Development and sequelae of canal transportation

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Instrumentation of curved root canals is still a challenge even for skilled and experienced operators. During shaping of these canals, canal transportation, straightening, or canal deviation may occur. This paper describes different preparation outcomes as possible results of canal transportation, and the action of different root canal instruments when used in curved canals, and provides an overview of current in vitro and in vivo studies assessing canal transportation. In the second part of this paper, the clinical consequences of canal transportation such as insufficient cleaning and over-reduction of radicular dentin are addressed. Finally, based on currently available evidence, the impact of canal transportation on the clinical outcome of root canal treatment is discussed.

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Introduction

The primary aim of any preparation of the root canal system is to enlarge the root canal space to facilitate either disinfection by antibacterial agents or to prevent (re-)infection through the placement of a fluid-tight root canal filling in combination with a sufficient coronal restoration. Despite recent advances in the field of endodontic instruments and devices, the mechanical preparation of a curved root canal is still a challenge even for very skilled and experienced clinicians. Different, well-described preparation errors may result during the shaping of these curved root canals, such as ‘canal transportation,’ ‘straightening,’ or ‘deviation’ (1). As most root canals are curved (2), a high prevalence of preparation errors or canal aberrations has been reported (3, 4).

What is canal transportation?

According to the Glossary of Endodontic Terms of the American Association of Endodontists, canal transportation is defined as follows (5): ‘Removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation; may lead to ledge formation and possible perforation.’ As a result of this asymmetrical material removal during shaping, the long axis of the curved root canal will be displaced and the angle of curvature will decrease, resulting in straightening of the original curvature of the root canal (Fig. 1).

Independent of the alloy used, any root canal instrument tends to straighten itself inside the root canal (3, 6–8). Owing to the restoring forces, an uneven force distribution of the cutting edges of the instrument in certain contact areas along the root canal wall results, leading to an asymmetrical dentin removal (3, 8). In particular, the cutting edges are pressed against the outer side of the curved canal (convexity) in the apical third and against the inner side at the middle or coronal thirds (concavity). As a result, apical canal areas tend to be overprepared toward the convexity of the canal, whereas more coronally greater amounts of dentin will be removed at the concavity, leading to canal transportation or straightening of varying degrees (3, 8) (Fig. 2).

The following undesirable apical preparation outcomes have been described as possible results of canal transportation (1, 4, 9–12):

- Damage to the apical foramen – Deviation from the original curvature of the root canal or displacement of the original long axis of the canal may result in a loss of an apical stop (4). As a consequence, the periapical tissues may be irritated by extruded debris, irrigants, or filling materials.
Zip formation – A transported root canal with its overpreparation along the outer aspect of the curvature adopts an elliptical shape at the apical endpoint. Similar terms describing the shape of a zipped apical part of the root canal are an ‘hourglass shape,’ a ‘teardrop,’ or a ‘foraminal rip’ (1, 4, 8). Zipping of a root canal influenced the apical seal negatively when these transported canals were obturated in vitro by lateral compaction (11).

Elbow formation – Narrow portion of the root canal between the excessive material removal along the outer aspect in the apical and the overenlargement of the inner aspect of the curvature more coronally, which is usually localized at the point of maximum curvature (Fig. 2). This preparation outcome results in insufficient taper and flow and may endanger proper cleaning and obturation of the apical part of the root canal (1, 4).

Perforation – A perforation of the apical part of the root canal may result when instruments with sharp cutting tips are used in a rotary working motion (3, 4) and represent a communication between the root canal space and the external root surface, causing irritation of the periradicular tissues (Fig. 3).

Strip perforation – Whereas all the aforementioned procedural errors are located at the apical part of the curved root canal, a strip perforation may result from overpreparation along the inner side of the curvature in the middle or the coronal third of the canal (4, 13). Strip perforations signify a communication between the root canal system and the periodontal ligament, mainly found in mesial roots of mandibular molars at the furcal aspect, which is therefore termed the ‘danger zone.’

Ledging – A ledge is located at the beginning or the outer side of the curvature as a platform (4) when the working length can no longer be reached and the original path of the root canal has deviated. Hence, ledge formations can be localized in the middle or the apical part of root canals (Figs. 4 and 5). More details concerning ledge formations can be found in an excellent review published recently (12).

The following aspects are associated with an increased risk of canal transportation:

- Insufficiently designed access cavities, as this leads to an improper guiding of the instruments by the walls of the cavity with a loss of control of the instruments during root canal preparation (12).
unrestricted access of the instruments to the apical foramen minimizes the risk of canal transportation.  
- Alloy (stainless-steel versus nickel–titanium) and design features (cross-sectional design, number of flutes, and rake angle) of root canal instruments (6, 8, 14, 15).
- Use of instruments with sharp cutting tips (1, 10, 12, 16–19).
- Use of inflexible instruments in sizes above #20 in severely curved root canals (7, 20).
- Forcing the instrument into the root canal (that is, to avoid the use of a crown-down approach in curved canals) (12).
- Instrumentation technique (step-down approaches or balanced-force technique versus a step-back or a standardized technique) (4, 7, 8, 10, 21–23).
- Insufficient irrigation during mechanical enlargement (12).
- Operator-related factors (e.g. experience) (3, 24–26).
- Degree of canal curvature and radius of the curvature (Fig. 6) – In general, it can be stated that the greater the degree of curvature and the smaller the radius of curvature, the greater the risk of canal transportation (3, 27–30). There is evidence that root canals with a large angle and a small radius of curvature can hardly be enlarged without any transportation, independent of whether rotary nickel–titanium or stainless-steel hand instruments were used (10).
Radiographically unseen canal curvatures (31) – These unseen curvatures can play a significant role in the cleaning and shaping process because they may account for loss of working length during instrumentation. Also, the enlargement of a canal with a proximal curvature can result in severe canal transportation or even in strip perforation (9, 25).

Instrument action and development of transportation

Numerous studies have been performed on the preparation of curved root canals, focusing on canal transportation, straightening, or maintenance of the original root canal curvature (4). The vast majority of them used either simulated curved canals in plastic blocks or extracted human teeth with defined canal curvatures (4) (Table 1). Unfortunately, clinical studies assessing the effects of different instruments or instrumentation techniques are very scarce (Table 2). Until now, only one report has described the impact of canal transportation on the outcome of endodontic therapy.

In vitro studies

Stainless-steel reamers, which should be used in a reaming working motion, cause marked transportation or straightening of the canal, especially in canals with ovoid cross-sections (29, 53–55). Distinct transportation of curved canals was also a consistent finding for stainless-steel K-files with a rotational cutting action in combination with a longitudinal filing motion (20, 55–58) (Fig. 7). Hedstroem files used in a linear filing motion (7, 15, 29, 59) are associated with severe straightening of the inner canal wall as well as excessive material removal on the outer side of the curvature, resulting in distinct transportation or even apical perforations (20, 29, 60, 61) (Fig. 8). These undesirable effects can be explained by the metallic memory...
Table 1. Root canal straightening after preparation of curved canals *in vitro* (extracted human molars)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Mean original curvatures (°)</th>
<th>Instruments</th>
<th>Straightening degree (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yang et al. (32)</td>
<td>27.8 ± 8.6</td>
<td>ProTaper</td>
<td>1.20 ± 0.74</td>
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<td></td>
<td>29.2 ± 9.4</td>
<td>Hero Shaper</td>
<td>0.74 ± 0.56</td>
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<tr>
<td>Rödig et al. (33)</td>
<td>26.8</td>
<td>ProFile .04</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>27.0</td>
<td>GT Rotary</td>
<td>0.3</td>
</tr>
<tr>
<td>Bürklein &amp; Schäfer (34)</td>
<td>30.71 ± 3.36</td>
<td>Mtwo (torque-limited handpiece)</td>
<td>2.24 ± 2.35</td>
</tr>
<tr>
<td></td>
<td>30.66 ± 3.27</td>
<td>Mtwo (torque-control motor)</td>
<td>1.24 ± 2.36</td>
</tr>
<tr>
<td>Schäfer et al. (35)</td>
<td>30.20 ± 3.26</td>
<td>Mtwo</td>
<td>1.22 ± 1.32</td>
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<td></td>
<td>30.21 ± 3.33</td>
<td>K3</td>
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<td>30.15 ± 3.54</td>
<td>RaCe</td>
<td>2.59 ± 2.32</td>
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<tr>
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<td>NiTi–TEE</td>
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<td>27.7</td>
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<td>20.4 ± 17.1</td>
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<td>21.7 ± 19.3</td>
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<td>0.9 ± 1.0</td>
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<td>1.2 ± 0.6</td>
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<td><strong>16.6 ± 13.7</strong></td>
<td>Hand stainless-steel Reamer+Hedstroem files</td>
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<td>Lightspeed</td>
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<tr>
<td></td>
<td>26.7</td>
<td>Quantec SC</td>
<td>1.7</td>
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Table 1. Continued

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<thead>
<tr>
<th>Authors</th>
<th>Mean original curvatures (°)</th>
<th>Instruments</th>
<th>Straightening degree (°)</th>
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<tr>
<td>Karagöz-Küçükay et al. (43)</td>
<td>28.15 ± 5.36</td>
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<td>30.30 ± 8.62</td>
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<td>FlexMaster</td>
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<td>1.36 ± 1.55</td>
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<td>29.85 ± 3.08</td>
<td>Stainless-steel K-Flexofile hand instruments</td>
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<td>Schäfer &amp; Lohmann (46)</td>
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<td>FlexMaster</td>
<td>2.14 ± 2.42</td>
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<td></td>
<td></td>
<td>30.60 ± 2.24</td>
<td>7.31 ± 2.90</td>
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<td>Versümer et al. (47)</td>
<td>27.8</td>
<td>ProFile .04</td>
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<td>28.4</td>
<td>Lightspeed</td>
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<td>Hülsmann et al. (48)</td>
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<td>Hero 642</td>
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<td></td>
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<td>Hülsmann et al. (49)</td>
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<td>Excalibur: Flexofiles</td>
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<td>31.0</td>
<td>Stainless-steel hand instruments</td>
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‘Mean original curvatures’ are the canal curvatures assessed before instrumentation according to the method described by Schneider (50); ‘straightening degree’ was defined as the difference between canal curvature before and after instrumentation. Extremes are marked in bold.

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Table 2. Clinical studies assessing root canal straightening

<table>
<thead>
<tr>
<th>Authors</th>
<th>Mean original curvatures (°)</th>
<th>Instruments</th>
<th>Straightening degree (°)</th>
</tr>
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<tbody>
<tr>
<td>Hu et al. (51)</td>
<td>23.30 ± 5.80</td>
<td>ProTaper</td>
<td>4.02 ± 2.80</td>
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<td>21.60 ± 4.67</td>
<td>Hero 642</td>
<td>1.72</td>
</tr>
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<td>Schäfer et al. (26)</td>
<td>23.31 ± 8.70</td>
<td>FlexMaster</td>
<td>1.12 ± 1.87</td>
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<td>22.75 ± 7.17</td>
<td>Stainless-steel hand instruments</td>
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<td>Pettiette et al. (52)</td>
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<td>Stainless-steel K-files hand instruments</td>
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<td></td>
<td>30.09</td>
<td>NiTi hand instruments</td>
<td>4.39 ± 4.53</td>
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‘Mean original curvatures’ are the canal curvatures assessed before instrumentation according to the method described by Schneider (50); ‘straightening degree’ was defined as the difference between canal curvature before and after instrumentation. Extremes are marked in bold.
and inherent inability of all but the smallest stainless-steel instruments to maintain the original canal curvature (7, 12, 55). Instruments, especially above size 20, become inflexible, resulting in a noticeable tendency to straighten themselves inside the curved canals (Fig. 9). If the first instrument starts to overcut dentin along the outer aspect of the curved canal, this effect will be intensified with each subsequently used larger instrument (20, 59).

Recently, several experiments assessed the effects of tip modifications on canal preparation. Instruments with a non-cutting tip, that is a reduction of the tip or the transition angle and incorporation of a guiding plane (12, 17–19) (Fig. 10), exert less canal transportation and lead to more material removal at the inner curvature of curved root canals compared with similar instruments having conventional tips (10, 14, 17–19, 62–64). There is clear evidence that instruments with...
modified tips are superior in maintaining the original canal curvature, independent of whether stainless-steel or nickel–titanium hand instruments or rotary nickel–titanium instruments were used (3, 4, 12, 65). Nevertheless, even flexible stainless-steel instruments with non-cutting tips do not produce entirely satisfactory results in terms of adequately centered enlargement of severely curved canals (13, 22, 57).

The introduction of the superelastic alloy nickel–titanium has resulted in instruments that exert much lower forces on the root canal walls compared with stainless-steel instruments (4, 6). There is evidence that nickel–titanium hand instruments cause less deviation from the original curvature than their stainless-steel counterparts when used in curved root canals (20, 66–71). Moreover, the substantially increased flexibility of nickel–titanium instruments compared with stainless-steel instruments has made it possible to produce instruments with tapers greater than the ISO standard, which is a 2% taper (3, 4, 6, 72). These nickel–titanium rotary instruments, nearly all of which have non-cutting tips (6, 72), are particularly suitable for preparing curved root canals with fewer procedural aberrations (Fig. 11) than stainless-steel hand instruments. In fact, the magnitude of absolute canal transportation caused by these instruments is very small (6, 41, 37) (Fig. 12). Differences in the centering ability of rotary nickel–titanium versus stainless-steel

![Fig. 11. Instrumented curved root canals with no radiographically visible canal transportation.](image)

![Fig. 12. Extracted human molar with a severely curved root canal. (a) Initial radiograph with a size 15 instrument inserted; curvature 42°. (b) Final radiograph after instrumentation with a size 40 nickel–titanium instrument inserted; curvature 35°. As a result of instrumentation, the root canal was only slightly transported toward the outer aspect of the curvature.](image)
hand instruments are more pronounced when the final apical preparation is larger than size 30 (6).

Even those rotary instruments with active cutting edges do not negatively affect the maintenance of the original curvature of the root canals (3, 8, 41). Nevertheless, these instruments should be used with some caution and should be withdrawn as soon as the apical endpoint of instrumentation is reached. Otherwise, an overpreparation might result with the risk of apical canal transportation (8, 72). Also, apical preparation with rotary instruments having tapers >0.04 should be avoided as canal transportation toward the outer aspect of the curvature might result (73).

**Clinical studies**

On a qualifying note, evidence from clinical studies is currently scarce (Table 2) and therefore conclusions should be drawn with some caution.

A total of 520 root canals with various degrees of curvature were treated by supervised dental students using either a reaming or a filing technique with stainless-steel Reamers and Hedstroem files, respectively (74). Canal straightening was more pronounced in the root canals prepared according to the reaming technique, whereas perforations in the apical part of the root canals were more often found with the filing technique (74).

More recently, senior students prepared a total of 221 root canals in patients either by hand with stainless-steel K-files using the step-back technique or by rotary instrumentation with nickel–titanium files. While the incidence of canal transportation was low for the rotary nickel–titanium instruments (3%), 20% of the canals were transported when using stainless-steel instruments with the step-back technique (25).

In a further clinical study, 60 molar teeth in patients were treated by inexperienced dental students using nickel–titanium 0.02 taper and stainless-steel K-files hand instruments. All root canals were enlarged according to the step-back technique, and canal straightening was defined as the difference between pre-operative and post-operative canal curvature (52). Significantly less canal straightening (P<0.001) was caused by nickel–titanium than by stainless-steel instruments.

Subsequently, the same group of researchers published a further investigation (75) comparing the 1-year success rates of the same teeth used in the aforementioned study. The comparison of success rate was based primarily on radiographic interpretation of the periapical status of the teeth. A significantly better success rate for teeth prepared with nickel–titanium than with stainless-steel K-files was observed (P<0.03). The authors concluded that maintaining the original canal shape leads to a better prognosis for the endodontic treatment (75).

A recently published study compared the canal straightening of teeth prepared by dentists experienced in endodontics using different hand instruments and the rotary nickel–titanium FlexMaster system (VDW, Munich, Germany) (26). Hand instruments produced a more pronounced straightening of the curved canals than the FlexMaster files. Overall, the original curvature of the root canals was significantly better maintained with automated FlexMaster files than with hand instruments. The authors hypothesized that the hand instrumentation left the possibility of the canal space being inadequately debrided of vital or necrotic pulp tissue, which might result in an inadequate obturation of the root canal space (26).

**Clinical consequences of canal transportation: insufficient cleaning**

A consecutive clinical problem of canal transportation is that a part of the original root canal will remain unprepared and thereby insufficiently cleaned (4) (Fig. 13). Post-operative canal cleanliness in extracted human teeth has been investigated histologically and under the SEM using longitudinal and horizontal sections (4). More recently, three-dimensional analyses using micro-computed tomography were used for more accurate evaluation of post-operative canal shapes (3).

Analyses of cross-sections indicate that usually 60–80% of the root canal outlines were touched by root canal instruments during the instrumentation procedure (76, 77). This is in agreement with results obtained from longitudinal sections showing that neither instrumentation technique was totally effective in cleaning the entire root canal space (33, 35, 39, 42, 44–49, 78, 79). After instrumentation of curved root canals in extracted teeth, both rotary nickel–titanium instruments and stainless-steel hand instruments left uninstrumented canal areas with debris remaining behind, especially in the apical third of the root canal (33, 35, 39, 44–46, 48). These observations were
supported by micro-CT data. Both stainless-steel K-files and modern rotary nickel–titanium instruments left about 35% of the canal wall surface untouched (46). In general, the amount of prepared root canal surface seemed to be independent of the instrument type used but was significantly affected by pre-operative canal anatomy (80–82).

Keeping these data in mind, it becomes evident that, when treating an infected root canal, transportation may further increase the amount of residual infected debris in the uninstrumented portion of the root canal (Fig. 14). Canal transportation will jeopardize the ability of the subsequent instruments with greater diameters to clean the inner aspect of the apical curvature and the outer aspect of the middle part of the canal, especially when already established during the initial enlargement of the root canal when the first instruments are inserted to the full working length. Thus, canal transportation may result in insufficient cleaning because of the inability to eliminate intra-radicular micro-organisms from the infected root canal systems. In particular, canal sections opposite to the regions, which in the case of canal transportation are characterized by typically overreduction of dentin, may harbor great amounts of residual debris.

In summary, it remains questionable whether canal transportation might be the direct cause of treatment failure. Rather, in infected root canals, tissue remnants and remaining micro-organisms might impede the outcome.

Clinical consequences of canal transportation: overreduction of radicular dentin

Canal transportation is defined as any undesirable deviation from the natural canal path (3). In curved canals, the outside (convex) wall of the apical portion may be overinstrumented and healthy dentin may be unnecessarily removed. The inside (concave) wall may be untouched and infected dentin may remain (83). This can result in inadequately cleaned root canals, with the possible outcome of persistent apical lesions, but also in strip perforations of the lateral root canal
wall and, due to the unnecessary removal of healthy dentin, in weakening of the entire root (3, 24).

**Fracture resistance**

It is generally accepted that the strength of an endodontically treated tooth is directly related to the amount of remaining sound tooth structure (84–88). With regard to fracture resistance, intact roots are significantly stronger than instrumented roots. Instrumentation alone can significantly weaken the roots (89). Also, roots enlarged using instruments with a 0.12 taper are weaker than those prepared with hand instruments (taper 0.02). Zandbiglari et al. (90) found an *in vitro* loss of fracture resistance of 25% after hand instrumentation (taper 0.02), 22% after enlargement with FlexMaster (taper 0.02–0.06), and 43.7% after preparation with GT files (taper 0.04–0.12) compared with intact control teeth. Thus, roots enlarged with instruments with greater tapers were more prone to fracture than those prepared with instruments with smaller tapers. The reason for the lower fracture resistance of roots prepared with a greater taper is probably that more dentin is removed. The amount of remaining dentin thickness significantly affects the resistance to fracture of prepared root canals (86).

Root canals unquestionably need to be opened coronally to a certain extent and the entire root canal should be adequately tapered (conical shape) in order to allow effective irrigation and to facilitate obturation, but overenlargement of the root canal must be avoided to prevent unnecessary weakening of the root (91). Residual dentin width should be preserved as much as possible so as not to compromise tooth integrity (88).

Although scientific evidence is lacking, common sense suggests that severe canal transportation associated with an overreduction of sound dentin along the inner aspect in the middle part and along the outer aspect in the apical part of the root canal may result in a marked reduction of the fracture resistance of enlarged root canals.

**Strip perforation**

Overpreparation of curved root canals along the inner side of the curvature can lead to strip perforation in the middle or the coronal part of the root canal (13, 92, 93). As long as straight root canals are treated, the incidence of perforation seems rather low. But as soon as curved canals are instrumented, the incidence of straightening and other procedural mishaps increases, especially if stainless-steel files are used (52). The authors compared the effects of stainless-steel and nickel–titanium hand instruments by students on the extent of straightening and on other endodontic procedural errors *in vivo*. In 10% of the root canals enlarged with stainless-steel K-files, strip perforations occurred, whereas none were observed with nickel–titanium instruments (52).

In a retrospective study, Eleftheriadis and Lambia-nidis examined the treatment outcome after *in vivo* root canal preparation by students and found root perforations in 2.7% of the cases. The root canal curvature was found to be the only statistically significant factor associated with root perforations (24).

Ouzounian and Schilder sectioned the distal roots of 20 endodontically treated mandibular molars at 3, 5, and 7 mm from the apex and found the average furcal side dentin thickness to be <0.8 mm at all three levels (94). Kuttler et al. examined the residual dentin thickness in distal roots of *in vitro* mandibular molars after endodontic treatment. In 82% of the cases, the canal wall on the furcal side was thinner than 1 mm and in 17.5%, thinner than 0.5 mm, with an average of 0.708 mm (95). It was recommended that the residual dentin thickness after post-space preparation should be a minimum of 1 mm (96). Ouzounian and Schilder (94) as well as Kuttler et al. (95) showed that after sole root canal preparation (and before post-space preparation), residual dentin thickness can already be considerably less than 1 mm. Moreover, Berutti and Fedon compared the thickness of dentin–cementum on sections and radiographs and found that the amount of hard tissue was effectively about one-fifth less than that appearing on the radiograph (97). This again emphasizes the risk of root weakening and strip perforation during mechanical root canal preparation.

**Clinical outcome**

Although it is widely assumed that several aspects of canal preparation (such as the final preparation size, maintenance of the original canal curvature, and incidence of procedural errors) have a huge impact on the outcome of the endodontic therapy (3, 98), especially when treating infected root canals (94), little evidence is currently available supporting this
assumption. Of note, all laboratory and most clinical studies investigated the technical quality of root canal preparation and this might not necessarily result in a better prognosis for the teeth prepared without canal transportation.

Concerning the final apical preparation size, conflicting results have been reported (4, 95, 96). Recently, Ørstavik et al. (99) performed a multivariate analysis on treatment variables that may influence the outcome. Only a few variables affected the outcome, but apical extension showed no impact on treatment outcome in any group. The variables of significant impact were the age of the patient, periapical status, marginal support, overinstrumentation, apex-to-filling distance, and root filling density (99). Friedman (100) has pointed out that the inability to demonstrate differences in the prognosis with regard to apical preparation size may be due to the fact that both alternatives (extensive versus minimal enlargement of the apical part of the root canal) are associated with certain problems. Wider apical preparation might result in some canal straightening and undesirable weakening of the tooth structure, whereas minimal enlargement may leave tissue remnants and infected dentin behind (3, 100). Thus, both alternatives have a certain risk of compromising the outcome to some extent. Nevertheless, it should be noted that most rotary nickel–titanium instruments allow wider apical preparations (even in severely curved root canals) than stainless-steel hand instruments without major preparation errors or over-reduction of radicular dentin (3, 4, 26). However, whether these properties automatically result in improved disinfection and thereby an enhanced prognosis currently remains an open question.

In a retrospective clinical study, 268 teeth with 661 root canals were instrumented with three different rotary nickel–titanium instruments, obturated, and radiographically assessed after a mean observation time of 27.1 months. No differences regarding the treatment outcome between the different instruments were observed (101). A radiographic and histopathologic evaluation of the effect of rotary nickel–titanium and manual stainless-steel K-files in dogs failed to show any significant impact of the instrumentation technique on the healing of the experimentally induced periapical lesions after an observation period of up to 12 days (102).

In contrast, two clinical studies indicate that prognosis may depend on the instrumentation technique (75, 103). In the first one, using stainless-steel instruments, treatment outcome was superior using the standardized compared with the serial technique (103). The second study used a prospective cross-over design to evaluate root canal treatment performed by undergraduate students. While the first part of this investigation (52) showed that canal curvatures were better maintained with nickel–titanium hand instruments than with stainless-steel ones, the second part (75) demonstrated a significantly better success rate for teeth prepared with nickel–titanium instruments at the 1-year recall. Hence, better maintenance of the original canal curvature was associated with a better prognosis.

Moreover, there is some evidence gained from laboratory studies that canal transportation is correlated with apical leakage. To some extent, obturated root canals showing transportation were associated with leakage, whereas canals with only minimal or no transportation were not (11, 104).

In summary, it can be concluded that canal transportation seems not to be the direct cause of reduced treatment outcome or even failure (98). Rather, this procedural error increases the risk of leaving behind infected tissue in the uninstrumented canal areas (12, 98). It seems reasonable that canal transportation is correlated with a huge amount of debris and microorganisms left in the apical portion of the root canal (12), especially when formed early in the shaping procedure. For instance, the first instruments of the preparation sequence create an overpreparation of the outer aspect of the curved root canal, leaving uninstrumented areas behind at the opposite side of the root canal (Fig. 14).

**Conclusion**

Canal transportation is an inherent problem when enlarging curved root canals, irrespective of the instrumentation technique or the type of instrument. In principle, canal transportation may result in (i) inadequately cleaned root canals, harboring debris and residual micro-organisms, (ii) overreduction of sound dentin with the possible outcome of reduced fracture resistance, and (iii) destruction of the integrity of the root, that is, an apical or strip perforation. Currently, evidence on the impact of these consequences of canal transportation on the clinical outcome is lacking. Also, at present, no evidence links reduced incidence of canal
transportation through nickel–titanium instruments with superior clinical success rates.

References


