One of the major challenges in endodontics is the enormous complexity of root canals. Among other things, a large number of difficulties must be overcome in terms of the number, position, possible branches and curvatures of the canals. Case studies are used to demonstrate how predictable treatment results can be achieved in adverse anatomies too.

The aim of root canal preparation is the complete removal of all vital and necrotic tissue, infected canal wall dentine, foreign matter and root filling material. Adequate chemical disinfection should be made possible and shaping should allow wall-to-wall obturation of the canal system. As early as 1974, Herbert Schilder published guidelines on this topic, which have virtually remained unchanged, including the creation of a continuously conical canal shape from the access cavity to the apex, respecting the course of the root canal and maintaining the position of the apical foramen at a size as small as practicable.1

In the presence of very pronounced curvatures, especially abrupt or even S-shaped (i.e. double) curvatures, it can prove extremely difficult to implement these...
guidelines. The angle of curvature is not the only factor here; the length of the distance after the curvature is also decisive for the demands on the instruments. As the degree of difficulty increases, the risk of step formation, splinting and instrument fracture quite naturally increases.

**Treatment planning**

Initial information is provided by the preoperative radiographic image. In complex anatomies, such as those that often occur in the posterior region, a CBCT scan provides valuable information on 3-D curvatures and the confluence of canals. This information is extremely important for treatment planning, as it allows the clinician to determine a strategy regarding the instruments to be used and canal preparation in advance. For example, very narrow, strongly curved roots should, if applicable, be prepared with a smaller ISO size or a slimmer taper, since even very flexible nickel-titanium (NiTi) file systems become significantly stiffer with increasing dimensions, which entails unwanted transportation or even strip perforations as risks. Each case should be considered individually to allow sufficient removal of infected tissue without risking unwanted excessive removal of dentine.

In vital cases, the size of the preparation may be more moderate than in cases of pulp necroses or revisions, as less removal of dentine will be required here. Ultimately, of course, the treatment size should be determined by apical gauging (apical measurement). As this is only practicable to a limited extent in the case of very extreme, even opposing curvatures, even more attention should be paid to tactile feedback during instrumental canal preparation. Sufficient preparation is always required for root canal irrigation and subsequent obturation so that a shape of at least size 30.04, or better of size 30.06 or 35.06 (rarely larger in the case of strong curvatures), which is usually required in extreme cases, must be prepared manually using the step-back technique. Otherwise, it will not be possible to achieve sufficient disinfection and filling of the root canal.

**Notes on preparation**

The preparation of an optimal primary and secondary access cavity is extremely important, particularly in the case of strong curvatures. Therefore, a most straight-line access to the canal system is very important, as otherwise steps or blockages are created right at the beginning of treatment that can only be corrected with great difficulty.

First, the course of the canal should be probed with an ISO size 6, 8 or 10 scouting file, if necessary, after coronal pre-flaring with an orifice shaper or Gates–Glidden drill. Irrespective of the file system used, the preparation of a glide path is essential for safe canal preparation. Particularly in the case of strongly curved, narrow canals, the use of rotary NiTi glide path files is not only less prone to complications than with manual instruments, but also
more comfortable. The gliding space created allows a significantly lower-risk use of the following rotary NiTi files for canal preparation.³

The point of confluence of canals represents a special case of curvature, as this often occurs particularly abruptly. It, therefore, makes sense, for example in the case of two canals in the mesial root of a mandibular first molar, to initially prepare only one canal fully to its working length. This will often be the mesiolingual canal. To determine the confluence, a gutta-percha point is then positioned in the prepared canal and a Kerr file is inserted into the other canal. The marking of the instrument tip in the gutta-percha point determines the length up to which the second canal must now be prepared. This avoids risky stressing of the instruments, as well as the unnecessary removal of dentine. Furthermore, the chemical preparation of the canal system is an indispensable part of the preparation, since only part of the canal wall surface is addressed during mechanical preparation.

Case 1: Pulp necrosis in an S-shaped canal
In November 2013, a 46-year-old emergency patient with acute symptoms of tooth #25 presented. The tooth had been restored with a ceramic inlay, the sensitivity test for cold was negative, and the tooth was sensitive to percussion and pressure. The preoperative radiograph revealed periapical periodontitis (Fig. 1). The diagnosis was pulp necrosis after a previous preparation close to the pulp. The inlay was removed and an adhesive pre-endodontic build-up was fabricated from composite. During trepanation, pus drained from the canal entrances. Working length was then determined, followed by initial preparation with Kerr files up to only ISO size 8, for time reasons, together with intermittent irrigation with heated 6% sodium hypochlorite (NaOCl). Subsequently, a drug deposit was inserted by rotating in Ledermix. Owing to the small preparation size, the use of calcium hydroxide would only have been possible to a limited extent.

Root canal therapy was continued approximately six weeks later: after anaesthesia and placement of a rub-
ber dam, tooth #25 was trepanned under the microscope (Fig. 2). The glide path was first prepared manually with C+ Files of ISO sizes 6 and 8 (Dentsply Maillefer), then mechanically with PathFiles of size 13, 16 and 19 (Dentsply Maillefer). The more flexible HyFlex Glidepath files (COLTENE) were not yet available at the time of treatment. A detailed image of the brand-new PathFile illustrated how extremely the S-shaped canal configuration had stressed the rotary NiTi instruments after a single use (Fig. 3). It depicted the plastic deformation of the instrument, a clear indication that this instrument could only withstand the requirements with good fortune. A fractured instrument would certainly have been within the realms of possibility.

After radiographic confirmation of the working length, the canals were prepared with the HyFlex CM (controlled memory) NiTi files (COLTENE; Figs. 4 & 5). The following sequence was used: 15.04, 20.04, 20.06, 25.04, 25.06, 30.04 and 30.06. Intermittent irrigation was again performed with heated 6% NaOCl.

After apical gauging, the final preparation was performed in steps of 0.5 mm from ISO size 35 to ISO size 60 using manual NiTi Kerr files in the step-back technique for safety reasons. Thus, a cone of ten was created in the apical region. Although possible in principle, the use of a 35.06 HyFlex CM was deliberately abstained from, as while these instruments offer high flexibility in general, the stiffness might still have been too great for the S-shaped course of the canals. Finally, irrigation was performed with a 17% EDTA solution and 6% NaOCl, activating the irrigation liquids by ultrasound.

After the master point try-in with configured gutta-percha points, warm vertical root canal filling was performed using the modified Schilder technique (Figs. 6–8). The tooth was sealed adhesively with composite and a glass-fibre pin (Fig. 9). Postoperative radiographs after one year and 4.5 years, respectively, showed the complete healing of the extensive osteolysis (Figs. 10 & 11).

Case 2: Pulpitis aperta of tooth #37

A 46-year-old patient presented with pulpitis complaints regarding tooth #37 in October 2013. The tooth had been restored with a partial gold crown, and the marginal seal was incomplete (Fig. 12). After local anaesthesia, the restoration and the cement build-up were removed. Underneath was the opening of the pulp chamber (Fig. 13). The diagnosis was pulpitis aperta. First, an adhesive, pre-endodontic composite abutment was created under rubber dam isolation. At the same time, the coronal pulp was removed during trepanation of the pulp chamber (Fig. 14). As pain treatment, Ledermix was applied as a drug owing to the time limitation, and the tooth was closed adhesively with composite.

Further treatment was performed in one visit in December 2013. After local anaesthesia, the drug was removed and the course of the canal was probed with C+ Files of ISO sizes 6, 8 and 10 under control of an endodontic motor. The radiographic confirmation of the working length showed a pronounced, abrupt curvature of
the canals in the apical third of the mesial root (Fig. 15). The glide path was prepared with PathFiles of sizes 13, 16 and 19, then expanded with ProTaper hand files S1 and S2 (Dentsply Maillefer), which were prebent with the Endo-Bender (Kerr). Rotary preparation was performed with the HyFlex CM.

In this case, the following sequence was used with ascending sizes and tapers: 15.04, 20.04, 20.06, 25.06, 30.04, 30.06 and 35.06. The path of the canal was manually expanded intermittently with prebent ProTaper hand instruments F1 to F3 and then perfectly shaped with the corresponding rotary HyFlex files, as the instruments were stopped in the mesial root by the speed limiter of the endodontic motor owing to the extreme curvature. The entire preparation was performed under intensive irrigation with heated 6% NaOCl. In addition, an ultrasound-activated final irrigation with 17% EDTA and NaOCl was performed three times for 20 seconds. After the master point try-in, the root canal was obturated vertically with warm gutta-percha using the modified Schilder technique (Figs. 16–18). Tooth #37 was sealed adhesively with a glass-fibre pin and composite (Fig. 19). Postoperative radiographic control after one year and approximately 4.5 years showed continued uneventful apical conditions (Figs. 20 & 21).

Discussion

These cases demonstrate that the safe preparation of even extreme curvatures is predictable owing to the use of highly flexible instruments such as the HyFlex CM.4
Meanwhile, additional instruments have become available in sizes 15.01, 15.02 and 20.02, as has HyFlex EDM size 10.05, which are superior to the files used at the time in terms of material properties and thus offer greater safety in difficult cases (Figs. 22 & 23). Furthermore, it can be seen that hybridisation with manual instruments can be helpful or even necessary to minimise the risk of fracture and to control abrupt curvatures. The file sequences used are of course material-intensive, especially since the files were discarded after use in each patient case. This procedure is costly, but offers the best possible safety to avoid cross-contamination and instrument fracture.

**Conclusion**

The postoperative radiographic checks after several years proved that even very complex anatomies can nowadays be treated safely, predictably and sustainably with suitable instruments. For the patient, this implies the long-term preservation of the natural dentition, even in challenging cases.

*Editorial note: A list of references is available from the author.*