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Dynamic recording of irrigating fluid distribution in root canals using thermal image analysis

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Abstract

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Aim To investigate the influence of the size and the depth of insertion of irrigating needles, and the diameter of the master apical file on flow distribution during fluid irrigation in root canals.

Methodology Stepback canal instrumentation was employed on seven extracted human single canal teeth. The size of the master apical files ranged from sizes 25, 30, 35, 40, 45, 50 to size 80 within the seven teeth, respectively. A thermal imaging system (*ThermaCAM*; National Instruments Co., Austin, TX, USA) was used to record the dynamic fluid distribution following root canal preparation. The dynamic fluid distribution was analysed during irrigation by insertion of different irrigating needle tips (23, 25 and 27 gauge) at various depths (3, 6 and 9 mm) from the root apex. The whole process of irrigation was recorded by a video camera and analysed by two observers separately. The success of the irrigation process was defined when the irrigant was able to flow into to the apical region immediately after injection.

Results The aqueous irrigant was flushed into the apical region when a size 27 gauge irrigating needle was placed into a size 30 canal at a point 3 mm from the apical stop. When the same needle tip was placed 6 mm from the root canal apex, successful irrigation was achieved only in the canals prepared to size 50 or larger. When a size 25 gauge irrigating needle was placed 3 mm from the working length, the canal size had to be no <45 to allow for successful irrigation. When a size 23 gauge needle was placed at the same position, the canal needed to be prepared to size 50 to allow thorough irrigation of the apex. At 9 mm from the apical stop, none of the irrigating needles could achieve successful irrigation of any canal size.

Conclusion The flow distribution of root canal irrigation can be affected adversely by large diameter irrigating needles, by greater distances between the needle tip and the apical stop, and by narrow root canals.

Keywords: file diameter, irrigation, root canal surgery, thermal image analysis, tooth.

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Introduction

Thorough debridement of the root canal system is essential for successful root canal treatment (Moiseiwitsch & Trope 1998). Debridement involves instrumentation and irrigation and both appear equally important for a successful outcome (Gomes *et al.* 2003, Hülsmann *et al.* 2003a,b, Oncag *et al.* 2003, Teixeira *et al.* 2005). The efficacy of irrigation is influenced by many factors such as the diameter of the irrigating needle (Usman *et al.* 2004), the depth of the irrigating needle engaged in the root canal (Brown *et al.* 1995, Sedgley *et al.* 2005), the final size of the enlarged root canal (Coughlin 1976, Falk & Sedgley 2005), the

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viscosity of the irrigant (Coughlin 1976, Becker & Woollard 2001), the velocity of the irrigant at the tip of needle (Coughlin 1976, Moser & Heuer 1982, Becker & Woollard 2001) and even the orientation of the bevel on the needle (Coughlin 1976).

Radiography has been used to examine the efficacy of irrigation when removing radiopaque contrast medium from the prepared canals of extracted teeth (Ram 1977). Radiopaque contrast medium mixed with dentinal shavings has also been used in the canals of extracted teeth to evaluate the efficiency of irrigation (Abou-Rass & Piccinino 1982). The effectiveness of irrigation has also been examined by flushing bead-form gel from glass tubes (Chow 1983), or red food colour dye from resin blocks (Kahn *et al.* 1995). However, none of these methods is entirely satisfactory. For example, gravity prevents the canal from filling with a homogenous fluid, as the bead particles settle in the apical region. Radiographic images of radiopaque contrast medium exposed as the material clears from the canal are difficult to interpret. Simulation glass or resin canals differ from natural teeth in surface roughness and in how they interact with the irrigant solution. Moreover, previous studies have failed to examine the depth of the irrigating needle in the root canal, and have only examined the final static condition rather than the dynamic processes occurring in fluids during irrigation.

Infrared image techniques have been applied for the detection of skin temperature on the dorsal surface of hands of different office workers (Gold *et al.* 2004), the visualization of temperature distribution on oral tissues (Komoriyama *et al.* 2003), and for obtaining intraoperative real-time physiological, anatomical and pathological information using high-resolution dynamic infrared imaging (Ecker *et al.* 2002). Thermal image analysis systems have been used to measure radiated infrared energy of irrigant solution and converted the data to corresponding images of temperatures (Campbell *et al.* 2003, Sherar *et al.* 2004, Chiu *et al.* 2005, Straume *et al.* 2005). It has also been used in analysis of temperature rise on the root surface during the continuous wave of condensation technique (Mc Cullagh *et al.* 2000). This non-contact measurement technology can measure dynamic flow distribution change in root canals simultaneously.

To investigate the impact of the size of irrigating needle, the depth of irrigating needle insertion, and the size of enlarged root canals on the flow distribution of irrigant solution, a thermal image analysis system was applied to record dynamically the irrigation fluid distribution in prepared root canals.

Materials and methods

Following informed consent, seven extracted single canal teeth with intact pulps were collected. After access cavity preparation and pulp extirpation, the working lengths were determined radiographically. Stepback instrumentation of the canals was employed to achieve different sizes of master apical file ranging from size 25, 30, 35, 40, 45, 50 to size 80 within the seven teeth, respectively. Each apical foramen was sealed with paraffin wax and the tooth was fixed on a resin stand. Resin and dentine was removed to leave a thin layer of dentine overlying the root canal in order for heat transmission from the canal to be presented. Immediately below the root apex, infrared-reflective aluminium tape was placed as a baseline marker (Fig. 1a,b). The same set of enlarged root canals was used for subsequent tests. Three sizes of irrigating syringe needles (gauges 23, 25 and 27) were used at one of three different depths inside the root canals: 3, 6 and 9 mm from the apical stop.

Distilled water at 50 °C in a 10 mL syringe (Becton Dickinson Company, Franklin Lakes, NJ, USA) was used as the irrigant. The irrigation force was the same as that used clinically (approximately 20 N). All the teeth were cooled to 10 °C to enhance image resolution for the thermal image analysis by increasing the temperature difference between irrigant and tooth. The irrigant was delivered into the root canal using a syringe adapted with different irrigation needles (gauges 23, 25 and 27), and the waste solution was collected via a plastic suction tube on the coronal orifice of the root canal (Fig. 1a,b). The irrigation system was fixed using an adjustable holder. Changes in the flow of the fluid were recorded continuously using the camera of thermal image analysis system (*ThermaCAM*; National Instruments Co., Austin, TX, USA).

The test for each tooth was recorded three times, and consistent results acquired by two observers were deemed necessary for a successful procedure. The results were defined as positive or negative (Fig. 2a, d or b, e, respectively) according to the thermal image of the irrigating fluid in the apical region of root canal. When 50 °C irrigant (white thermal colour) flowed into the 10 °C root canal (black thermal colour), the white thermal colour image of irrigant appeared simultaneously. If the white colour in the apical part of the root canal reached to apex instantly and subsequently

(a)

(b)

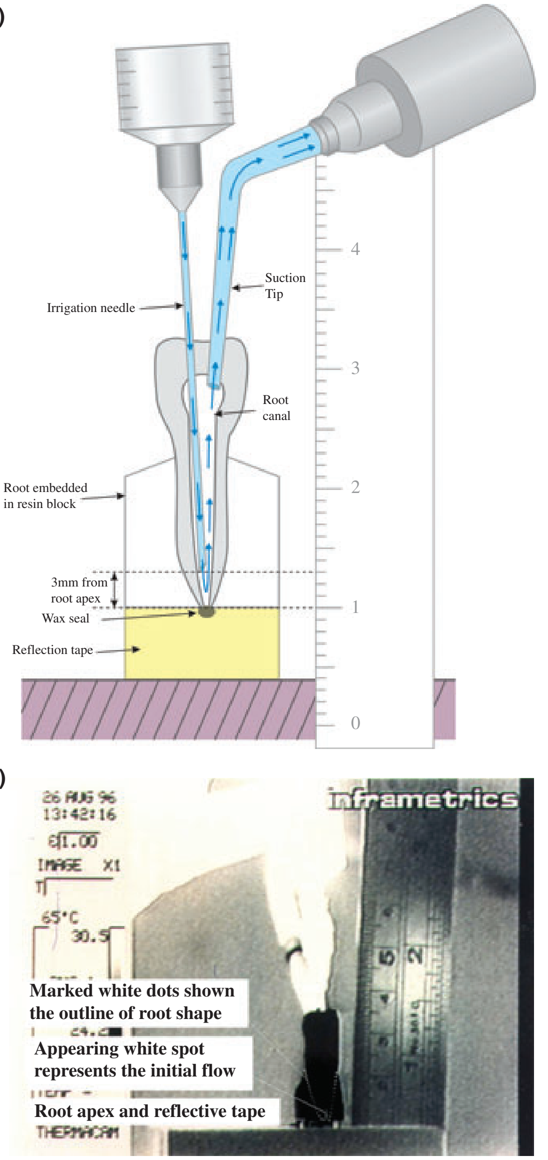

Figure 1 (a) Diagram of experimental apparatus illustrating that the canal apical foramen was sealed with paraffin wax and the tooth was fixed on a resin stand. The apical region was marked with infrared reflective aluminium tape. The irrigating needles were engaged 3, 6 or 9 mm from root apex. (b) Photograph retrieved from the dynamic recorded tape demonstrated the experimental apparatus. The measured thermal colour ranged from −10 °–60 °C reflecting from black to white, respectively. Irrigant temperature was 50 °C and the tooth/resin stand was cooled to 10 °C.

extended to the rest of the root canal space, this was defined as a positive result (Fig. 2d). This was interpreted as the flow of irrigant from the needle tip reaching the canal apex instantly. After that, the irrigant current flowed out of the canal orifice and was removed (Fig. 2a). When the white colour emerged at the needle tip (3, 6 or 9 mm from the apex of root canal) but then flowed backward, and exited the canal to leave a black colour in apical canal region, a negative result was recorded.

Results

The results are summarized in Fig. 3 and Table 1 and illustrated according to the final master apical file size of the root canal.

Canal size 25

None of the irrigation needles (27 gauge, 25 gauge and 23 gauge) was able to be placed at 3 or 6 mm from the apical stop of the root with a canal of size 25. For all needle sizes, negative results were observed while the distance from apical stop was 9 mm.

Canal size 30

The irrigant flowed into the apex successfully when a size 27 gauge needle was inserted 3 mm from the apical stop. A size 23 or 25 gauge needle was not able to reach the point 6 or 3 mm from canal apex. Negative results were observed with other combinations of needle sizes and distances to apex even when the needle tip was able to reach to the position.

Canal size 35

The irrigant flowed into the canal apex successfully when a size 27 gauge needle was inserted 3 mm from apical stop. Neither a size 25 nor 23 gauge needle was able to pass 3 mm from the canal apex. At 6 or 9 mm from the apex, no irrigation fluid was able to flow into canal apex with any of the three needle sizes.

Canal size 40

Similar result was noted as for canal size 35 except that a negative result was observed with a size 25 gauge needle inserted 3 mm from canal apex.

Canal size 45

Irrigant flowed into the apex if a size 27 or 25 gauge needle was placed 3 mm from the apex. For other

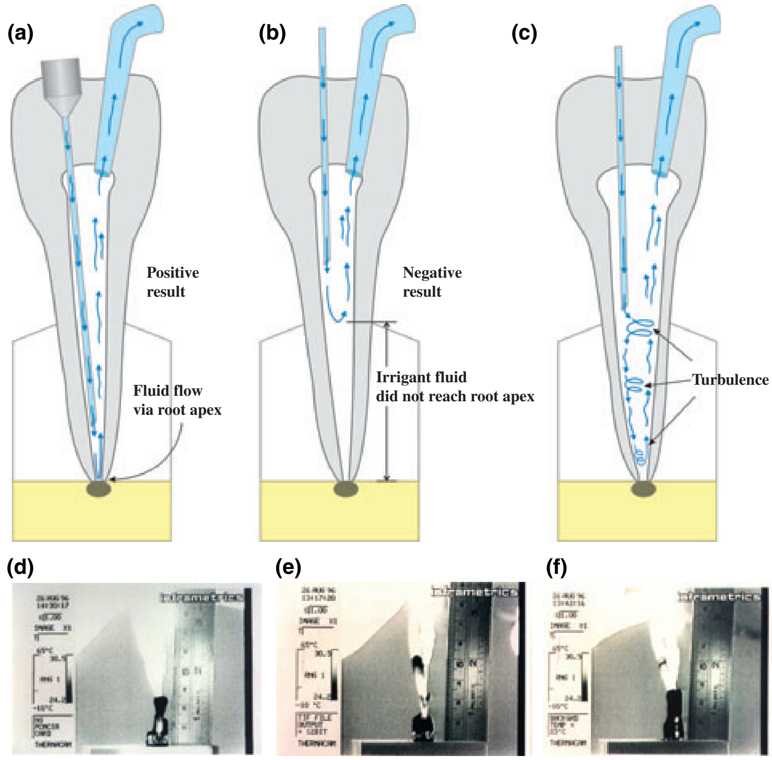

Figure 2 (a–c) Diagrams illustrating the positive, negative and turbulence results in thermo-images respectively. (d–f) Photographs retrieved from the dynamic recorded tape demonstrated the thermal image of positive, negative and turbulence results respectively.

combinations of different irrigation needle sizes and different depths of insertion, fluid failed to flush into the apical region. A size 23 needle could not be placed 3 mm from the apex.

Canal size 50

When a size 27 gauge needle was inserted 3 or 6 mm from apex, or a size 25 or 23 gauge needle inserted 3 mm from apex, successful fluid distribution into the apex was noted. Under other conditions, the irrigant was unable to flow into the apical region.

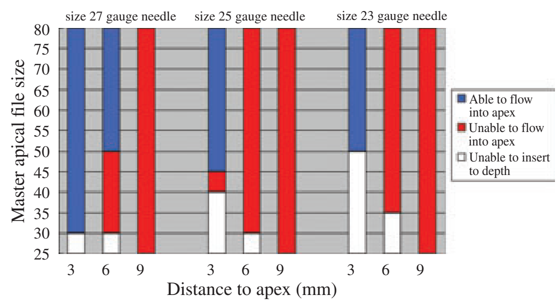

Figure 3 The bar chart illustrates the influence of irrigation needle size, distance to apex and file diameter on the flow distribution of root canal irrigant.

Canal size 80

All three sizes of gauge needles were able to reach 3, 6 or 9 mm from the apex. However, turbulence occurred as the fluid flowed backward toward the orifice of the canal immediately after reaching the apex (Fig. 2c,f).

In summary, successful irrigation was achieved more frequently using a 27 gauge needle with its tip inserted close to the apical stop. On the other hand, root canals prepared to larger diameters (≧ size 50) were adequately irrigated by any size of needle inserted 3 mm from the apex. When the needle was withdrawn to 6 mm or further away from the apical stop, it was not possible to obtain satisfactory irrigation by any combination of irrigation needle and diameter of enlarged root canal, with the exception of a 27 gauge needle used for irrigating canals enlarged to size 50 or larger within 6 mm from the apex.

Table 1 The flow of irrigant in canals of different sizes using various sizes of needle engaged at several distances from the apex

	23 Gauge needle			25 Gauge needle			27 Gauge needle		
Depth to apex canal size	3 mm	6 mm	9 mm	3 mm	6 mm	9 mm	3 mm	6 mm	9 mm
25	NA	NA	N	NA	NA	N	NA	NA	N
30	NA	NA	N	NA	N	N	P	N	N
35	NA	N	N	NA	N	N	P	N	N
40	NA	N	N	N	N	N	P	N	N
45	NA	N	N	P	N	N	P	N	N
50	P	N	N	P	N	N	P	P	N
80	P	N	N	P	N	N	P	P	N

NA, the diameter of apical canal size was too narrow for the needle tip to enter; P, positive result; irrigant was able to flow into the canal apex; N, negative result; irrigant was not able to flow into the canal apex.

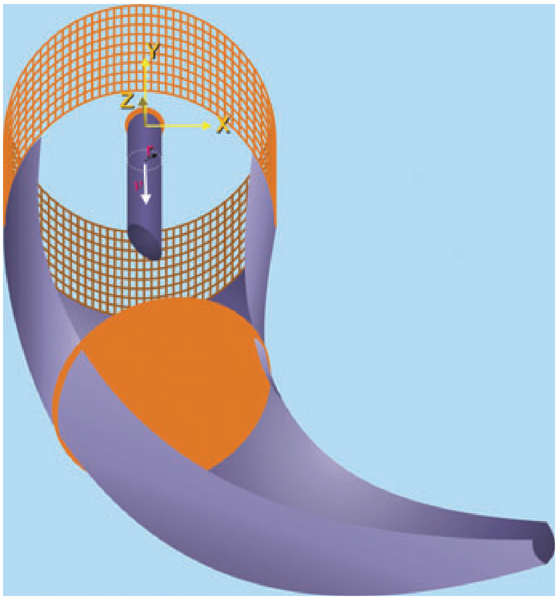

Figure 4 The model wind tunnel mimics a curved root canal system. *X*, *Y* and *Z* indicate the three-dimensional position of an irrigant needle engaged in the root canal; γ is the radius of needle and υ is the velocity of the irrigation fluid.

Discussion

With the limitation of available techniques to analyse the dynamic distribution of irrigation fluid in prepared root canals, few studies have examined the delivery of irrigation fluid in root canals, or have tested the effectiveness of irrigation instruments (Ram 1977, Abou-Rass & Piccinino 1982, Chow 1983, Kahn *et al.* 1995). Moreover, no reports have established the requirements for successful flow of irrigant. The application of a thermal image analysis system to measure radiated infrared energy of irrigant and convert the data to corresponding images of temperatures is a valuable approach. The dynamic flow of irrigant in root canals was clearly observed and measured by the technique used in this study, especially when the overlying dentine was thin. Although this *in vitro* study model showing thermal differences between irrigant (50 °C) and experimental teeth (10 °C) may not actually replicate the intraoral situation, it largely overcomes the insufficiencies of previous experimental methods.

The results of this study showed that flow of irrigation approached the apex in large root canals and when the irrigating needle tip was placed close to the root apex. Successful irrigation of a root canal prepared with a size 30 to size 40 master apical file required a 27 gauge irrigating needle to be placed 3 mm away from the apex. A root canal prepared with a size 45 master apical file was successfully irrigated with a 27 gauge needle tip placed 3 or 6 mm or with a 25 gauge needle placed 3 mm from the apex. When the root canal preparation was increased to size 50 master apical file or larger, it was necessary to use either a 27 gauge needle at 3 or 6 mm, a 25 gauge needle at 3 mm, or a 23 gauge at 3 mm from root apex for irrigation. Thus, for the narrower root canals, a finer needle inserted closer to the apex was necessary for efficient root canal irrigation (Fig. 3).

With very wide root canals (prepared with a size 80 master apical file), turbulence (Fig. 2c) was observed in the irrigation fluid. Such turbulence may cause dentinal chips and microorganisms to be retained in the root canal, with impaired efficiency of irrigation. The flow of any fluid becomes turbulent when the Reynolds number, *R*, exceeds a certain critical value, where *R* depends upon the specific gravity σ, the viscosity η, the velocity υ of the fluid, and the radius γ of the tube through which the fluid flow. Empirical evidence shows that, in certain systems, when it is assumed that σ, η, υ, and the total volume of irrigant C, flowing through the

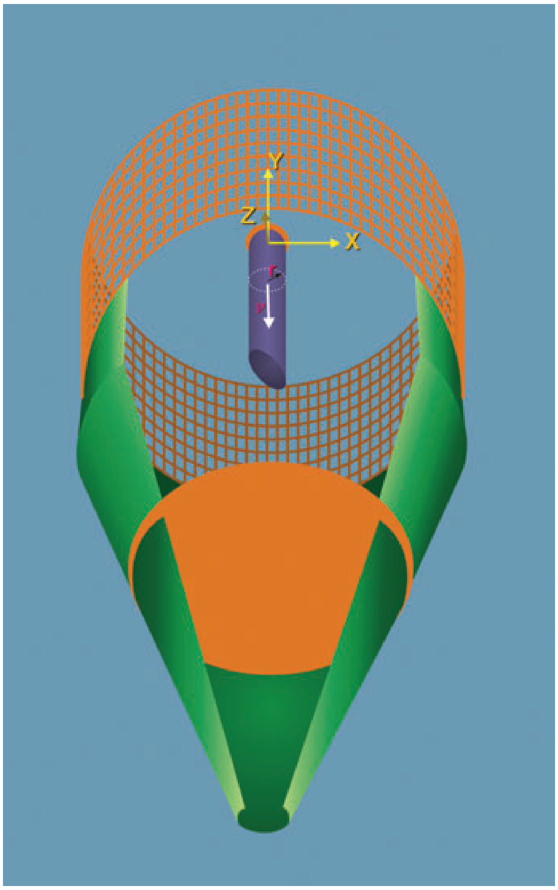

Figure 5 The model wind tunnel mimics a straight root canal system. X, Y and Z indicate the three-dimensional position of an irrigatant needle engaged in the root canal; γ is the radius of needle and υ is the velocity of the irrigation fluid.

canal chamber are constant, the values of R for which non-turbulent flow is maintained are given by $R(r) = \sigma/\pi\eta \ln\gamma - B\gamma$, where B is a constant depending upon the particular fluid and system in question (Coughlin 1976).

The root canal system can be modelled as a wind tunnel (Figs 4 and 5), where the speed of irrigating fluid injected from the needle tip (related to υ), the viscosity of the irrigant (related to η), the roughness of the canal wall, the orientation of the bevel of irrigating needle tip, the position of the irrigating needle tip inside the canal, and the curvature of the root canal system will all influence fluid distribution around the root canal. This can explain the phenomenon of turbulence in wide root canals (e.g. size 80) found in this study. A previous study (Kahn *et al.* 1995) also reported that even with ultrasonic and subsonic hand pieces, irrigation was less effective in the apical portion of canals prepared by large size files. Large master apical files are beneficial to successful irrigation in instrumented root canals, but very large tools (i.e. size 80 or above) cause turbulence and incomplete root canal irrigation. Further studies on the effectiveness of root canal irrigation should address these hydrodynamic aspects if they are to achieve a thorough understanding of the dynamics of irrigation fluid distribution in root canal systems.

Conclusions

Root canal irrigation was affected by the diameter of the irrigating needle, the depth of the irrigating needle engaged in the root canal and the final size of the root canal preparation. Needles of larger diameter placed further from the root apex, used in conjunction with a narrow master apical file, were less efficient. This prevents the irrigation fluid from flushing into the root canal apex region. The wind tunnel concept is a valuable model in the study of the hydrodynamic changes occurring during the irrigation of root canals.

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References

Abou-Rass M, Piccinino MV (1982) The effectiveness of four clinical irrigation methods on the removal of root canal debris. *Oral Surgery, Oral Medicine, Oral Pathology* **54**, 323–8.

Becker TD, Woollard GW (2001) Endodontic irrigation. *General Dentistry* **49**, 272–6.

Brown DC, Moore BK, Brown CE Jr, Newton CW (1995) An in vitro study of apical extrusion of sodium hypochlorite during endodontic canal preparation. *Journal of Endodontics* **21**, 587–91.

Campbell PA, Cresswell AB, Frank TG, Cuschieri A (2003) Real-time thermography during energized vessel sealing and dissection. *Surgical Endoscopy* **17**, 1640–5.

Chiu WT, Lin PW, Chiou HY et al. (2005) Infrared thermography to mass-screen suspected SARS patients with fever. *Asia Pacific Journal of Public Health* **17**, 26–8.

Chow TW (1983) Mechanical effectiveness of root canal irrigation. *Journal of Endodontics* **9**, 475–9.

Coughlin R (1976) Applications of the derivative. In: Coughlin R, ed. *Applied Calculus*, 1st edn. Boston, MA: Allyn and Bacon, pp. 110–1.

Ecker RD, Goerss SJ, Meyer FB, Cohen-Gadol AA, Britton JW, Levine JA (2002) Vision of the future: initial experience with intraoperative real-time high-resolution dynamic infrared imaging. Technical note. *Journal of Neurosurgery* **97**, 1460–71.

Falk KW, Sedgley CM (2005) The influence of preparation size on the mechanical efficacy of root canal irrigation in vitro. *Journal of Endodontics* **31**, 742–5.

Gold JE, Cherniack M, Buchholz B (2004) Infrared thermography for examination of skin temperature in the dorsal hand of office workers. *European Journal of Applied Physiology* **93**, 245–51.

Gomes BP, Souza SF, Ferraz CC et al. (2003) Effectiveness of 2% chlorhexidine gel and calcium hydroxide against Enterococcus faecalis in bovine root dentine in vitro. *International Endodontic Journal* **36**, 267–75.

Hülsmann M, Gressmann G, Schafers F (2003a) A comparative study of root canal preparation using FlexMaster and HERO 642 rotary Ni–Ti instruments. *International Endodontic Journal* **36**, 358–66.

Hülsmann M, Herbst U, Schafers F (2003b) Comparative study of root-canal preparation using Lightspeed and Quantec SC rotary NiTi instruments. *International Endodontic Journal* **36**, 748–56.

Kahn FH, Rosenberg PA, Gliksberg J (1995) An in vitro evaluation of the irrigating characteristics of ultrasonic and subsonic handpieces and irrigating needles and probes. *Journal of Endodontics* **21**, 277–80.

Komoriyama M, Nomoto R, Tanaka R et al. (2003) Application of thermography in dentistry–visualization of temperature distribution on oral tissues. *Dental Materials Journal* **22**, 436–43.

Mc Cullagh JJ, Setchell DJ, Gulabivala K et al. (2000) A comparison of thermocouple and infrared thermographic analysis of temperature rise on the root surface during the continuous wave of condensation technique. *International Endodontic Journal* **33**, 326–32.

Moiseiwitsch JR, Trope M (1998) Nonsurgical root canal therapy treatment with apparent indications for root-end surgery. *Oral surgery, Oral Medicine, Oral Pathology, Oral Radiology, Endodontics* **86**, 335–40.

Moser JB, Heuer MA (1982) Forces and efficacy in endodontic irrigation systems. *Oral Surgery, Oral Medicine, Oral Patholog* **53**, 425–8.

Oncag O, Hosgor M, Hilmioglu S, Zekioglu O, Eronat C, Burhanoglu D (2003) Comparison of antibacterial and toxic effects of various root canal irrigants. *International Endodontic Journal* **36**, 423–32.

Ram Z (1977) Effectiveness of root canal irrigation. *Oral Surgery, Oral Medicine, Oral Pathology* **44**, 306–12.

Sedgley CM, Nagel AC, Hall D, Applegate B (2005) Influence of irrigant needle depth in removing bioluminescent bacteria inoculated into instrumented root canals using real-time imaging in vitro. *International Endodontic Journal* **38**, 97–104.

Sherar MD, Gladman AS, Davidson SR, Easty AC, Joy ML (2004) Infrared thermographic SAR measurements of interstitial hyperthermia applicators: errors due to thermal conduction and convection. *International Journal of Hyperthermia* **20**, 539–55.

Straume A, Oftedal G, Johnsson A (2005) Skin temperature increase caused by a mobile phone: a methodological infrared camera study. *Bioelectromagnetics* **26**, 510–9.

Teixeira CS, Felippe MC, Felippe WT (2005) The effect of application time of EDTA and NaOCl on intracanal smear layer removal: an SEM analysis. *International Endodontic Journal* **38**, 285–90.

Usman N, Baumgartner JC, Marshall JG (2004) Influence of instrument size on root canal debridement. *Journal of Endodontics* **30**, 110–2.