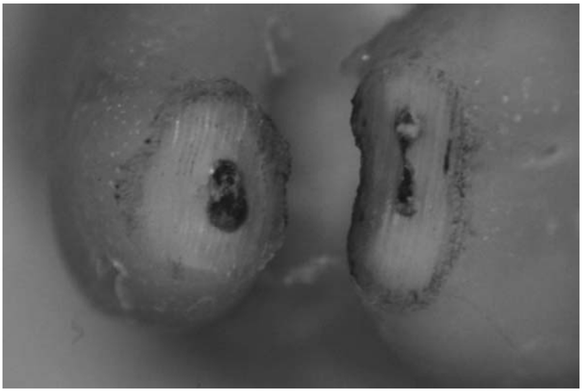

Fig. 7. A cross-section of incompletely prepared and filled canals demonstrates the complicated situation of endodontic WW. Understanding the concepts and the techniques of endodontic WW can minimize misadventures of incomplete instrumentation and a failed root canal treatment.

ideal condition, especially for long-oval and flattened root canals, they can be cleaned and shaped properly with minimal mishaps of weakening, stripping, or perforating the canal walls as shown in Fig. 4D. Circumferential preparation or instrumentation may have to be considered for these cases to minimize incomplete cleaning of the root canal system. Most of the NiTi rotary instruments provide a continuous reaming action that makes the canal relatively circular in shape. Indiscriminate use of NiTi rotary instruments alone for root canal cleaning and shaping may result in incomplete cleaning of the root canal system and lead to failure of the endodontic therapy (Fig. 5). Recent studies [10,12,14–16] have indicated that no current instrumentation technique was able to completely clean dentin walls of the oval, long-oval, and flattened root canals. The manual crown down instrumentation technique, however, was more efficient and effective in cleaning flattened root canals than rotary instrumentation.

Determination of the minimal and maximal final working width at working length

To what extent the canal is supposed to be prepared has been a myth in the endodontic field. Grossman [17] described the rules governing biomechanical instrumentation in his textbook *Endodontic Practice*. Among them, he stated that the canal should be enlarged at least three sizes greater than its original diameter. He gives four reasons to widen the canal space:

1. To remove bacteria and their substrates
2. To remove dead pulp tissue

3. To increase the capacity of the root canal to retain a larger amount of sterilizing agent
4. To prepare the tooth to receive the canal filling

These statements are reasonable; however, studies have suggested that root canals have not been thoroughly cleaned even after being enlarged three sizes greater than their original diameters. The concepts and techniques of WW may play an important role in this finding. Any investigation of the effectiveness of cleaning the root canal system without carefully estimating the MinIWW and MaxIWW in the oval, long-oval, and flattened root canals may result in misleading data, especially if the horizontal canal morphology was not carefully assessed. In an oval, long-oval or flat canal, circumferential instrumentation seems to be the only reasonable way to properly clean and shape the canal. Especially in the infected canals, the infected dentin has to be removed to ensure a successful treatment. Ideally, during root canal preparation, the instruments and techniques used should always conform to and retain the original shape of the canal to maximize the cleaning effectiveness and minimize unnecessary weakening of tooth structure to achieve the optimal result. It is very challenging to aggressively clean and shape the infected canal without weakening the tooth structure. Clinically, the heavily infected cervical part of the canal has often been enlarged with Gates–Glidden burs or canal wideners to a round shape instead of following the original oval, long-oval, or flat shape. Although the strength of the tooth structure is evidently reduced [22], the FWW in the cervical area has been determined by the clinician's preference instead of scientific evidence. Based on limited information [1,2,5–7,17–24] and reasonable concepts, several guidelines were developed to determine the MinFWW0 (see Table 1). The maximal discrepancy between the MaxFWW0 and MinFWW0 can be six to eight ISO sizes. Complicated by canal curvature, the instrument used, and the techniques implemented, the concepts for determining the MinFWW0 and MaxFWW0 seem unclear and chaotic. Between the cervical and apical areas, the clinician has the absolute freedom to determine the MinFWW at N mm from working length (MinFWWN) and MaxFWW at N mm from working length (MaxFWWN) because the scientific information and evidence are not yet available.

Most of the research for root canal instrumentation has not addressed the importance of the horizontal dimensions or WW of the root canal system. In preparing the long-oval or flat canals, the WW concept plays a more critical role that alerts the operator to the possibilities of incomplete root canal preparation. In vitro studies found that manual circumferential filing had statistically significant better effectiveness than rotary instrumentation for cleaning flattened root canals [14]. The concepts of the WW indicate that different approaches and techniques are needed to improve root canal preparation and promote better quality of root canal treatment.

Summary

There has been minimal development of concepts, techniques, and technology to measure IWW and to determine FWW accurately or properly. Understanding the current concepts and techniques of WW can reduce the underestimation of the MinIWW0 and apical MinIWW and subsequent incomplete cleaning of the root canal system. The detailed information regarding horizontal morphology of the root canal system can help to solidify concepts and improve techniques of cleaning and shaping the root canal system. Carefully maintaining the aseptic chain, using adequate irrigating solutions to enhance efficacy, and cautiously applying current concepts and techniques of WW may provide a better quality of endodontic therapy for the patient.

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