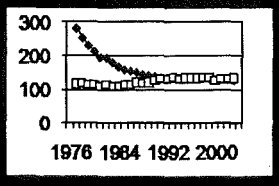
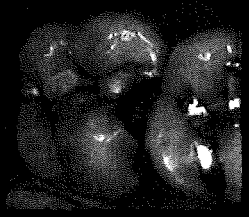
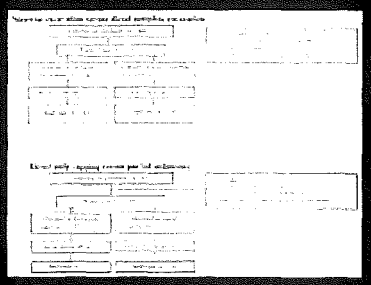
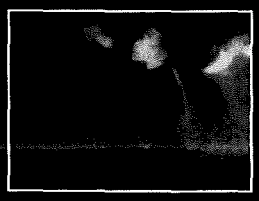
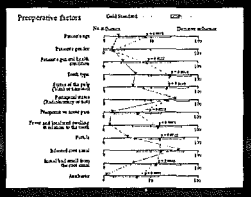
Endodontic treatment: reasons, prevention and quality-shaping factors

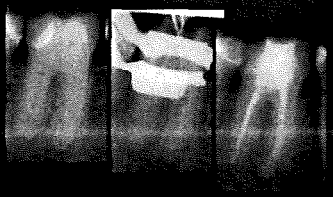












LARS BJØRNDAL

FACULTY OF HEALTH SCIENCES
UNIVERSITY OF COPENHAGEN
DEPARTMENT OF ODONTOLOGY

Denne afhandling er af Det Sundhedsvidenskabelige Fakultet ved Københavns Universitet antaget til offentligt at forsvares for den odontologiske doktorgrad.

København den 27 december 2010.

Ulla Wewer
Dekan

Forsvaret finder sted fredag den 27 maj 2011 kl. 14 i Victor Haderup Auditoriet, Panum Instituttet, Københavns Universitet, Blegdamsvej 3, 2200 København N.

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Endodontic treatment: reasons, prevention and quality-shaping factors

LARS BJØRNDAL

Section of Cariology and Endodontics
Department of Odontology
Faculty of Health Sciences
University of Copenhagen
Denmark 2011

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quality-shaping factors

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Preface

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Preface

The present dissertation has been carried out during the period 2002-2010 in the Section of Cariology and Endodontics, Department of Odontology, Faculty of Health Sciences, University of Copenhagen, Denmark.

I'm deeply grateful to prof., odont. dr. Claes Reit, Institute of Odontology, The Sahlgrenska Academy at Gothenburg, University of Gothenburg, Sweden, for his collaboration and support from the very beginning.

The Danish Dental Association and the Copenhagen Dental Association are highly acknowledged for their positive collaboration, and thanks to all the General Dental Practitioners. Chief advisor Christian Holt from the Danish Dental Association is kindly acknowledged for his assistance. The Danish National Health Insurance is acknowledged for the collaboration with the access to data on claims in dentistry.

Prof. Niels Keiding, Section of Biostatistics, Department of Public Health, University of Copenhagen, is truly acknowledged for the collaboration about analysis of data from the questionnaires and the dental service register.

I'm highly grateful to assoc. prof., dr. med. Christian Gluud, head of The Copenhagen Trial Unit (CTU), Centre for Clinical Intervention Research, Rigshospitalet, Copenhagen University Hospital, Copenhagen, for his great support during the running of the clinical trials, and together with dr. med. Per Winkel (CTU) their collaboration is highly appreciated, including acknowledgements to the CTU staff.

DDS, PhD Student Merete Markvart and DDS Gitte Bruun are acknowledged for the teamwork and Else Lykke Bjerre for the organizing of many patient visits.

Thanks to my co-authors for all your valuable contributions, I'm very grateful for that.

The staff of the Section of Cariology and Endodontics in Copenhagen is acknowledged for support during the years. Many thanks for data management and practical help to secretary Eva-Marie Reinwald, and laboratory technologists Ulla Larsen and Helga Givskov. Thanks for inspiring discussions with my colleagues of many years Deputy Head of Department assoc. prof., PhD Kim Ekstrand and assoc. prof., dr. odont. Vibeke Qvist, and to Senior Dentist Ulla Pallesen and prof., odont. dr. Svante Twetman for critical comments.

Financial support is acknowledged from the Danish Agency for Sciences and Innovation and the Danish Regions. Plandent, KerrHawe, 3m Espe, LM-instruments, Dentsply, DeTrey Dentsply, and Gedr. Brassler are acknowledged for providing trial products.

Last but not least, thanks to my wife Vibe for always giving me invaluable support and sharing life with me and our children Mikkel, Marie and Jonas.

Lars Bjørndal Copenhagen 4 June 2010

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I. Bjørndal L, Reit C (2004) The annual frequency of root fillings, tooth extractions and pulp-related procedures in Danish adults during 1977-2003. *International Endodontic Journal* **37,** 782-8.

II. Bjørndal L, Laustsen MH, Reit C (2006) Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. *International Endodontic Journal* **39**, 785-90.

III. Bjørndal L, Reit C, Bruun G, Markvart M, Kjældgaard M, Näsman P, Thordrup M, Dige I, Nyvad B, Fransson H, Lager A, Ericson D, Petersson K, Olsson J, Santimano EM, Wennström A, Winkel P, Gluud C (2010) Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. *European Journal of Oral Sciences* **118,** 290-7.

IV. Bjørndal L, Reit C (2005) The adoption of new endodontic technology amongst Danish general dental practitioners. *International Endodontic Journal* **38**, 52-8.

V. Bjørndal L, Laustsen MH, Reit C (2007) Danish practitioners' assessment of factors influencing the outcome of endodontic treatment. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology* **103**, 570-5.

VI. Bjørndal L, Reit C (2008) Endodontic malpractice claims in Denmark 1995-2004. *International Endodontic Journal* **41**, 1059-65.

This dissertation will refer to the included publications using **Study I-VI**.

SETTING THE STAGE

Endodontics may be regarded as a set of procedures to either prevent or treat apical periodontitis (Ørstavik & Pitt Ford 2008). Although technically complicated, such measures, when carried out meticulously, have been found to produce successful results, in terms of apical healing, in 85% to 95% of treated teeth (Kerekes & Tronstad 1979, Petersson *et al.* 1982, Sjögren *et al.* 1990). On the other hand, epidemiologists have observed high frequencies of substandard root filling quality and radiographic signs of apical periodontitis in root-filled teeth. In Denmark, for example, Kirkevang *et al.* (2000) found that 59% of the root-filled teeth showed inadequate lateral seal and 40% displayed inadequate length. Furthermore, 52% of the treated teeth were associated with signs of apical periodontitis. Obviously there is a great discrepancy between healing rates that can be achieved with root canal treatment and those observed in many populations. This 'gap' was the starting point for the present dissertation and the overall aim was to reveal factors that influence the incidence and quality of root canal treatment in general dental practice.

Pulpal disease has mainly been regarded as a sequel to caries and therefore it might be expected that when caries prevalence decreases, as in Denmark, the demand for endodontic treatment also decreases. However, there is a lack of knowledge concerning the incidence over time (**Study I**) as well as the contemporary reasons for root canal treatment (**Study II**). Furthermore, the acceptance of modern strategies for treatment of deep caries lesions and exposed pulps among general dental practitioners (GDPs) may decrease the future need for root canal treatment (**Study III**).

Factors that influence the endodontic treatment quality in general dental practice are not very well known. Quality is shaped by the interplay between the knowledge, attitude and skill of the dentist and the demand and satisfaction of the patient, framed in a societal context of available resources, insurance and remuneration systems and ethical codes (Fig. 1).

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Some of these factors were approached in the present series of studies. Recent years have seen a technological breakthrough within the field of root canal treatment. For example, it has been suggested that the adoption of new technology such as nickel-titanium rotary instruments will facilitate negotiation of the root canal system and make practitioners more often produce high quality root canal treatments (**Study IV**). Studies have pointed out various biological and technical factors that are important for the outcome of endodontic therapy. However, to what extent this knowledge is appreciated and correctly used by GDPs is not well understood (**Study V**) and neither is their confidence in performing root canal treatments (**Study II**). The final part of the present dissertation addresses the interaction between the dentist and the patient from an ethical and communicative point of view. It was assumed that important aspects of this interaction could be revealed by studying malpractice cases (**Study VI**).

Lay-out of the dissertation

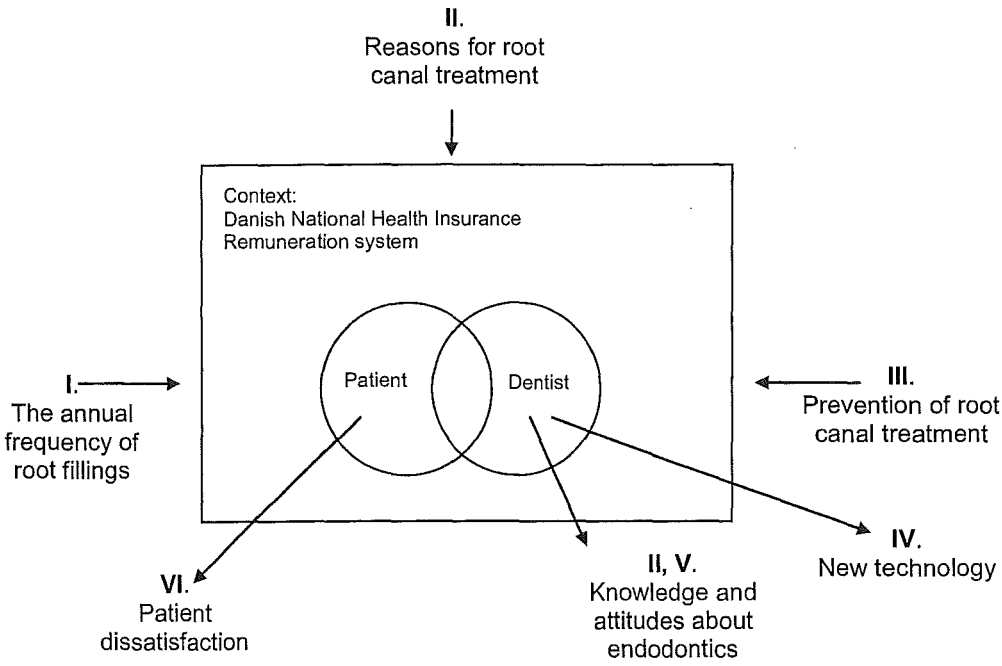

Fig. 1. In the interaction between the patient and the dentist the goal is to obtain the best treatment result. Within this context, the present dissertation has selected some factors (**I-VI**) which may determine the quality of root canal treatments and pulp-preserving procedures.

Frequency of endodontic treatment (Study I)

Cross-sectional studies on the frequency of root-filled teeth are typically based on randomized sub-populations (Allard & Palmqvist 1986, Eriksen *et al.* 1988, Ödesjö *et al.* 1990, Sidaravicius *et al.* 1999, Kirkevang *et al.* 2001), groups of university patients (Bergenholtz *et al. 1973)*, or patients referred to hospitals (Eckerbom *et al. 1987,* De Cleen *et al. 1993)*. The results of these studies disclose variations which may also arise from the selected tooth type, age of the individuals, other features of the examined population and period of observation. Moreover, a longitudinal interpretation in such cross-sectional studies should be carried out with caution (Kirkevang *et al.* 2006). The existence of large-scale population data on annual endodontic treatment statistics are rare but would provide some basis for making comparisons between the incidences of endodontic-related procedures performed in the past and today. The use of the dental service register from the

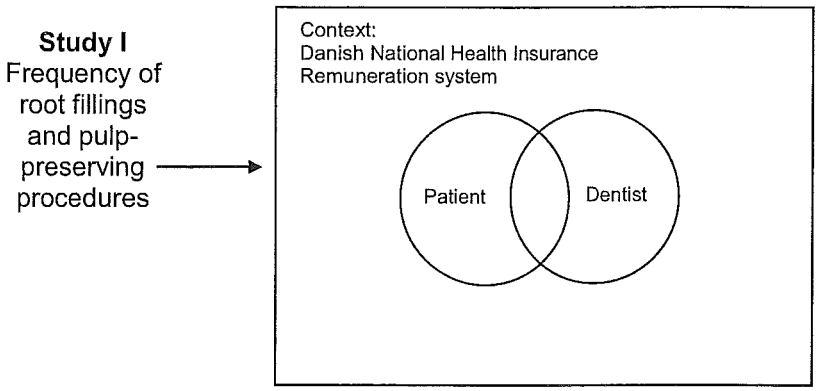

Fig. 2. In **Study I** the first factor chosen addresses frequency of endodontic treatments including tooth extractions.

Danish National Health Insurance provides treatment statistics over a 25-year period. In the past decades many countries including Denmark have seen a marked decline in caries activity (Marthaler 2004), and it could be expected that the need for endodontic treatment has been decreasing over the years.

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Hypothesis I:

The decline in caries prevalence should imply a decrease in the incidence of pulpal disease and subsequently a decrease in the annual number of endodontic treatments.

Aim I:

To describe the annual treatment frequency over 25 years in relation to root fillings, tooth extraction and pulp-related procedures.

Materials and Methods (Study I)

Danish dental treatment statistics have been available through the Danish National Health Insurance dental service register due to the fee-for-service system. This system has been based on an agreement between the National Health Insurance and the Danish Dental Association about the remuneration system for dental services. The Danish Dental Association has since 1977 collected treatment statistics as carried out by GDPs. Permission was obtained from the Danish Dental Association to access these records and to perform a search profile from these treatment statistics, which also contain patient age and sex. The search included the following treatment procedures:

a) Root fillings
b) Tooth extraction
c) Pulpotomy
d) Pulp capping
e) Stepwise excavation

Results (Study I)

Status of tooth extraction and endodontic treatment frequency

The vast majority of the Danish population is involved in the Danish National Health Insurance dental service register. Therefore, it is possible to make some generalizations. The annual number of root fillings during the 25-year period (1977-2003) had increased from 268,233 to 364,867 (36%) and the annual number of root-filled teeth increased from 160,119 to 191,803 (20%). During the same period, the annual number of registered patients increased by 16%. Expressed per 1000 patients the number of root fillings showed a statistically significant increase of 17%, where the

majority of root fillings was noted in adults between 40 and 59 years of age. The number of root-filled canals per tooth (ratio) increased from 1.67 to 1.96. Concomitantly, the annual number of tooth extractions was more than halved (Fig. 3). The number of pulpotomies was substantially reduced from 30,616 in 1977 to 2357 in 2003.

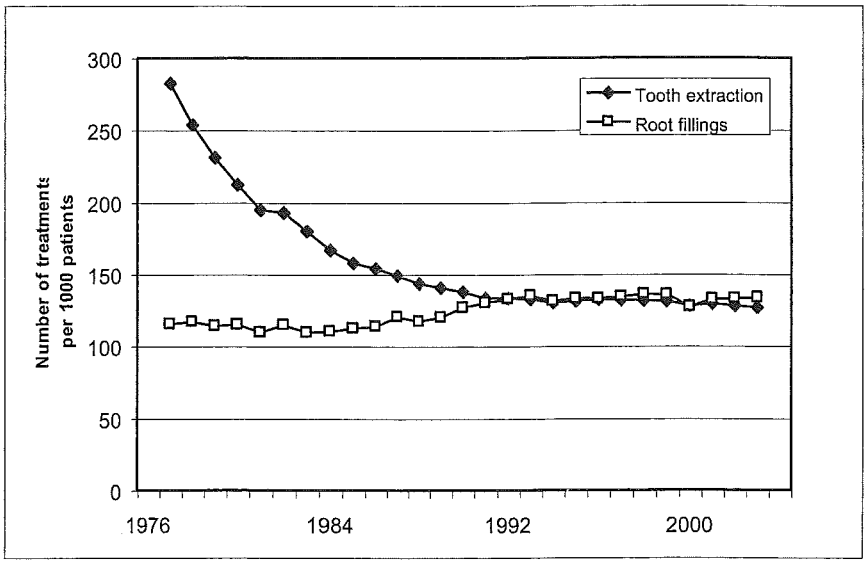

Fig. 3. The number of root fillings and tooth extractions per 1000 patients from 1977 to 2003. (Source: Fig. 2 from **Study I**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

Reasons for root canal treatment (Study II)

The main causes for the development of pulp disease are bacterial infection, traumatic and iatrogenic injuries following dental treatment procedures, of which the latter can be divided into preparation trauma, bacterial leakage and toxic effects of restorative materials (Olgart & Bergenholtz 2010).

Although caries generally is regarded as the main aetiological reason for pulpal injury (Trowbridge 2002), the demand for root canal treatment does not necessarily decrease in a population with a decreasing caries prevalence. The reason and

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indications for contemporary root canal treatment, as performed in general dental practice, are not well known.

Hypothesis II:

Caries is not the major reason for performing endodontic treatment.

Aim II:

To explore the reasons for performing endodontic treatment among 600 randomly selected GDPs.

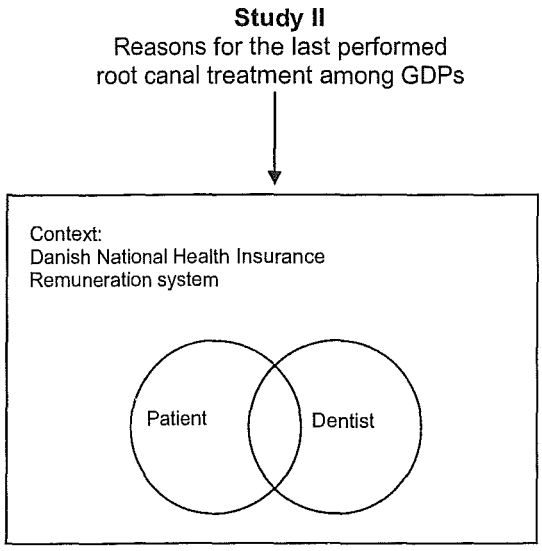

Fig. 4. The reasons for the last performed root canal treatment by the General Dental Practitioners (GDPs) are displayed in **Study II**.

Material and Methods (Study II)

GDP population

Questionnaires were sent to 600 Danish GDPs. The GDPs were randomly selected from the roster of the Danish Dental Association, which at that time listed 3293 members (2004). The selection was carried out with the agreement of the Danish Dental Association. The questionnaire was mailed together with a letter guaranteeing confidential and anonymous processing of the data and a stamped, coded return envelope. Non-responders were identified by the code and approached by a second mail. The responder was asked to recall the last endodontic treatment they had

undertaken and state the sex and age of the patient, the type of tooth treated, the reason for treatment and the pulpal diagnosis. The questionnaire also asked for responder demographical data: number of years in practice, employment status, weekly number of working hours as well as the time devoted to endodontic treatments. (These data is discussed in section 'Quality-shaping factors in endodontic treatments').

Results (Study II)

The final response proportion was 75.3% (n = 452). The most frequent reason (55% of all patients) for performing root canal treatment was caries and the majority involved vital pulp (54%). In the youngest patient group traumatic injury was the only reason for root canal treatment (Table 1). The Danish GDPs carried out retreatment in 2% of the patients. The reason was most often due to persistent apical inflammation or suboptimal root filling prior to prosthetic retention.

	Caries	Dentine cracks	Pain[a]	Trauma	Defective restoration	Prosthetic retention	Inadequate seal	Old/large restoration	Apical radiolucency	[b]	*n* (%)
0–15 years	0	0	0	3	0	0	0	0	0	0	3 (1)
16–19 years	4	0	1	1	0	0	0	0	0	0	6 (1)
20–29 years	48	3	0	4	2	2	1	1	0		61 (14)
30–39 years	73	11	12	7	4	1	1	2	1	0	112 (25)
40–49 years	51	21	8	7	4	3	5	2	2	1	104 (23)
50–59 years	48	18	10	5	6	4	2	2	2	2	99 (22)
60–69 years	15	4	5	6	3	4	2	2	2	1	44 (10)
70–79 years	9	2	1	2	0	0	2	0	0	0	16 (4)
80- years	0	0	0	0	0	4	0	0	0	0	4 (1)
No inf.	2	0	0	0	0	0	0	0	0	1	3 (1)
n (%)	250 (55)	59 (13)	37 (8)	35 (8)	19 (4)	18 (4)	13 (3)	9 (2)	7 (2)	5 (1)	452

[a]When pain could not be placed in relation to the other reasons listed.
[b]Other information.

Table 1. Distribution of number of root-filled teeth in relation to age of the patient and the aetiology of the root canal treatment (Source: Table 3, **Study II**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

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Apical radiolucency	[b]	*n* (%)
0	0	3 (1)
0	0	6 (1)
0		61 (14)
1	0	112 (25)
2	1	104 (23)
2	2	99 (22)
2	1	44 (10)
0	0	16 (4)
0	0	4 (1)
0	1	3 (1)
7 (2)	5 (1)	452

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Treatment of deep caries in adults - an endodontic preventive strategy (Study III)

Caries was still the major reason for performing root canal treatments in vital teeth (**Study II**), and it seems relevant to investigate the treatment of deep caries as an endodontic preventive strategy.

The treatment of deep caries lesions represents a dilemma between initiating pulp invasive procedures or preventing endodontic treatment (Bjørndal 2008). A deep carious lesion has been defined as a carious lesion where there is a risk of exposing the pulp during excavation (Fitzgerald & Heys 1991). Among general practitioners a deep caries lesion usually means that 75% or more of the dentin thickness is involved when examined using x-rays (Bjørndal & Thylstrup 1998). Findings from general practice in the USA indicate that radical treatment of deep carious lesions is preferred (Oen *et al.* 2007). One final complete excavation is chosen as the first choice of treatment, followed by endodontic treatment (Oen *et al.* 2007). Older studies have shown that the removal of carious dentin using a single excavation in the primary dentition leads to exposure in about half of the cases (Magnusson & Sundell 1977). A stepwise excavation of young permanent teeth performed during two visits seems to lead to fewer pulp exposures (Leksell *et al.* 1996) than direct complete excavation. A less invasive stepwise excavation approach in adults has shown that the caries progression is reduced as evidenced by a decrease of the cultivable microbial flora, and clinically demonstrated by a darker, dryer and harder surface of the retained carious dentin (Bjørndal *et al.* 1997, Orhan *et al.* 2008). A Cochrane review of caries excavation concluded that partial caries removal is preferable to complete caries removal in terms of risk for pulp exposure (Ricketts *et al.* 2006). However, none of the reviewed trials included well-defined deep lesions in permanent teeth in adults. In three of the trials the material comprised primary teeth (Magnusson & Sundell 1977, Ribeiro *et al.* 1999) or young permanent molars (Leksell *et al.* 1996). They also comprised different or not well-defined lesion sizes, probably because the actual aim in two of the trials was related to the quality of the restorations (Mertz-Fairhurst *et al.* 1998, Ribeiro *et al.* 1999). With only four included trials in the above mentioned Cochrane review, with a high risk of bias, there is a need to carry out new randomized clinical trials (Ricketts *et al. 2006,* Kidd *et al.*

2008). Another recent Cochrane review investigated the pulp management for caries in adults (Miyashita *et al.* 2007). Four trials were found suitable for inclusion, but again no definitive indication as to the most effective method of pulp treatment of carious teeth was found, and the review authors concluded that further well-designed trials are needed. Randomized trials are internationally considered the gold standard for comparing interventions (Gluud & Sørensen 1995, Chalmers 2001, Gluud 2006a) and at the top of the hierarchy of evidence (Sackett *et al.* 2000, Gluud 2006a, Gluud 2006b). Dental research in general is progressing towards adopting adequate trials, reducing the risk of systematic errors ('bias') and the risk of random errors ('play of chance') (Sjögren & Halling 2001), and utilising systematic reviews of such trials (Bader & Ismail, 2004). The strategy for managing deep caries and pulp inflammation has been expressed differently through the years (Bjørndal 2008). The variation may be related to: (i) lack of non-invasive devices that could measure the status of the pulp, (ii) the tradition of not defining the depth and progression rate of the caries lesion, (iii) the lack of randomized clinical trials investigating the outcome of deep caries excavation. It has been suggested (Miyashita *et al.* 2007) that a decision must be made as to whether all carious tooth tissue should be removed, and this warrants a clinical trial in itself. Another category of clinical trials should relate to the management of the exposed pulp.

Hypothesis IIIa:

One direct complete excavation procedure is as good as a less invasive stepwise excavation approach to prevent root canal treatment.

Aim IIIa:

To carry out a randomized clinical trial comparing stepwise excavation versus direct complete excavation on deep caries in adults, using pulp exposure, 1-year pulp vitality without apical radiolucency, and pain as the outcome measures.

Hypothesis IIIb:

Treatment of pulp exposures with direct pulp-capping is as good as partial pulpotomy in terms of pulp survival.

Aim IIIb:
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Aim IIIb:

To carry out a randomized clinical trial comparing direct pulp-capping versus partial pulpotomy of pulps exposed as a result of caries, using 1-year pulp vitality without apical radiolucency, and pain, as the outcome measures.

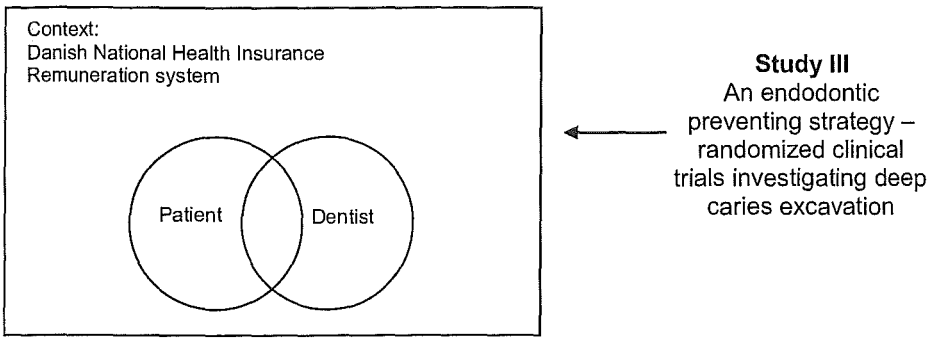

Fig. 5. In **Study III** an endodontic preventive strategy is investigated.

Trial designs (Study III)

Definitions of patients to be enrolled in the two randomized clinical trials

The number of patients needed to explore the hypothesis was found on the basis of a sample size calculation (excavation trial): 134 patients were needed in each group to detect a 20% difference between stepwise excavation and direct complete excavation at a two-sided alpha level of 5% (type I error) and 90% power (type II error of 10%), when expecting 50% in the direct complete excavation group to retain pulp vitality without apical radiolucency after 1 year. The study needed at least 308 patients, taking a possible patient drop-out rate of 15% into account (134 x 2 x 1.15). Consecutive patients referred to two Danish centres and four Swedish centres participated. Sample size calculation was performed for the excavation trial only, as the enrolment of patients to the pulp capping trial would be restricted to the actual numbers of exposed pulps in the excavation trial. In this light the results of the pulp trial would be difficult to assess and this trial should be considered a 'pilot trial'. Inclusion and exclusion criteria were well-defined in both trials (**Study III**).

Outcome measures for the excavation and the pulp capping trials

The treatment results from both trials were assessed at least one year after completion of the treatment. In the excavation trial (Fig. 6, top) the *primary outcome measure* was unexposed pulps with sustained pulp vitality without apical radiolucency (= success). Pulp vitality was defined as a positive response to thermal (cold) or electrical stimulation. Periapical radiolucency was diagnosed if the apical part of the periodontal ligament space was at least twice as wide as in other parts of the root and the lamina dura was absent. Two blinded observers independently examined the radiographs. Pain relief (*secondary outcome*) was defined as the difference in visual analogue scale (VAS) scores (mm) between pretreatment pain and pain at one and seven days after treatment. The *tertiary outcome measure* was pulp exposure during excavation. In the pulp capping trial (Fig. 6, bottom), the *primary outcome measure* was pulp vitality without apical radiolucency.

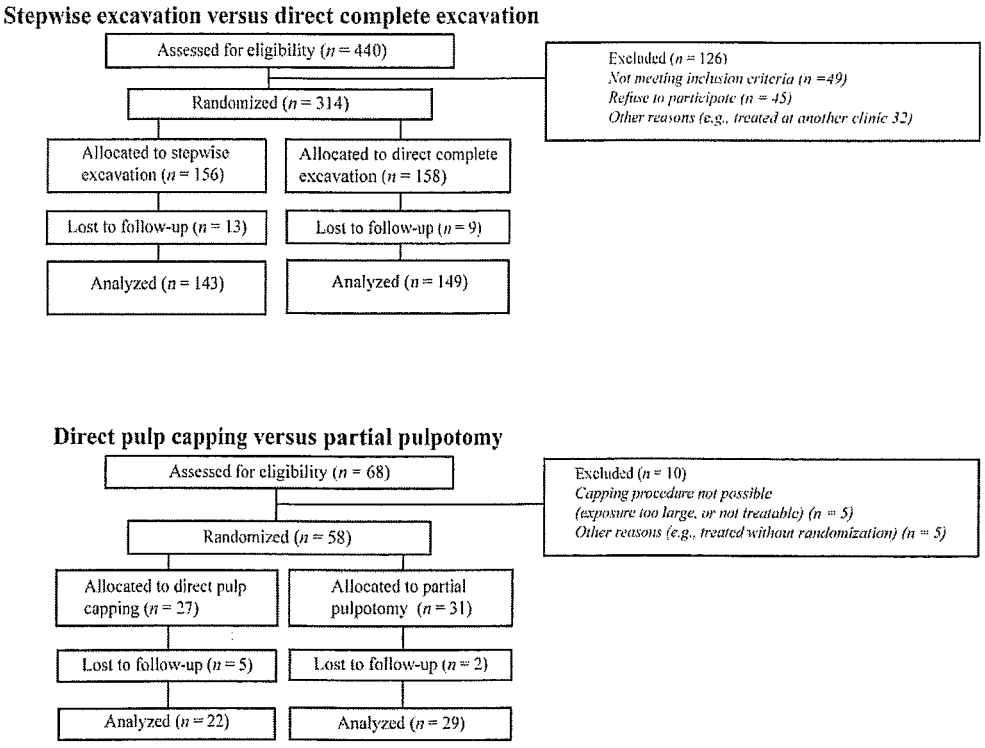

Fig. 6. Flowchart showing the number of patients according to enrolment, allocation, follow-up and final number of analyzed patients in the two trials (source: Fig.1, **Study III**. Reprinted with permission from European Journal of Oral Sciences, Wiley-Blackwell, Oxford).

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Results (Study III)

Excavation trial

314 patients were randomized. The stepwise excavation group had a significantly higher success rate (74.1%) at 1-year follow-up (median 476.5 days) compared with the direct complete excavation group (62.4%) ($P = 0.044$). The pulp was exposed in 25 teeth (17.5%) after stepwise excavation and in 43 teeth (28.9%) after direct complete excavation (Table 2).

Randomized (*n* = analyzed teeth)	Stepwise excavation (*n* = 143)	Direct complete excavation (*n* = 149)	Difference between groups (95% CI)	*P*-value
Success				
Pulp vitality without apical radiolucency *n* (%)	106 (74.1)	93 (62.4)	11.7 (0.5; 22.5)	0.044
Failures				
Pulp exposure *n* (%)	25 (17.5)	43 (28.9)	−11.4 (−21.3; −1.2)	0.030
Pulp vitality with apical radiolucency *n* (%)	2 (1.4)	2 (1.3)	0.1 (−3.5; 3.8)	0.665
No pulp vitality with apical radiolucency *n* (%)	2 (1.4)	4 (2.7)	−1.3 (−5.5; 2.8)	0.712
Unbearable pain* *n* (%)	8 (5.6)	7 (4.7)	0.9 (−4.8; 6.8)	0.934

*Resulting in pulpectomy.
CI, confidence interval.

Table 2. Outcome measure analysis of teeth at follow-up (Source: Table 2, **Study III**. Reprinted with permission from European Journal of Oral Sciences, Wiley-Blackwell, Oxford).

Prognostic factors

Patients with pretreatment pain were significantly less likely to show a successful treatment result at follow-up compared to those without pain, when adjusting for the effect of treatment, age, and centre. Treatment of patients younger than 50 years (median for the group: 28 years) was more likely to result in sustained pulp vitality without apical radiolucency than following treatment of older patients (median age of the group: 58 years); however, only borderline significance was noted. The odds ratios of pulp exposure differed among the centres, with centres 1 and 2 significantly more often avoiding pulp exposure (adjusted for the effect of treatment, age and pain).

Pulp capping trial

58 patients were randomized. The total proportion of teeth retaining pulp vitality without apical radiolucency at the follow-up did not differ significantly between the direct pulp capping group and the partial pulpotomy group (31.8% versus 34.5%). The majority of the failed pulp treatments were due to pain.

Outcome analysis of all treated patients

The following represents an analysis of all treated patients, where pulp exposure is not included as a failure *per se*. The patients with unexposed pulps and patients with pulp exposure in which pulp capping was performed were assessed together at the ~1½-year follow-up, and with the identical outcome measure: sustained pulp vitality without apical radiolucency (= success). This analysis was not included in **Study III,** but reflects the outcome measure presented in the database at www.ClinicalTrials.gov (NCT00187837 (= excavation trial, CAP-1) and NCT00187850 (= pulp capping trial, CAP-2)). However, on the basis of the outcome measures as given in the database, the proportion of teeth with pulp vitality without apical radiolucency in the stepwise excavation group was 80.7% versus 73.9% in the direct complete excavation group and the estimated differences between the proportions is displayed in Table 3. Irrespective of excavation mode, the frequency of retained pulp vitality amongst teeth without pulp exposure (88.8%) was significantly higher than amongst teeth with pulp exposure (32.8%), yielding a difference of 56% with a 95% CI of [42.3; 67.3], ($P < 0.0001$, χ^2 - test).

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Outcome measures (n = analyzed teeth[a])	Stepwise excavation group (n = 140)	Direct complete excavation group (n = 142)	Diff. between groups (95% CI)	*P*-Value
Success: Pulp vitality without apical radiolucency n (%)	113(80.7)	105(73.9)	6.8(-3.0; 16.4)	0.222
Failures: Pulp vitality with apical radiolucency n(%)	2(1.4)	2(1.4)	0.0(-3.8; 3.7)	0.612
No pulp vitality with apical radiolucency n (%)	3(2.1)	6(4.2)	2.1(-2.5; 7.0)	0.504
No pulp vitality and unknown apical radiolucency status[b] n (%)	22(15.7)	29(20.4)	4.7(-4.3; 13.7)	0.384

[a]Difference between number of analyzed cases in **Study III** is due to the additional lost cases among the patients with exposed pulps. [b]Includes patients with unbearable pain.

Table 3. Outcome measure analysis of all treated patient at ~1½-year follow-up.

Quality-shaping factors in endodontic treatments (Study II, IV-VI)

There is a marked discrepancy between the outcome of root canal treatments reported in clinical controlled studies performed by specialists in endodontics (Strindberg 1956, Petersson *et al.* 1982) or by dental students (Kerekes & Tronstad, 1979, Sjögren *et al.* 1990), compared to the estimated outcome found on the basis of epidemiological studies among GDPs (review: Eriksen *et al.* 2002). In most populations, a high frequency of technically defective root fillings, a high prevalence of periapical radiolucencies in root-filled teeth, and a strong correlation between the two is demonstrated (Bergenholtz *et al.* 1973, Allard & Palmqvist 1986, Eckerbom *et al.* 1987, Ödesjö *et al.* 1990, Petersson *et al.* 1986, Eriksen *et al.* 1988, Imfeld 1991, De Cleen *et al. 1993*, Buckley & Spångberg 1995, Saunders *et al.* 1997, De Moor *et al.* 2000, Kirkevang *et al.* 2001, Boucher *et al.* 2002, Lupi-Pegurier *et al.* 2002, Dugas *et al.* 2003, Loftus *et al.* 2005, Ridell *et al.* 2006).

Healing proportions for vital pulp treatments are high and range between 92% and 96% (Kerekes & Tronstad 1979, Petersson *et al.* 1982, Sjögren *et al.* 1990), and are about 10% lower for the treatment of the infected root canal with apical radiolucency (Kerekes & Tronstad 1979, Sjögren *et al.* 1990). In contrast, the estimated healing proportion among GDPs ranges from 50 to 75% (Ödesjö *et al.* 1990, De Cleen *et al.* 1993, Kirkevang *et al.* 2000, Kabak & Abbott 2005). Root canal treatment is one of the most technically challenging clinical procedures. In a radiographic examination of randomly selected individuals from Aarhus Kirkevang *et al.* (2000) observed that 59% of the root-filled teeth showed inadequate lateral seal and 40% displayed inadequate length. Furthermore, 52% of the treated teeth were associated with signs of apical periodontitis. An evaluation of the same population in 2003 (Kirkevang *et al.* 2006) disclosed that a large proportion of suboptimal treatments was still apparent.

Quality-shaping factors in root canal treatment

Despite the high proportion of suboptimal treatments reported, few studies have been concerned with factors that might improve the quality of root canal treatments performed in general practice. It is assumed that quality-shaping factors are related to the individual dentist in terms of knowledge, skills, as well as attitudes (Fig. 7). The context in which the dentist works would also be influenced by external environmental factors such as the society represented by the National Health Insurance, the remuneration system, but also the expectations and demands of the patient - as viewed through malpractice claims (Fig. 7).

Hypothesis IV:

The performance of root fillings of suboptimal quality amongst Danish GDPs might be associated with the use of suboptimal treatment procedures.

Aim IV:

*To investigate the rate of adoption of new endodontic advances among a group of GDPs (**Study IV**).*

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Hypothesis V:

The performance of root fillings of suboptimal quality amongst Danish GDPs might be associated with deficient knowledge of factors important to treatment outcome and low confidence in performing endodontic treatment.

Aim V:

*To explore the status of significant endodontic knowledge amongst GDPs (**Study II, V**) in terms of: The influence of prognostic factors on treatment outcome, and the self-awareness of the practitioners in various endodontic topics.*

Hypothesis VI:

Endodontic treatments are complicated and the number of endodontic-related claims is relatively high. The claims reflect the consequences of suboptimal endodontic treatment procedures.

Aim VI:

*To study reasons for and verdicts of dental malpractice claims in Denmark during a 10-year period (1995-2004). Specific interest was given to cases that included endodontic treatment practice (**Study VI**).*

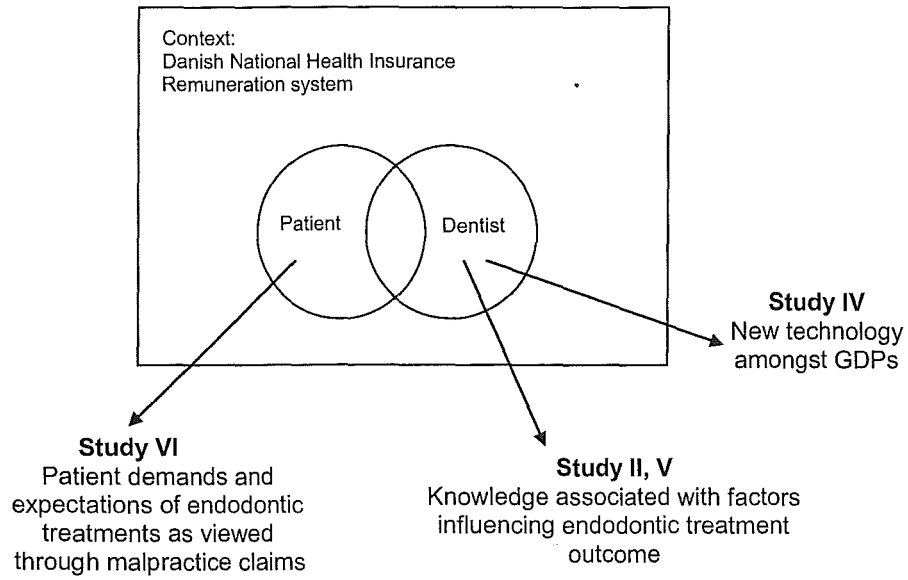

Fig. 7. Three selected areas which may determine the quality of endodontic treatment as performed by GDPs.

Materials and Methods (Study II, IV-VI)

*GDP populations (**Study II, IV, V**)*

Questionnaires were sent to 600 Danish GDPs. The GDPs were randomly selected from the roster of the Danish Dental Association, which at that time listed 3293 members (2004). The selection was carried out with the agreement of the Danish Dental Association (**Study II, V**). In **study IV** questionnaires were sent to all 1156 members (2003) of the Copenhagen Dental Association. Therefore, the pattern of answers may represent an urban attitude as opposed to the entire Danish population of GDPs. After 4 weeks a reminder card was sent out. In addition, an announcement was placed on the website of the Danish Dental Association and in one issue of the Danish Dental Journal to obtain a high response rate.

*Visual analogue scales (VAS) was used for GDP self-assessments (**Study II, V**)*

The GDPs were asked to envisage endodontic treatment of a mandibular molar and assess their confidence in performing access cavity preparation, providing an aseptic operation field, finding the canal orifices and instrumenting the root canals. The assessment was made on a 100 mm VAS, where the extremes were marked as 'very easy' and 'very difficult' (**Study II**). In **study V** the GDPs were asked to assess the influence of 24 factors on endodontic treatment outcome using a 100 mm VAS with 'no influence' and 'decisive influence' as extremes. The GDP group response was compared to a gold standard. The gold standard was based on the mean values (using the same VAS assessments) from seven researchers fulfilling the criteria of authoring or co-authoring three papers dealing with endodontic outcome within the last 14 years. They made their first assessment without knowing the answers of the other researchers. During a second round they had the option to make a re-evaluation of their first assessment but now having the scores of the others, as carried out in the Delphi method (Reit & Gröndahl 1987). The GDP group opinions and the gold standard were compared using Wilcoxon tests because a normal distribution assumption was rejected.

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*Categorization of GDP self-assessments (**Study II, IV,V**)*

The GDP responders were asked to estimate the time spent to prepare the access cavity and perform mechanical root canal preparation and root filling, and the reports were categorised in five groups: *≤15 min.*, *16-30 min.*, *31-45 min.*, *46-60 min.*, and *≥ 61 min.* (**Study II**). Moreover, the GDPs were approached with questions concerning the frequency with which endodontic instruments, materials and procedures were used (**Study IV**). The respondent had three options: *often, occasionally* and *never.* Also, the GDPs were evaluated with respect to their endodontic knowledge, and they were asked to make a self-assessment (**Study V**) graded as *excellent*, *satisfactory* or *non-satisfactory* of various topics ('pulpal pathology', 'microbiology', 'clinical diagnostics' and 'prognostic factors') as well as of endodontic-related technical skills ('injecting local anaesthesia', 'emergency treatment', 'root canal preparation procedure' and 'root filling procedure'). Most often the variables were ordered categorically (**Study II**, **IV**, **V**); therefore the basic tool chosen was Goodman-Kruskal's γ-coefficient (Upton 1999). It is an association measure with a positive value indicating a positive association and a negative value a negative association

*Malpractice claims (1995-2004) (**Study VI**)*

Permission to get access to the files was obtained from the Danish National Health Insurance and the Danish Data Protection Agency. All claims handled by the regional as well as the national Dental Complaint Boards were included. The total complaint material comprised files from 1995 to 2004 (n = 3611). An endodontic problem could be detected in 517 claims registered between 1995 and 2002, and in 93% (n = 482) a more specific report was available. An age and sex analysis of dentists and complaining patients was performed on these 482 claims, and a further endodontic sub-classification in terms of causes for the claims could be carried out.

*Categorization of the endodontic malpractice claims (**Study VI**)*:

(1) *Technical complications or incorrect treatment.* 'Technical complications' occurred in the course of treatment. A case was assigned to 'incorrect treatment' when a problem, as experienced by the patient, was a result of the treatment, such as tooth fracture.

(2) *Persistent pain*: Following treatment the patient was in pain for a subjectively unacceptable period of time.

(3) *Wrong treatment*: The patient thought that the wrong tooth was treated or believed that a tooth was treated for the wrong reason.

(4) *Prolonged treatment*: The treatment was extended over a long period of time, including several appointments, often leading to complications or extraction of a tooth.

(5) *Lack of information*: The patient was not informed of crucial steps in diagnosis or treatment.

(6) *Other reasons*: The main reason for complaint was not endodontic, but an 'unnecessary' root canal treatment was the result of a diagnostic or a non-endodontic treatment problem.

For claims assigned to the *technical complications or incorrect treatment* group the written reasons for the Dental Complaint Board decisions were studied in detail with the intention to find explicit or implicit verdict policies.

Results (Study II, IV-VI)

The endodontic treatment procedure

The vast majority of the Copenhagen GDP responders (75%) relied on conventional stainless steel files or reamers to shape root canals (**Study IV**). When the endodontic

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treatment procedure of a mandibular molar was divided into access cavity preparation, mechanical preparation of the root canal and root-filling, the GDPs reported spending most time on the canal preparation (Table 4).

Estimated time $n = 452$	≤15 min (%)	16–30 min (%)	31–45 min (%)	46–60 min (%)	≥61 min (%)	γ-coefficient (*P*-value)
Access cavity						
Men	213 (89)	24 (10)	0	3 (1)	0	$\gamma = 0.31$ ($P = 0.014$)
Women	173 (82)	34 (16)	3 (1)	2 (1)	0	
Mechanical root prep.[a]						
Men	31 (13)	142 (59)	50 (21)	14 (6)	2 (1)	$\gamma = 0.29$ ($P < 0.0005$)
Women	21 (10)	99 (47)	61 (29)	28 (13)	2 (1)	
Root filling						
Men	84 (35)	135 (56)	17 (7)	4 (2)	0	$\gamma = 0.20$ ($P = 0.010$)
Women	61 (29)	111 (52)	32 (15)	8 (4)	0	

[a]In two cases no information.

Table 4. The estimated time taken by the male or female dentist for treatment of a mandibular molar (Source: Table 5, **Study II**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

Copenhagen GDPs frequently used two sessions to instrument a molar and 20% often needed three or more appointments to finish the instrumentation of a molar (Table 5).

	Number of visits					
	1		2		≥3	
	Oft. (%)	Occ. (%)	Oft. (%)	Occ. (%)	Oft. (%)	Occ. (%)
Instrumentation of a molar	40	24	53	37	20	46
Complete treatment of vital pulp cases	28	31	61	28	14	42
Complete treatment of necrotic pulp cases	5	12	47	32	53	36

Oft., often; Occ., occasionally.

Table 5. The frequency of number of visits used for endodontic treatment amongst 692 GDPs (Source: Table 2, **Study IV**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

A relatively small group of GDPs had adopted new endodontic technologies (Table 6) such as nickel-titanium hand instrumentation (18%), nickel-titanium rotary instrumentation (10%), electronic apex locators (23%) and warm gutta-percha

techniques (19%). The completion of treatment was accomplished in a lower number of visits if the canals were obturated with warm gutta-percha techniques [γ = -0.15; P = 0.012] and if instrumentation had been carried out by either nickel-titanium hand instruments [γ = -0.12; P = 0.029] or nickel-titanium rotary systems [γ = -0.25; P = 0.004]. One third of the GDP responders had no experience at all in any of the new techniques that were asked about in the questionnaire (**Study IV**).

	Often (%)	Occasionally (%)	Never (%)
NiTi instrumentation	18	17	65
NiTi rotary	10	5	85
Electronic apex locator	23	19	67
Warm gutta-percha	19	16	65

Table 6. The adoption rate of new endodontic technology amongst 692 GDPs. NiTi denotes nickel-titanium (Source: Table 1, **Study IV**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

The GDP 'self-assessments' of level of endodontic knowledge and skills disclosed that 94% of the GDPs rarely assessed themselves as being at a *non-satisfactory* level with respect to 'root canal preparation procedure' and 'root filling procedure'. The same was found concerning 'injecting local anaesthesia' and 'emergency treatment' (Table 7).

	Excellent			*Satisfactory*			*Nonsatisfactory*			*No*
Endodontic topics	*Total (%)*	*M*	*F*	*Total (%)*	*M*	*F*	*Total (%)*	*M*	*F*	*influence*
Pulpal pathology	156 (34.9)	87	69	263 (58.8)	142	120 (1*)	28 (6.3)	7	21	23
Microbiology	39 (8.7)	14	25	225 (50.4)	127	97 (1*)	182 (40.8)	96	86	24
Clinical diagnostics	310 (68.9)	162	148	138 (30.7)	75	62 (1*)	2 (0.4)	1	1	20
Injecting local anesthesia	361 (80.0)	200	161	85 (18.8)	38	46	5 (1.1)	0	5	19
Emergency treatment	333 (74.8)	182	151	107 (42.0)	53	54	5 (1.1)	2	3	25
Root canal preparation procedure	182 (40.4)	109 (1*)	72	245 (54.3)	115	130	24 (5.3)	14	10	19
Root filling procedure	151 (33.5)	95 (1*)	55	273 (60.5)	135	138	27 (6.0)	19	8	19
Prognostic factors	114 (25.7)	70	44	296 (66.7)	150	145 (1*)	34 (7.7)	15	19	26

M, male; *F*, female.
*Number of responds not specified in relation to gender.

Table 7. The distribution of male and female GDP 'self-assessments' of level of endodontic knowledge and skills (N = 470) (Source: Table I, **Study V**. Reprinted with permission from OOOOE, Elsevier Inc., Philadelphia, PA).

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	Nonsatisfactory			*No*
	Total (%)	*M*	*F*	*influence*
(1*)	28 (6.3)	7	21	23
(1*)	182 (40.8)	96	86	24
(1*)	2 (0.4)	1	1	20
	5 (1.1)	0	5	19
	5 (1.1)	2	3	25
	24 (5.3)	14	10	19
	27 (6.0)	19	8	19
(1*)	34 (7.7)	15	19	26

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Aseptic operation field and rubber dam

The GDPs' confidence in performing endodontic treatment in relation to a mandibular molar varied, but was relatively high, expressed as VAS scores below 50. When mean comparisons of the VAS scores were compared, the creation of an aseptic operation field was regarded as the most difficult procedure (**Study II**). In the urban GDP population only 4% were frequent users of rubber dam, and 14% used rubber dam occasionally (**Study IV**). However, a technology cluster was observed, as frequent rubber dam application was correlated with the adoption of nickel-titanium hand instruments [γ = 0.24; *P* = 0.003], nickel-titanium rotary systems [γ = 0.50; *P* < 0.0005] and warm gutta-percha techniques [γ = 0.29; *P* = 0.0005]. The use or non-use of rubber dam was not noted in a single Dental Complaints Board related to an endodontic malpractice claim (**Study VI**).

Microbiology and endodontic prognosis

The gold standard regarded the preoperative presence or not of microorganisms to be all important as evidenced by their high-lighting of 'periapical status' and 'infected root canal' to have a particular influence on the endodontic prognosis (**Study V**). In contrast, the GDPs highlighted 9 out of 12 preoperative factors as having a relatively high influence (VAS scores > 50) on the outcome of endodontic treatment (Fig. 8). Furthermore, ~40% of the GDPs regarded their microbiological knowledge as not up to standard (Table 7).

GDP graduation year/age

Dentists from the early graduation years performed fewer endodontic treatments per week than dentists in the later group (**Study IV**). Younger dentists compared to older scored a higher influence on treatment outcome in relation to 'status of the pulp' and 'periapical status', 'interappointment dressing in treatment of the necrotic infected pulp' and 'presence of bacteria in the root canal after completion of instrumentation' (**Study V**).

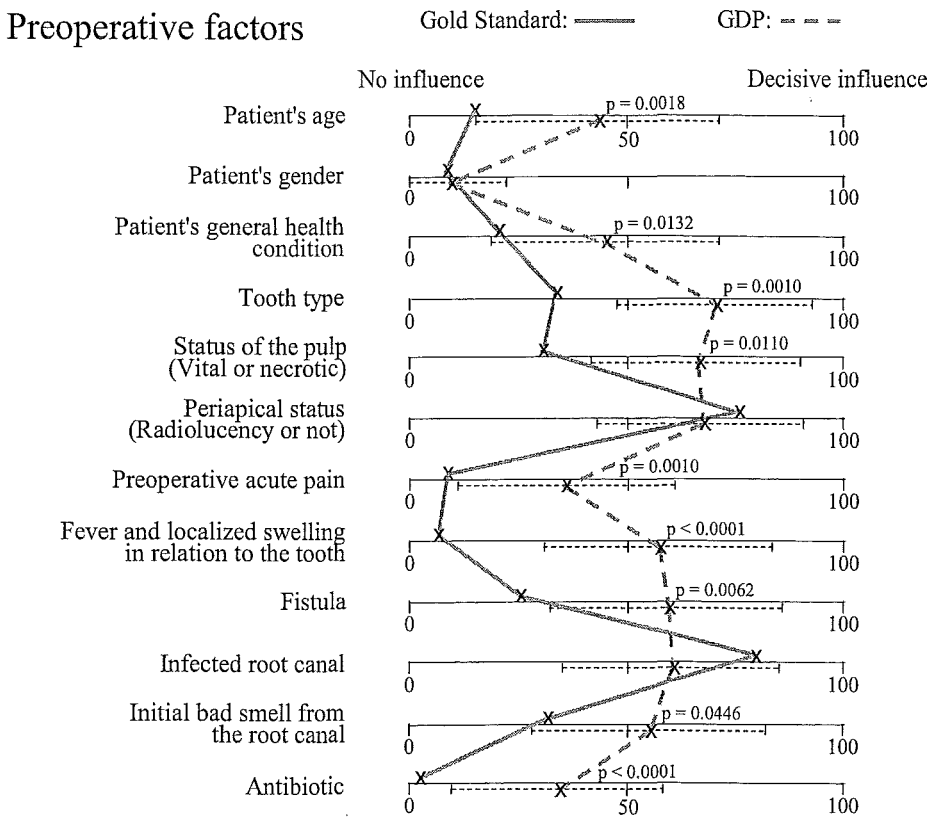

Fig. 8. The gold standard on preoperative factors affecting endodontic outcome compared to the GDP (General Dental Practitioner) group response. P values denote the significant results from the Wilcoxon tests. (Source: Fig. 1, **Study V**. Reprinted with permission from OOOOE, Elsevier Inc., Philadelphia, PA).

The patient's expectations as viewed through malpractice claims

The endodontic-related claims (**Study VI**) were the second most frequent category from 1995 to 2004 (13.8%) (Table 8). In 43% of the claims from all the categories the dentist was judged to be guilty of malpractice. In the majority of the appealed cases the original verdict was affirmed (62.2%) by the national Dental Complaint Board.

Categories
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Periodontal treatm
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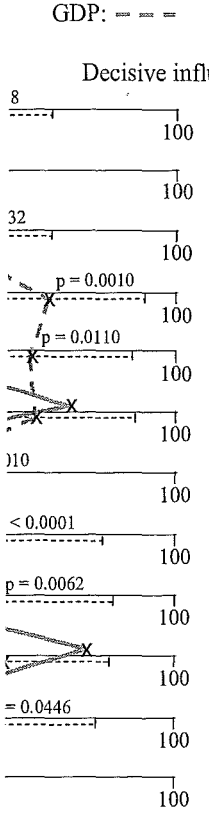

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Categories	1995–1999 Number	%	2000–2004 Number	%
Crown & Bridge	559	23.0	678	22.8
Dentures	372	15.3	302	10.2
Endodontic treatment	354	14.5	388	13.1
Diagnostics	308	12.7	355	11.9
Caries	237	9.7	380	12.8
Periodontal treatment	171	7.0	168	5.7
Implantology	109	4.5	51	1.2
Oral surgery	108	4.4	120	4.0
Informed consent	75	3.1	122	4.1
Other	61	2.5	110	3.7
Pain	33	1.4	166	5.6
Office records	19	0.8	91	3.1
Aesthetic dentistry	14	0.6	22	0.7
Preventive care	13	0.5	19	0.6
Financial cost	1	0.0	1	0.0
Total	2434	100.0	2973	100.0

Table 8. Number of malpractice claims for different categories. More than one category could be used in a single claim (Source: Table 2, **Study VI**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

A specific report was available in 93% (n = 482) of the endodontic-related cases in the period 1995-2002. A classification of the causes of these endodontic cases showed that the malpractice claims in 28% (n = 137) reflected technical shortcomings (occurring in the course of treatment) or technical treatment complications (as experienced by the patient), such as symptoms of infection, tooth fracture or post operative pain (Table 9).

	DCB decisions				
	Verdict of malpractice	No verdict of malpractice	Settlement	Rejection	Total *n* (%)
Technical complications or incorrect treatment	55	74	5	3	137 (28.4)
Other reasons	56	26	3	1	86 (17.8)
Persistent pain	24	39	1	–	64 (13.3)
Wrong treatment	11	37	2	–	50 (10.4)
Lack of information	11	10	–	–	21 (4.4)
Prolonged treatment	10	6	–	–	16 (3.3)
No data	12	21	69	6	108 (22.4)
Total	179	213	80	10	482 (100)

Table 9. Endodontic claims and Dental Complaint Board (DCB) decisions 1995-2002. (Source: Table 3, **Study VI**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

A further elaboration of these 137 cases is displayed in table 10. In the 'technical complication' group the problems were insufficient root-filling quality and in the 'incorrect treatment' group persisting infection was the commonest.

If the dentist had explained why it was not possible to reach the best technical result, for example due to difficult root canal anatomy the dentist was found not guilty. In case of separated instruments (Table 10) the vast majority of the involved teeth were multi-rooted and the dentist was found guilty of malpractice if the root canal anatomy was simple, the root filling on top of the instrument was defective, apical pathology was persistent, or the patient was not informed. In no case was the absence or presence of rubber dam commented on by any of the Dental Complaint Boards.

	DCB decisions				
	Verdict of malpractice	No verdict of malpractice	Settlement	Rejection	Total *n* (%)
Technical complications					
Defective root filling (short, long, leaking, not all root canals root filled)	31	11	–	2	44 (32.1)
Separated instrument	5	10	–	1	16 (11.7)
Root perforation (following instrumentation or post-preparation)	8	1	–	–	9 (6.6)
Medicament related (all events after use of a paraform- aldehyde product)	4	–	–	–	4 (2.9)
Other complications (e.g. a foreign body in maxillary sinus, nerve damage)	–	10	2	–	12 (8.8)
Incorrect treatment					
Symptoms of infection	3	18	2	–	23 (16.8)
Tooth was weakened/fractured/extracted	1	10	1	–	12 (8.8)
Treatment related persistent pain	2	12	–	–	14 (10.2)
Incorrect treatment is stated but not further detailed	1	2	–	–	3 (2.2)
Total	55	74	5	3	137 (100.1)

Table 10. Sub-categorization of "technical complications" and "incorrect treatments" and the DCB (Dental Complaint Board) decisions 1995-2002. (Source: Table 4, **Study VI**. Reprinted with permission from International Endodontic Journal, Wiley-Blackwell, Oxford).

A significantly higher frequency of a verdict of malpractice was noted in the 'technical complication' group (56%) compared to the 'incorrect treatment' group (13.5%).

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	2	44 (32.1)
	1	16 (11.7)
	–	9 (6.6)
	–	4 (2.9)
	–	12 (8.8)
	–	23 (16.8)
	–	12 (8.8)
	–	14 (10.2)
	–	3 (2.2)
	3	137 (100.1)

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Sex differences between GDPs

The female GDPs took significantly more time (**Study II**) than the males for all procedures (access cavity, mechanical root preparation, root filling), as expressed by the positive γ-coefficients (Table 4). Moreover, female GDPs more often scored the following factors as being important for the outcome of endodontic treatments: 'tooth type','fever', 'localized swelling' and the presence of a 'fistula', all other matters being equal (**Study V**). Technological advances such as apex locators were more frequently used by males than by females. Males had also more frequent endodontic sessions per week than females (**Study V**). In general, males had a perception of a satisfactory level of endodontic knowledge, and males made satisfactory self-report about their clinical skills more often. Other findings could contradict these perceptions. For example, the 'periapical status' as a preoperative prognostic factor was underestimated by the males as compared to the gold standard and to the females (**Study IV**). In addition, males were more likely to receive an endodontic claim (**Study VI**). Male dentists were involved in 69% (n = 331) of the endodontically related complaints, which differed significantly ($P < 0.0005$; $\chi^2 = 15.189$) from the general proportion of male GDPs (57.8%) during the period. In contrast, the majority of complainants were women (71.0%, n = 342), which differed significantly ($P < 0.0001$; $\chi^2 = 77.543$) from the general proportion of females (50.8%) among patients who received root canal treatment within the same period (**Study I**).

DISCUSSION

Status of tooth extraction and endodontic treatment frequency

On the basis of data from the Danish National Health Insurance register containing treatment statistics for GDPs it was shown that the number of tooth extractions had markedly declined during the past 25 years, whereas the number of root fillings performed increased by 17% (**Study I**). Firstly, it is well documented that the progression of caries declined within this period (Marthaler 2004) and it is assumed that the improved oral health is partly reflected by a decline in the number of tooth extractions. Secondly, it may be that the attitude of people has changed over the years. A report on the relation between oral health status and the use of dental services in USA concluded that 'intuition suggests that healthier people will demand less care' (Davies *et al.* 1985); however, the same review also presented an intriguing hypothesis that 'improved oral health might lead to a greater demand for dental services'. More education and income may lead people to demand a higher standard of oral health and enable them to obtain it (Petersen & Holst 1995), and people keep their teeth for a longer period of time (Petersen *et al.* 2004). The strength of **Study I** was the fact that total nationwide data has been available for 25 years; however, the level of details is low, for example without specific data on tooth type and diagnosis. Moreover, the actual number of treatments per number of patients is based on estimates which may differ from actual numbers.

The increased number of root fillings during the past 25 years can be understood as an expansion of the patient population; expressed as the number of root canals treated per 1000 patients the increase reached 17%. The reduced extraction rate putting more teeth at risk for a pulpal injury and the increased treatment of multi-rooted teeth were given as possible explanations (**Study I**). The molars were also the most frequently treated when GDPs were asked about the tooth type of their last performed root canal treatment (**Study II**), and the same findings were observed by Kirkevang *et al.* (2001) based on radiographs from epidemiological data. The bulk of root fillings were associated with middle-aged patients, but endodontic treatment was also common among younger as well as older individuals (**Study I**).

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These time trends were confirmed by a recent 20-year radiographic re-examination of a population in Sweden (Eckerbom *et al.* 2007), showing an increase in root canals treated with increasing age and an overall increase in the number of root fillings. They concluded that there is still a great need for endodontic treatment because the frequency of teeth with apical periodontitis had also increased during the period.

Reasons for root canal treatment

The questionnaire survey among randomly selected GDPs (**Study II**) provided some evidence that caries is still the main reason for root canal treatment. In the present study the mailed questionnaire was accompanied by a letter guaranteeing confidentiality including a coded and stamped reply envelope. Non-responders were first approached by a reminder card and finally by a telephone call (Tan & Burke 1997). The use of coded reply envelopes led to a failure to respond by at least 1.7% of the GDPs. Ten practitioners questioned the anonymity (in spite of coded return envelopes) and did not want to take part in the study. The final response proportion (75.3%) was regarded as sufficient to make valid conclusions (Parashos & Messer 2004). A survey (Madarati *et al.* 2008) was recently performed amongst endodontists and GDPs in the United Kingdom with a similar sample size (n = 476) and response proportion (75%). They concluded that such a response proportion should be considered to be representative of all dental practitioners in the United Kingdom. In that survey the nonresponse bias was assessed between early responders and late responders. However, such an analysis was not carried out in **Study II** because the number of late responders was very low (<5%).

The reason for endodontic treatment was caries in 55% whereas the second most frequent reason was 'dentin cracks' (14%). The majority of the GDPs performed their last root canal treatment on a 'vital pulp' indication. In spite of the large pool of insufficient root fillings in Denmark few retreatments were performed, but this was in accordance with observations based on two Swedish sub-populations (Reit *et al.* 1993, Karlsson & Reit 1994), where retreatment of symptomless persistent periapical lesions in root-filled teeth was infrequent. The same pattern was recently seen in a

Danish study re-evaluating the same cross-sectional data from 1997 and 2003 (Kirkevang *et al.* 2006), where the retreatment frequency was 6.5% for the total pool of root-filled teeth (42 out of 618 root-filled teeth).

Reflection on hypotheses I and II:
Endodontics still seems to be an important part of the dental service provided, and the expected decrease in the number of root fillings over a 25–year period could not be confirmed.

In spite of the reduced rate of caries progression, caries still appears to be the main reason for performing root canal treatments in Denmark.

Treatment of deep caries as an endodontic preventive strategy

A randomized multicentre trial concerning treatment of deep caries in adults has never been carried out before. Besides being a multicentre trial the strength of the two trials was the use of well-defined inclusion and exclusion criteria. The caries lesion depth was measured and comparable lesion depths were found between all centres. Two blinded observers independently examined the follow-up radiographs. Inter-examiner agreement was judged as good (kappa = 0.67). Moreover, the two trials in **Study III** had adequate generation of the allocation sequence and allocation concealment. The statistically significant difference in pulp exposures between the centres may be due to differences in depths or progression rates of the caries lesions. However, our analysis of lesion depths indicated that proper depths had been selected at all centres. Other plausible reasons could be differences in technical skills or random error.

Based on the excavation trial (**Study III**) a stepwise excavation approach versus a complete direct excavation reduced the prevalence of pulp exposures significantly. At approximately 1½-year follow-up there was a significant difference between the two excavation procedures in the primary outcome (unexposed pulps with sustained pulp vitality without apical radiolucency). In the stepwise excavation group the proportion

was 74.1% versus 62.4% in the direct complete excavation group (Table 2). The biological rationale for this difference could be that the first phase of stepwise excavation inactivates caries progression. The caries dentin becomes darker, harder and drier (Massler 1978, Bjørndal *et al.*1997, Maltz *et al.* 2002, Kidd *et al.* 2008, Orhan *et al.* 2008), which makes it easier to remove without exposing the pulp at the final excavation. It has also been reported that a more dramatic reduction in the cultivable microflora is noted during stepwise excavation as compared with a direct complete excavation procedure (Orhan *et al.* 2008), which may provide some explanation for the significant difference found in the long-term outcome.

It was expected that the partial pulpotomy procedure in the pulp capping trial had increased the potential of healing, as observed in young permanent teeth (Mejàre & Cvek 1993, Qudeimat *et al.* 2007). However, the relatively small number of pulp exposures makes the confidence intervals wide and definite conclusions concerning choice of capping procedure could not be drawn from the pulp capping trial (**Study III**). In this trial the treatment of the cariously exposed adult pulp seemed to be a greater problem than expected. Irrespective of the capping method the majority of capped teeth failed (due to pain) before the follow-up examination. At follow-up 32.8% of the capped teeth were successful (pulp vitality without apical radiolucency), confirming recent findings by Al-Hiyasat *et al.* (2006), where direct capping with calcium hydroxide of caries exposures was classified as successful in 33% after a 3-year period. It has been argued that pulp capping with Mineral Trioxide Aggregate (MTA) may significantly increase the healing rate, however, in a retrospective analysis of carious pulp exposures in adults treated with MTA, the pulp survival proportion was only 56.2% after 2 years (Miles *et al.* 2010).

When assessing both trials together (**Study III**) using the primary outcome measure of sustained pulp vitality without apical radiolucency, no significant difference in success rate could be found between the stepwise excavation group versus the direct complete excavation group as a whole (Table 3).
However, investigation of excavation approaches avoiding pulp exposure merits further study, when the markedly different outcome between teeth with unexposed

and exposed pulp is taken into account. This observation emphasizes the importance of maintaining an unbroken dentin barrier against the pulp.

Reflections on hypotheses IIIa and IIIb:
A significantly higher success rate in terms of sustained pulp vitality without apical radiolucency was observed between stepwise versus direct complete excavation of deep caries lesions in adult teeth.

No significant differences were found between direct pulp capping and partial pulpotomy. The treatment success rates were low and the majority of treatments failed due to pain before the follow-up examinations.

Irrespective of excavation mode, the treatment of teeth with caries exposures had a significantly lower pulp survival than teeth with unexposed pulps. Therefore, a stepwise excavation procedure is preferable for the management of deep caries lesions.

Knowledge of factors influencing endodontic outcome

We have examined topics that provide insight regarding factors that shape the quality of endodontic treatments. Some explanations may be apparent for the differences in treatment outcome between what goes on 'de facto' in general practice (Ödesjö *et al.* 1990, De Cleen *et al.* 1993, Kirkevang *et al.* 2000, Kabak & Abbott 2005) versus the outcome that can be achieved (Kerekes & Tronstad 1979, Petersson *et al.* 1982, Sjögren *et al.* 1990).

The results of the knowledge of endodontic outcome (**Study V**) revealed that many preoperative factors amongst the GDPs were over-evaluated as having an important influence on the outcome (Fig. 8). The gold standard had only two preoperative factors with a high influence on endodontic outcome: 'periapical status' and 'infected root canal'. These data support the finding that performance of root fillings of substandard quality may be associated with deficient knowledge of factors important

to the outcome of endodontic treatment. The data may to some extent reflect the 'praxis concept' as generated by Kvist *et al.* (1994), because the GDPs did not seem to follow the gold standard and a huge inter-individual variation was apparent when factors were evaluated as having influence on the outcome. The 'praxis concept theory' hypothesizes that the GDPs imagine periapical health and disease, not as either/or situations, but as stages on a continuous scale. The cut-off point for the decision to treat is value dependent, bringing about a huge inter-individual variation among the GDPs. The criteria for treatment are influenced by factors such as economy, quality of seal and accessibility to the root canal, but also the size of the apical radiolucency (Kvist *et al.* 2004). In contrast, Strindberg's (1956) definition of an endodontic treatment failure is the tooth with a diagnosed unhealed periapical lesion and referred to as 'the Strindberg concept' (Reit & Kvist 1998). The Strindberg concept reflects an 'ideal' concept of disease (Juul Jensen 1985), which is exclusively founded on biology and is neutral towards various clinical situations and agents. In short, the results of **Study V** showed that there was a large variation in the response of the GDPs. No specific focus was placed on 'periapical status' and 'infected root canal', as indicated by the gold standard (Fig. 8). In particular, the GDPs emphasized factors associated with clinical symptoms.

A focus on uncomfortable clinical symptoms was also noted among a small group of Swedish practitioners in their decision making on whether or not to retreat a root-filled tooth (Kvist *et al.* 2004). They further suggested that this so-called 'retreatment preference score' was guided by various retreatment strategies of which the one based on discomfort was defined as illness-focused (Hofmann 2002); *i.e.*, as long as the patient does not complain or show any clinical symptoms of periapical disease the treatment result is accepted.

Although the decision on when to retreat was not a part of the questionnaires in **Study V**, it seems obvious that the pre-operative evaluation of factors believed to be important for the outcome plays an important part in the decision-making process. An illness-focused strategy seems to attract the majority of Danish GDPs during such a

process, as many of the preoperative factors believed to impair the endodontic outcome were related toward acute symptoms of infection.

The non-adoption of new endodontic technology

Changes explaining the quality of endodontic treatment may also take place when the dental students are about to leave the university environment. The young dentist demonstrates knowledge on outcome closely related toward the gold standard with respect to 'periapical status' and the understanding of the treatment of the necrotic infected root canal (**Study V**). It could be speculated that the young dentist applies the practice owner's routine procedures with a low rate of adoption of new endodontic procedures (Table 5). The use or non-use of rubber dam as part of an aseptic operation field, time spent to instrument a molar, and the endodontic treatment procedure (in the context of the Danish remuneration system) are briefly discussed below.

Rubber dam

Rubber dam as part of the aseptic operation field is mandatory in the university departments in Denmark; however, the vast majority of the GDPs (82%) never use it (**Study IV**), and a similar situation is found in other countries (Saunders *et al.* 1999a, Whitworth *et al.* 2000, Jenkins *et al.* 2001, Slaus & Bottenberg 2002). Based on a questionnaire (Mala *et al.* 2009), attitudes of final year dental students to the use of rubber dam showed that more than 50% of the students predicted that the use of rubber dam would decrease once in independent practice. This underlies the need to maintain the awareness of both the dental students and the GDPs to the need to use rubber dam (Mala *et al.* 2009). To produce asepsis without the use of rubber dam is difficult, and since a majority of the treated teeth have vital pulps (**Study II**) the risk of contaminating a sterile pulp is high, which in turn might be an explanatory factor for the high rate of periapical lesions observed in root-filled teeth (Kirkevang *et al.* 2001).

In the material provided by the Dental Complaint Board it was noted that the use or non-use of rubber dam was never mentioned in the statements made by the Dental

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Complaint Boards (**Study VI**). This could indicate that there are differences between the Dental Complaint Board policy and that of the official guidelines (European Society of Endodontology 2006) taught at the universities. It could be speculated that the low focus on rubber dam application may also be related to the actual level of knowledge of microbiology among GDPs. Interestingly, ~40% of the GDPs regarded their knowledge as not up to standard concerning microbiology (**Study V**).

Time spent to instrument a molar

Fifty-six per cent of the responders estimated the time to treat a mandibular molar at ~1 hour (± 15 min.). Compared to other self-reported time evaluations this is rapid. In a Scottish sample the treatment of a single-rooted tooth was estimated to take about 70 min. (Saunders *et al.* 1999b). The attitude of working rapidly within endodontics was recently associated with a low economic incentive (Basmadjian-Charles *et al.* 2004). The time-cost dilemma in dentistry has also been elaborated by McColl *et al.* (1999), where in-depth interviews of GDPs revealed that there was a discrepancy between the time required for molar endodontic treatment and the fee offered by the United Kingdom National Health Insurance.

The endodontic treatment procedure

The vast majority of the GDPs (75%) used stainless steel instruments (**Study IV**), which today may be considered as an inferior method for instrumenting a tooth (Molander *et al.* 2007, Bergmans & Lambrechts 2010). Although the clinical outcome studies on nickel-titanium instruments are still sparse, the available clinical trials indicate that the use of rotary systems will lead to a reduced incidence of errors and possibly to improved clinical outcomes (Peters & Paqué 2010). The rate of adoption was recently reported to be ~65% for both nickel-titanium hand instruments and for nickel-titanium rotary systems among GDPs in the United Kingdom (Madarati *et al.* 2008). In a Public Dental Service in Sweden a long–term adoption rate was reported to be as high as 88% when hands-on training was included (Reit *et al.* 2007), demonstrating the effect of educational intervention on the adoption of nickel-titanium instruments. A similar development should be expected in Denmark in the years to

come as nickel-titanium rotary systems have been introduced at both universities in the undergraduate curriculum.

A majority of the responders (53%) often used two sessions to instrument a molar, and 20% often needed three or more sessions to finish the shaping. To complete treatment of a non-vital tooth most GDPs stated that they used at least three appointments.

The observed non-use of rubber dam and often prolonged and seemingly irrational treatment procedures might be due to time pressure resulting in short treatment sessions. Such pressure is often caused by restrictions imposed by the remuneration system. However, in 1999 a new contract between the Danish Dental Association and the Danish National Health Insurance was introduced (where the fixed fee for root canal treatment was abandoned) and this has considerably decreased the time-cost dilemma. Therefore, GDPs today have a remuneration system that could give an adequate reward for quality, because an individual fee can be introduced reflecting the actual costs of equipment, time, etc. It was speculated that the change of the remuneration system in Denmark in 1999 might be reflected in a reduced number of malpractice claims after 1999, but this could not be confirmed (**Study VI**).

Sex differences

The female dentists did not make the same positive self-reports compared to the males (**Study V**). This confirms general sex discussions, where females tend to doubt their own ability, whereas males tend to overestimate it; moreover females often have a lower expectation of obtaining a good result (Frankenhaeuser 1993).

Endodontic topics were the second most frequent reason for the patient to make a malpractice claim (**Study VI**). A sex effect was noted in malpractice claims, where an overrepresentation of male dentists was found but also an overrepresentation of female complainants, in accordance with the observations made by René & Öwall (1991). The body of work presented by the Roter group (Hall *et al.* 1994, Levinson *et*

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al. 1997, Hall *et al.* 2002, Roter *et al.* 2002), demonstrates the importance of the patient-doctor communication, where more patient-centred communication was found amongst female doctors (Levinson *et al.* 1997), which might decrease the risk of becoming involved in liability claims.

A paradox?

The GDPs themselves did not seem to experience sub-optimal root canal treatments as a problem. Ninety-four per cent regarded their level of endodontic skill as either excellent or satisfactory (**Study V**). Moreover, the GDPs had high confidence in performing endodontic treatments. The endodontic treatment of a mandibular molar was evaluated with mean values situated in the 'easy' half of the scale (**Study II**). This may be due to responder bias, as there may be a discrepancy between what the health care providers say they perform and document versus what they actually do in their daily practice (Helminen *et al.* 2002). However, the GDPs may also have their focus on illness, as previously discussed. As the focus of the Danish GDPs seems to be on the presence of clinical symptoms it is speculated that root filling quality is accepted as long as it prevents such symptoms.

Reflections on hypotheses IV-VI:

The performance of root canal treatments of substandard quality amongst Danish GDPs may be associated with:

- *The use of sub-optimal endodontic routine procedures.*
- *Deficient knowledge of factors important to treatment outcome.*
- *A focus on illness attracting the majority, whereby a high confidence in performing root canal treatments can be remained.*
- *The presence of a relatively high number of malpractice claims involving endodontic treatment, as they reflect sub-optimal endodontic treatments due to technical shortcomings and technical treatment complications.*

An additional sex difference was found as *male dentists and female patients were overrepresented in the material, indicating that aspects of the patient-dentist communication are also important for liability claims.*

CONCLUSIONS

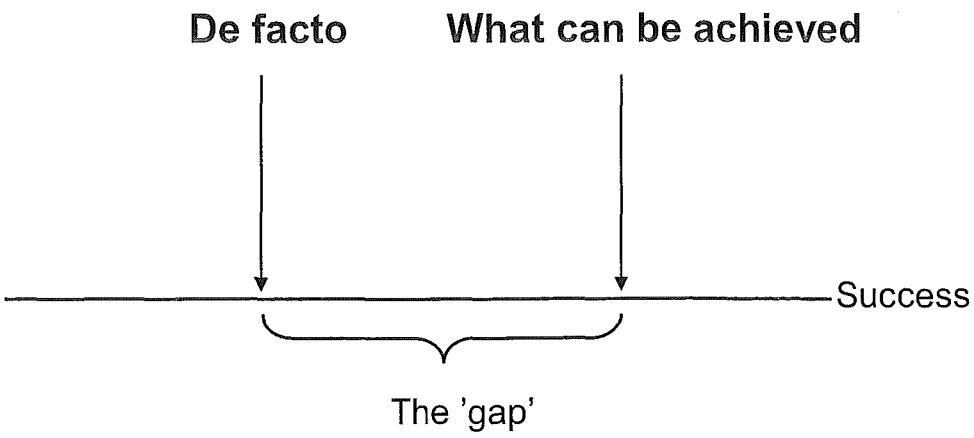
- In spite of a marked caries decline:
  - Endodontic treatment is still frequently performed.
  - Caries is still the main reason for performing root canal treatment.
- As a endodontic preventive strategy:
  - Stepwise excavation versus direct complete excavation showed a significantly higher success rate defined as unexposed pulps with sustained pulp vitality without apical radiolucency after ~1½-year follow-up.
  - The frequency of pulp vitality without apical radiolucency showed no difference after ~1½-year follow-up between partial pulpotomy and direct pulp capping.
  - Direct pulp capping and partial pulpotomy had low success rates in adults.
- Potential factors influencing endodontic treatment quality among GDPs were:
  - A low rate of adoption of new technology and rubber dam.
  - The creation of an aseptic operation field was regarded as the most difficult procedure, whereas root canal treatment was evaluated as relatively easy and was carried out rapidly.
  - The GDPs seemed to emphasize the presence of clinical symptoms too much and periapical diagnosis and root canal infection too little with respect to treatment outcome as opposed to a gold standard.

- The self-awareness of the GDPs disclosed a high level of confidence in performing endodontic treatments.
- Sub-optimal root filling quality might be accepted as long as it prevents symptoms.
- The GDPs assessed themselves as being at a non-satisfactory level only in relation to the topic *microbiology*.
- Endodontic-related claims were the second most frequent category during the period studied.
- Perceived technical shortcomings dominated the endodontic complaints.
- Male dentists and female patients were overrepresented in the claim material, indicating a sex difference on aspects of the patient-dentist communication, which is important for liability claims.
- The importance of aseptic treatment techniques was not mentioned in the available reports from the Dental Complaint Boards.

- Taken together in relation to root canal treatment, Danish GDPs seem to know what they should do, think that they are good at doing it, but often perform inadequately as indicated from epidemiological data.

FUTURE WAYS TO PROCEED

Is it possible to overcome the 'gap' between the outcome rates obtained amongst GDPs and what can be achieved?



Can we reduce the number of endodontic treatments?

- The use of stepwise excavation reduces the number of pulp exposures in adults, thus a more throughout application of this approach is acknowledged even though complete prevention seems unrealistic.

- Taking the different outcomes between treatment of unexposed and exposed pulp into account, excavation approaches to avoid pulp exposure merit further study.

When root canal treatments are performed, how can we reduce the 'gap'?

- The last statement in the conclusion may reflect lack of insight, where insight may be regarded as a combination of three related elements: awareness of one's own performance, awareness of the performance of others, and a capacity to reflect on both of these measures and make a judgement (Hays *et al.* 2002). In the GDP environment 'the awareness of the performance of others'

may be difficult, as the dentist quite often may run the office alone, and a valuable 'insight' cannot take place. A change of behaviour requires evaluation from an external source making feedback on quality possible. Postgraduate education in Denmark should place emphasis on these aspects.

- The adoption of new technologies/ innovations may also provide some answers/ routes to follow (Rogers 1983). If, for example, rubber dam is going to be adopted this appears to require prior adoption of a new value system, with more focus on the prevention and treatment of the endodontic infection, as well as visible consequences if it is not carried out.

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English summary

There is a great discrepancy between the healing rates that can be achieved with endodontic treatment and those found in most populations as performed by General Dental Practitioners (GDPs). This 'gap' was the starting point of the present dissertation. Factors that influence the endodontic treatment quality in general dental practice are not very well known. Quality is shaped in an interplay between the knowledge, attitudes, and skills of the dentist as well as the demand and satisfaction of the patient framed in a context that eventually involves the whole of society. The overall aim was to reveal *reasons*, *prevention*, and *quality-shaping factors* that influence endodontic treatments in general dental practice.

The first part of this dissertation examines the incidence and reasons to perform endodontic treatments in Denmark. Based on a 25-year record of annual treatment statistics obtained from the Danish Dental Association and the Danish National Health Insurance the endodontic-related service pattern among GDPs showed an increased frequency (17%) of performed root fillings per 1000 patients (**Study I**) and an increased rate of root fillings per tooth. Using a questionnaire among 600 randomly selected Danish GDPs, the most common reason for performing root canal treatments was caries in vital teeth (55%)(**Study II**).

The next part of the dissertation shows the potential of an endodontic preventive treatment strategy in deep caries in adults. Deep caries excavation was investigated in a randomized clinical multicentre trial (**Study III,** excavation trial) comparing stepwise excavation and direct complete excavation. In a nested randomized trial pulp capping procedures (direct pulp capping versus partial pulpotomy) were compared (**Study III,** pulp capping trial) in patients where excavation had led to pulp exposures. Stepwise excavation was significantly better in preventing pulp exposure and the proportion of patients with sustained tooth vitality without apical radiolucency at ~1½-year follow-up was significantly higher in the stepwise excavation group (74.1%) versus the direct complete excavation group (62.4%). In patients where pulp capping procedures were carried out, direct pulp capping (31.8%) and partial

pulpotomy (34.5%) had low success rates after ~1½–year follow-up, and the vast majority of the treatments failed due to pain.

The final part of the dissertation focuses on possible factors shaping endodontic treatment quality among GDPs. A factor that could explain a sub-optimal treatment quality was a low rate of adoption of new technology (such as nickel-titanium instruments, apex locators and warm gutta-percha techniques). Also the rare use of rubber dam was noted (**Study IV**). Other factors influencing treatment outcome investigated amongst the GDPs were their endodontic knowledge, and their skills and attitude to various endodontic topics based on 'self-assessments'. The creation of an aseptic operation field was regarded as the most difficult procedure, whereas root canal treatment was evaluated as relatively easy and was carried out rapidly (**Study II**). With respect to treatment outcome the GDPs seemed to put too much emphasis on factors associated with clinical symptoms, and too little emphasis on factors related to infection condition such as 'periapical status' and 'root canal infection' (**Study V**). Concomitantly, the GDPs regarded the technical root filling quality as important for the outcome of the treatment (**Study V**). The vast majority of the GDPs rarely assessed themselves as being at a *non-satisfactory* level with respect to 'root canal preparation procedure' and 'root filling procedure'. The only topic where the GDPs assessed themselves as being at a *non-satisfactory* level was 'microbiology'.

In the interplay between the dentist and the patient, the second most frequent malpractice claim category was endodontic treatment (**Study VI**). The most frequent reason for sub-optimal endodontic treatments was technical shortcomings and technical treatment complications. Male dentists and female patients were overrepresented in the material indicating a sex influence on aspects of the patient-dentist communication that are important for liability claims. No specific attention was paid to the importance of an aseptic technique during root canal treatment in the available reports from the complaint boards. Thus, the focus on endodontic infection control seems not yet entirely integrated between the education platforms found within the universities in Denmark.

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Taken together in relation to root canal treatment, Danish GDPs seem to know what they should do, think that they are good at doing it, but often perform inadequately as indicated from epidemiological data.

Clinical implications – *For the prevention of endodontic treatments in adults with deep caries a stepwise excavation approach should properly be recommended versus a direct complete excavation approach. Both pulp-capping procedures investigated had low success rates and whether these procedures should be performed at all in deep cariously exposed adult teeth is questioned.*

The 'gap' between the endodontic healing rates that can be achieved and those found in most populations may be decreased if:

- *A higher rate of adoption takes place of new technological advances combined with a focus on preoperative factors that are important in determining and controlling endodontic treatment outcome.*

- *A greater focus can be implemented on infection control (such as the mandatory use of a cleansed and disinfected rubber dam) during endodontic treatment.*

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Dansk resumé

Inden for endodontisk behandling er der stor forskel mellem helingsprocenter, der er mulige at opnå og dem, der rapporteres i de fleste populationer, hvor behandlingerne er udført af alment praktiserende tandlæger. Denne 'forskel' var udgangspunktet for den aktuelle afhandling. Faktorer der influerer på endodontisk behandlingskvalitet i almen praksis er ikke undersøgt og beskrevet i detaljer. Kvalitet er formet i et samspil mellem tandlægens viden, attitude og færdighed, samt ud fra krav og tilfredshed ikke bare fra patienten, men også i en kontekst, der involverer hele samfundet. Det overordnede formål med nærværende afhandling har været at beskrive *årsager, forebyggelse og kvalitetsformende faktorer,* der påvirker endodontisk behandling i almen tandlægepraksis.

Den første del af afhandlingen undersøger forekomst af og årsag til, at der udføres endodontisk behandling i Danmark. Baseret på en 25-års registrering af årlige behandlingsstatistikker fra Tandlægeforeningen og Sundhedsstyrelsen har de endodontisk relaterede serviceydelser udført af alment praktiserende tandlæger vist en stigning (17%) i antallet af udførte rodfyldninger per 1000 patienter (**Studie I**), samt en øget andel af rodfyldninger per tand. På baggrund af en spørgeskemaundersøgelse udført blandt 600 tilfældigt udvalgte danske tandlæger, kunne det konstateres, at den hyppigste grund til sidst udførte rodbehandling var caries i en vital tand (55%)(**Studie II**).

Den næste del af afhandlingen viser potentialet i en endodontisk forebyggende behandlingsstrategi over for profund caries hos voksne. Ekskavering af profund caries blev undersøgt i et randomiseret klinisk multicenter forsøg (**Studie III**, ekskaveringsforsøget), hvor gradvis ekskavering blev sammenlignet med én endelig ekskavering. I et efterfølgende randomiseret forsøg blev to pulpaoverkapningsprocedurer (direkte overkapning versus partiel pulpotomi) sammenlignet på patienter, hvor ekskavering havde ført til eksponering af pulpa (**Studie III**, pulpaoverkapningsforsøget). Gradvis ekskavering var signifikant bedst til at forebygge eksponering af pulpa. Andelen af patienter med vedvarende vital pulpa uden apikal opklaring efter omkring 1½ års kontrol var signifikant højere i gradvis ekskaverings-

gruppen (74.1%) versus gruppen, hvor én endelig ekskavering blev udført (62.4%). På patienter, hvor pulpa-overkapningsprocedurerne var udført, havde både den direkte overkapning (31.8%) og den partielle pulpotomi (34.5%) lave succesfrekvenser efter omkring 1½ års kontrol, og hovedparten af behandlingerne mislykkedes som følge af smerter inden kontrolbesøget.

Sidste del af afhandlingen har fokus på mulige faktorer, der kan influere på endodontisk behandlingskvalitet blandt alment praktiserende tandlæger. Indledende faktorer, som kunne forklare en 'sub-optimal' behandlingskvalitet, var lav adoptering af ny teknologi (f.eks. nikkel-titan hånd-instrumenter, roterende nikkel-titan instrumenter, apeks lokatorer og varm guttaperka teknik), men også den sjældne anvendelse af kofferdam (**Studie IV**). Af andre faktorer, der blev undersøgt blandt de alment praktiserende tandlæger, var deres endodontiske viden (baseret på selv-vurdering) vedrørende langtidsprognose af en behandling, samt tandlægernes attitude og færdigheder i relation til relevante endodontiske områder. Udfærdigelsen af et aseptisk arbejdsfelt blev opfattet som en relativt vanskelig procedure, hvorimod selve rodkanalbehandlingen blev vurderet som værende relativt 'let' og til at kunne blive udført hurtigt (**Studie II**). Hvad angik faktorer, der kunne påvirke en rodbehandlings prognose, syntes de praktiserende tandlæger at tillægge for mange præoperative faktorer for stor betydning sammenlignet med en guld standard. Eksempelvis var der stor fokus på, at akutte kliniske symptomer i sig selv kunne forværre prognosen for endodontisk behandling. Mindre betydning blev tilegnet faktorer, der var årsagsrelateret til infektion, såsom periapikal status samt bakterier i rodkanalen (**Studie V**). På samme tid anerkendte de alment praktiserende tandlæger vigtigheden af den tekniske kvalitet af rodfyldningen i forhold til behandlingens prognose (**Studie V**). Størstedelen af tandlægerne vurderede sig selv som værende på et *tilfredsstillende* niveau hvad angik 'mekanisk udrensning' og 'rodfyldning'. 'Mikrobiologi' var det eneste emne, hvor man vurderede niveauet som værende *ikke tilfredstillende*.

I samspillet mellem tandlæge og patient var den næsthyppigste årsag til en patientklage blandt de tandlægefaglige områder fra den endodontiske kategori

(**Studie VI**). Den hyppigste grund til endodontisk klage var 'sub-optimal' endodontisk behandling dvs. tekniske mangler samt tekniske behandlingskomplikationer. Mandlige tandlæger og kvindelige patienter var overrepræsenteret i det undersøgte klagemateriale, hvilket indikerer en mulig kønspåvirkning i relation til en 'patient-tandlæge kommunikation' som kan forårsage udvikling af en patientklage sag. I det tilgængelige materiale fra klagenævnene blev der ikke noteret særlig opmærksomhed omkring vigtigheden af en aseptisk procedure herunder en manglende anvendelse af kofferdam under rodbehandling. Med forbehold kan det konstateres, at fokus på endodontisk infektionskontrol endnu ikke synes fuldstændigt sammenfaldende med de vejledninger, der udgår fra universiteterne i Danmark.

Sammenfattende ved alment praktiserende tandlæger i Danmark godt, hvad de behandlingsteknisk skal gøre og synes selv de er gode, - men udførelsen er ofte utilstrækkelig, hvilket er underbygget ud fra epidemiologiske data.

Kliniske implikationer – *Ved forebyggelse af endodontiske behandlinger blandt voksne med profund caries kan en gradvis ekskaveringsprocedure formentlig anbefales frem for direkte ekskavering. Begge undersøgte pulpa-overkapningsprocedurer udviste lave helingsresultater og spørgsmålet er, om disse procedurer overhovedet skal udføres hos voksne patienter, hvor ekskavering af profund caries har ført til eksponering af pulpa.*

'Forskellen' mellem mulige endodontiske helingsresultater og dem der er rapporteret i de fleste populationer, kan formodentlig mindskes hvis:

- *Der iværksættes en øget adoptering af nyere endodontisk teknologi kombineret med fokus på de præoperative faktorer, der reelt influerer på det endodontiske behandlingsresultat.*

- *Der etableres en øget fokus på infektionskontrol (så som obligatorisk anvendelse af afvasket desinficeret kofferdam) under udførelsen af en endodontisk behandling.*

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Appendix I

Bjørndal L, Reit C (2004) The annual frequency of root fillings, tooth extractions and pulp-related procedures in Danish adults during 1977-2003. *International Endodontic Journal* **37,** 782-8.

The annual frequency of root fillings, tooth extractions and pulp-related procedures in Danish adults during 1977–2003

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Abstract

Bjørndal L, Reit C. The annual frequency of root fillings, tooth extractions and pulp-related procedures in Danish adults during 1977–2003. *International Endodontic Journal*, **37**, 782–788, 2004.

Aim To investigate a hypothesized long-time decrease of endodontic treatment in a population with low caries prevalence.

Methodology A Danish nationwide database including almost all dental diagnostic, prophylactic and therapeutic procedures performed in Danish adults was available. Data on the annual frequencies of root fillings, extractions, pulpotomies, direct pulp cappings and stepwise excavations between 1977 and 2003 were analysed. Data on pulpal and periapical diagnoses were not available and on patients age and gender only from 1996.

Results Between 1977 and 2003 the annual number of root filled canals increased from 268 223 to 364 867 (36%). The annual number of root filled teeth increased from 160 119 to 191 803 (20%). During the period, the annually registered patients increased by 16%. Calculated per 1000 patients, the number of root fillings showed a statistically significant increase of 17%. In root filled teeth the canal/tooth ratio increased from 1.67 to 1.96. Root fillings were frequently recorded in all age groups with the bulk of treatments performed on patients between 40 and 60 years of age. At a total population level, the rate of root fillings decreased among younger individuals and increased among older. The annual number of tooth extractions was more than halved from 656 624 in 1977 to 346 490 in 2003. Pulpotomies decreased markedly over the period and less than 10 treatments per 1000 patients were noted for pulp capping as well as stepwise excavation procedures.

Conclusions The present study failed to show a long-time decrease of endodontic treatment in a population with low caries prevalence. On the contrary, an increase of root filled canals was observed between 1977 and 2003, which was probably due to a reduction of the tooth extraction rate and an increased treatment of multi-rooted teeth.

Keywords: endodontic epidemiology, frequency of root fillings, pulp capping, stepwise excavation, tooth extractions.

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Introduction

Pulpal injury may be caused by several factors such as caries, trauma and dental procedures. Bacteria and bacteria-derived products may reach the pulp via carious lesions, leaking restorations or tooth fractures. Among these factors caries (including its sequelae) has traditionally been regarded as the main aetiological reason for pulpal disease (Trowbridge 2002). Within the last few decades, several western countries have seen a marked decline in caries activity in children and adolescents (Marthaler 2004) as well as in adults (Hugoson *et al.* 1986). Hypothetically, the decline in caries prevalence should imply a decrease in the incidence of pulpal disease and subsequently a decrease in the need for endodontic treatment in such

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populations. However, endodontic epidemiological surveys have mainly reported on the number of root filled teeth in various populations, while the time trend, in terms of annual treatment frequency, has attracted only scarce interest (for a review see Eriksen *et al.* 2002).

The prevalence of caries among Danish children has followed the international trend and decreased during the last three decades (Bille *et al.* 1986). Poulsen & Malling Pedersen (2002), for example, found that the mean of decayed, missed and filled surfaces (DMFS) in 15-year-old boys and girls changed from 6.68 in 1988 to 3.24 in 2001. The oral health status of the adult Danish population has also improved considerably during the past 15 years using the number of natural teeth present and the frequency of dental visits as oral health indicators (Petersen *et al.* 2003).

As a result of an economic agreement between the Danish Dental Association (DDA) and the Danish National Health Insurance (DNHI) in 1973, a nationwide database was established. This database includes registrations of almost all dental diagnostic, prophylactic and therapeutic procedures performed in Danish adults since 1977. The aim of the present report was to explore the hypothesized long-time decrease of endodontic treatment frequency in a population with low caries prevalence, by analysing data from 1977 to 2003 in the register of the DNHI.

Materials and methods

The database

In 1973, an economic agreement was made between the DDA and the DNHI, implying that parts of the dental treatment costs for adult patients were to be funded by the DNHI. In order to receive government fees, dentists had to make a report to a central register. In 1977 a database became available, reflecting the dental service pattern from almost all general dental practitioners (GDP) treating adult patients in Denmark (Schwarz 1996). From 1977 to 1999, the fees for dental treatments were fixed, and the NHI-funded part for endodontic treatments accounted for about 40%. From 1999, only the part funded by the NHI was fixed. The annual number of actual and potential users (in this study defined as individuals ≥20 years of age) of the DNHI system is displayed in Fig. 1 (Danmarks Statistik – http://www.statistikbanken.dk). Over the years, the number of actual users increased by 16% and the potential users by 14%. In the first 10-year period of the database (1977–1987), only the number of performed treatments was recorded. Therefore, the number of patients in the files had to be estimated. Each patient, who actually went to a dentist during these years, received an average of 1.5 dental examinations, and on this basis the number of patients was estimated (Schwarz 1996).

Recorded treatment procedures

1. Root filling: In the register treatments were basically recorded per canal and not per tooth. However, a specific fee was received for the first canal of a tooth allowing a distinction to be made between the annual number of treated teeth and treated canals. In the number of 'root fillings', cases treated with endodontic surgery are also included. Information was not available regarding pulpal and periapical diagnosis.
2. Tooth extraction: Surgically removed teeth were not included.
3. Pulpotomy.
4. Pulp capping: DNHI funding started 1992.
5. Stepwise excavation: This treatment was included in the economic agreement in 1999, and was recommended when a deep carious lesion was clinically judged to lead to pulp exposure.

Patient characteristics

From the register, patient characteristics as gender and age were available as total counts in 1996, and as relative counts (per 1000 patients) in 1998.

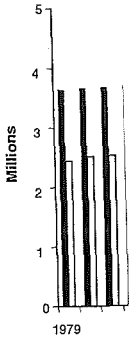
Statistics

Time trends were statistically examined by linear regression analysis. Using the slope of the line of the regression (β) the analysis produced an estimate of growth per year and a 95% confidence interval (β ± 2 SD). The null hypothesis (no growth) was rejected when P was less than 0.05. Positive values of β indicate positive growth, whereas negative values of β indicate negative growth.

Results

Root fillings

The DNHI recorded 268 223 root filled canals in 1977 and 364 867 in 2003, corresponding to a 36% increase. The number of root filled teeth increased



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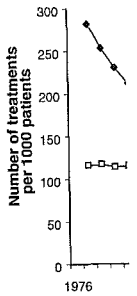

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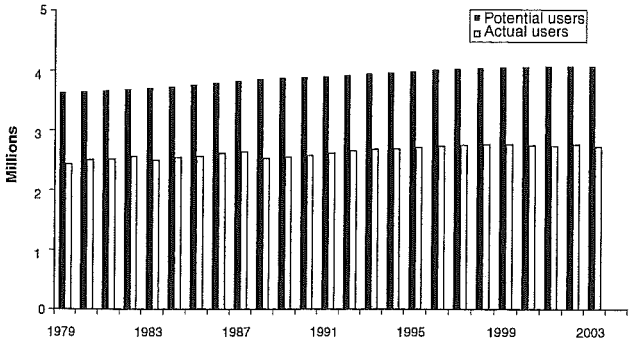

Figure 1 The annual number of potential (dark bars) and actual users (grey bars) of the DNHI system. The number of actual users are estimated up to 1987.

from 160 119 to 191 803 during the registered period (20% increase). The added number of annually performed root fillings was partly explained by an increased number of individuals (16%) using the NHI system (Fig. 1). As calculated per 1000 patients, the number of root fillings showed a statistically significant increase of 17% ($\beta = 1.1 \pm 0.24$; $P = 0.000$) (Fig. 2).

The ratio between the number of root filled canals and teeth increased continuously from 1.67 to 1.96 ($\beta = 0.014 \pm 0.000$; $P = 0.000$) indicating that more and more multi-rooted teeth were treated during the period.

The distribution of annually recorded root fillings over age and gender is displayed in Tables 1–3. Endodontic treatment was frequently recorded in all age groups with the bulk of treatments performed on patients between 40 and 60 years of age. During the last 6–8 years, small changes in the treatment pattern were observed. The number of root fillings increased significantly among patients (actual users) in the youngest age group, and decreased among patients 60–69 years of age and over 80 (Table 2). When calculations were based on all potential users of the system, a contrasting picture emerged: decreasing rate of root fillings among younger people and increasing among older (Table 3).

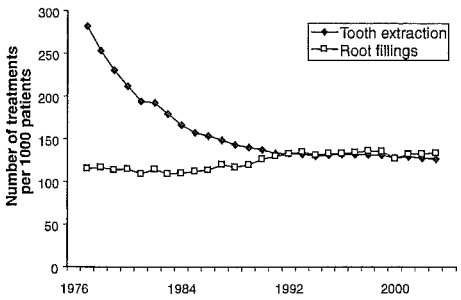

Figure 2 The number of root fillings and extractions is observed per 1000 patients from 1977 to 2003. Data on number of patients are based on estimates (1977–1987) and actual figures reported (1988–2003).

Tooth extractions

The number of tooth extractions was more than halved during the period of the study, from 656 624 in 1977 to 346 490 in 2003 (Fig. 2). The reduction rate was most obvious during the first 10 years of the period. However, on a total population basis a continuous decreased rate of extraction was observed in the later years of the period, 1996–2003, among individuals below 70 years of age. Among older persons the rate increased (Table 4).

Pulpotomies, direct pulp cappings and stepwise excavations

The frequency of pulpotomies was substantially reduced through the period of the study, from 30 616 in 1977 to 2357 in 2003. In 2003, the total number of direct pulp cappings reached 15 090, and 18 610 stepwise excavations were recorded. Recorded treatment procedures, counted per 1000 patients over the years, are displayed in Fig. 3.

Discussion

With only small variations over time, 70% of the potential users of the system were annually recorded in

Table 1 The total number of root fillings performed in relation to age and gender

Age groups	1996		1997		1998		1999		2000		2001		2002		2003	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
20–29	25 975	27 654	26 036	27 035	23 843	25 345	24 636	27 154	22 213	24 236	22 974	25 467	21 500	25 055	21 325	23 778
30–39	38 620	42 306	40 704	43 817	40 217	43 711	40 087	43 746	35 876	40 686	37 167	40 905	36 788	40 632	36 535	40 566
40–49	43 076	46 099	42 757	45 643	42 698	45 564	41 601	45 077	38 164	41 923	39 673	43 086	39 255	43 114	39 722	43 106
50–59	38 504	36 809	40 564	38 713	43 525	41 722	42 413	41 909	40 445	40 184	41 433	41 196	42 296	41 303	43 210	41 205
60–69	19 919	17 535	20 208	17 972	22 388	19 312	22 274	19 015	21 703	18 729	22 818	20 063	24 370	20 106	24 924	21 559
70–79	9362	9193	9497	9409	10 234	9963	9914	9377	9753	9046	10 031	9754	10 120	9586	10 468	9660
80+	2296	2880	2252	2851	2613	3396	2517	3230	2549	3335	2670	3304	2774	3591	2793	3630
Total	177 752	182 476	182 018	185 441	185 518	189 013	183 442	189 508	170 703	178 139	176 766	183 775	177 103	183 387	178 977	183 504

the DNHI database. In a questionnaire, Petersen *et al.* (2003) found that eight of 10 Danish adults reported that they made regular visits to the dentist and that only 9% had not seen a dentist through the past 5 years. In an international perspective, Danish adults are very frequent users of the dental health services (Petersen & Holst 1995). Within a major part of the observed period the DNHI funded about 40% of the total cost of an endodontic treatment. Hence, the economic incitement was high enough to believe that almost all endodontic treatments were reported.

The present study could not support the hypothesis that endodontic treatment frequency will decrease in a population with decreasing caries progression. Among Danish adults, 36% more root canals were filled in 2003 as compared with 1977. This addition can partly be understood as an expansion of the patient population (16%), and expressed as the number of root canals treated per 1000 patients the increase reached 17%. This observation can probably be explained by (i) the drastically reduced extraction rate, which has put substantially more teeth at risk of being pulpally injured, and (ii) the increased treatment of multi-rooted teeth. During the period, canal/tooth ratio increased from 1.67 to 1.96. The latter time trend was also found in a comparison of two radiographically examined samples from Aarhus, Denmark. In the later sample (1997–1998) molars were root filled more often than in the earlier studying period (1974–1975) and had become the most frequently root filled tooth group (Kirkevang *et al.* 2001).

A marked improvement of the oral health among Danish children and adolescents took place at the end of the 1970s and through the 1980s (Poulsen & Scheutz 1999). Ten years ago, in a study of Danish 20-year-old males, Ekstrand *et al.* (1994) reported a very low occurrence of endodontic treatment and concluded that the provision of dental health care to children had a remarkable long-term effect on the dental health status of young adults. However, from an endodontic point of view, data from the DNHI register show a somewhat different picture. Endodontics still seems to be an important part of the dental service provided. Although the bulk of root fillings is associated with middle-aged patients, endodontic treatment is common among younger as well as older individuals (Tables 2 and 3).

In recent years, some small but statistically significant changes were found. Based on the total Danish population ('potential users' of the DNHI), the number of annually provided root fillings decreased among individuals below 60 years of age, and

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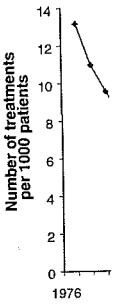

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Age groups	1998	1999	2000	2001	2002	2003	β ± 2 SD	*P*-value
20–29	102	110	103	113	114	116	2.6 ± 0.8	0.038
30–39	143	145	135	141	142	144	0.1 ± 1.8	0.955
40–49	156	154	144	150	150	151	−0.9 ± 2.0	0.429
50–59	156	151	141	143	145	146	−1.9 ± 2.2	0.175
60–69	139	132	124	127	125	123	−2.8 ± 1.6	0.029
70–79	113	106	102	106	103	101	−1.9 ± 1.4	0.057
80+	96	88	85	83	84	81	−2.5 ± 1.3	0.018

Table 2 The number of root fillings per 1000 patients (actual users) in relation to age. β denotes the slope of the line of regression, representing an estimate of growth per year

Age groups	1996	1997	1998	1999	2000	2001	2002	2003	β ± 2 SD	*P*-value
20–29	70	71	67	71	65	69	68	68	−0.2 ± 0.7	0.423
30–39	102	104	103	103	94	96	95	95	−1.5 ± 0.8	0.001
40–49	117	118	119	117	108	111	110	110	−1.5 ± 0.8	0.011
50–59	113	114	119	116	109	110	110	111	−0.8 ± 1.0	0.144
60–69	81	82	89	87	84	87	88	89	0.9 ± 0.7	0.046
70–79	50	51	55	53	52	56	54	57	0.8 ± 0.2	0.001
80+	25	25	29	28	28	28	29	29	0.6 ± 0.3	0.016

Table 3 The number of root fillings per 1000 potential users in relation to age. β denotes the slope of the line of regression, representing an estimate of growth per year

Age groups	1996	1997	1998	1999	2000	2001	2002	2003	β ± 2 SD	*P*-value
20–29	60	60	57	58	56	56	54	51	−1.1 ± 0.3	0.000
30–39	55	55	55	53	51	52	50	49	−0.9 ± 0.2	0.000
40–49	85	85	83	81	78	78	76	73	−1.7 ± 0.3	0.000
50–59	125	125	123	122	116	113	113	112	−2.3 ± 0.5	0.000
60–69	138	138	139	138	133	134	130	130	−1.4 ± 0.5	0.001
70–79	110	111	119	118	117	120	119	124	1.7 ± 0.7	0.004
80+	82	80	88	85	85	86	90	89	1.1 ± 0.7	0.013

Table 4 The number of tooth extractions per 1000 potential users in relation to age

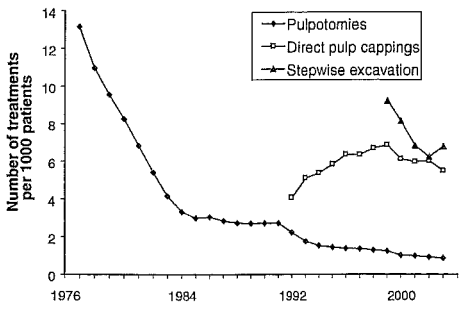

Figure 3 The number of pulpotomies, direct pulp cappings and stepwise excavations per 1000 patients as reported by the DNHI. The number of pulpotomies is estimated up to 1987. Data on number of patients are based on estimates (1977–1987) and actual figures reported (1988–2003).

increased among those above (Table 3). Similar changes were earlier described by Sundberg & Öwall (1989), who between 1974 and 1985 found a 51% decrease in endodontic treatment among younger Swedish patients (20–29 years) and a 21% increase among patients older than 70 years. In the Danish population the observations might partly be explained by recent changes in the dental visiting habits of adults. In an interview study, Petersen *et al.* (2003) reported that in 1987, 35% of the participants at ages 65–74 years saw a dentist regularly compared with 66% in 2000. A decrease of patients regularly attending the dental service was found among young adults. In 1987, 90% of individuals at ages 25–34 reported to visit a dentist on a regular basis and 78% in 2000. In addition, studying the aetiology of endodontic treatment in a Swedish county, Reit *et al.* (1993) found that about one-third of the treatments performed on patients over 60 years of age were not directly aimed to cure pulpal or periapical pathosis. Frequently, root canal treatments were carried out for prosthodontic reasons.

During the period of the study, the number of pulpotomies performed was drastically reduced. This

probably reflects that the old procedure of treating the curved root in a multi-rooted tooth with pulpotomy has become regarded as obsolete by the practitioners. Instead, the full canal is being instrumented and obturated.

Rather low frequencies of pulp capping and stepwise excavation were recorded. Studies have shown that both treatment methods can be applied with a good prognosis (Hørsted *et al.* 1985, Bjørndal 2002). The infrequent use among Danish dentists might be due to a preference for a more extensive pulp therapy, such as pulpectomy. However, it might also be a reflection of low caries prevalence in the population. The overall decline in the prevalence of caries can be understood as a reduced rate of disease progression (Thylstrup & Birkeland 1994). In addition, carious lesions may take longer to progress through enamel and dentine (Mejàre *et al.* 1998). Thus, it could be expected that a prolonged period is needed for caries to progress to the stage of causing irreversible pulp pathosis. Therefore, in the future, vital pulp therapies might change towards less radical and noninvasive methods (Murray *et al.* 2002, Smith 2002).

Conclusion

The present study failed to show a long-time decrease of endodontic treatment in a population with low caries prevalence. On the contrary, an increase of root filled canals was observed between 1977 and 2003, which probably was due to a reduction of the tooth extraction rate and an increased treatment of multi-rooted teeth.

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Appendix II

Bjørndal L, Laustsen MH, Reit C (2006) Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. *International Endodontic Journal* **39**, 785-90.

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Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare

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Abstract

Bjørndal L, Laustsen MH, Reit C. Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. *International Endodontic Journal*, **39**, 785–790, 2006.

Aim To study the reasons given by a representative sample of Danish general dental practitioners (GDPs) for undertaking root canal treatment and, to investigate their confidence in performing root canal treatment on molar teeth.

Methodology A questionnaire was sent to 600 Danish GDPs randomly selected from the roster of the Danish Dental Association. They were asked to recall various factors about their experience of the last root filling they completed, including the reason for treatment and the pulp diagnosis. Self-assessments on 100-mm visual analogue scales (VAS) were reported concerning the confidence in performing root canal treatment of a molar. End-point definitions were 'very easy' (0) and 'very difficult' (100), respectively. Time reports of molar treatments were given in categorized groups.

Results The most frequent reason for performing root canal treatment was caries within the tooth involved (55%). The majority of treatments involved teeth with vital pulps (54%). Retreatments were carried out in 2% of the cases. The confidence in performing root canal treatment varied but was relatively high, expressed as VAS-values below 50. The creation of an aseptic working field was regarded as the most difficult procedure followed by root canal preparation. Fifty-six percent of the responders stated a time frame of 46–75 min to complete root filling in a molar tooth.

Conclusions Root canal treatment in Denmark was reported to be undertaken most often because of caries. Treatment was typically performed in molar teeth with vital pulp. Even though apical periodontitis was frequently noted in root filled teeth, retreatments were rare. From a subjective perspective root canal treatment was not considered to be very difficult and was carried out relatively rapidly.

Keywords: aetiology of root canal treatment, caries, questionnaire survey, retreatment.

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Introduction

Although caries generally is regarded as the main aetiological reason for pulpal injury, the demand for root canal treatment does not necessarily decrease in a population with a decreasing caries prevalence. On the contrary, Bjørndal & Reit (2004) found a 17% increase in the annual frequency of root filled canals in Danish adults between 1977 and 2003. Essentially, this was due to (i) a drastic reduction of the tooth extraction rate, putting more teeth at risk of having pulp disease, and (ii) an increased treatment of multi-rooted teeth. In a sample obtained in Denmark from the Aarhus region in 1997–98, Kirkevang *et al.* (2001) found that molars had become the most frequently root filled tooth group. Thus, over time a change in the root canal treatment panorama was observed, from treatments mostly

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involving incisors and pre-molars to molars, hypothetically representing an increased frequency of technically demanding cases.

The reasons and indications for contemporary root canal treatment, as performed in general dental practice, are not well known. Although there is a large pool of potential retreatment cases, Reit *et al.* (1993) and Karlsson & Reit (1994) reported a low incidence of retreatment in two Swedish samples. Rather, they found that root canal treatment was most often performed as a consequence of symptoms such as pain and tenderness, and that treatment was instituted in teeth with symptomless chronic pathological processes more rarely.

The aim of the present study was (i) to study the reasons for root canal treatment as given by a representative sample of Danish general dental practitioners (GDPs), and (ii) to investigate their confidence in performing technically challenging root canal treatment of molar teeth.

Material and methods

In January 2004, a questionnaire was sent to 600 Danish GDPs. The GDPs were selected from the roster of the Danish Dental Association, which at that time listed 3293 members. The selection was carried out at random, with the acceptance of the Danish Dental Association, using a database software programme (Microsoft SQL Server 2000 Standard Edition, version 8.0.534, Minnesota, MN, USA). At present, no recognized post-graduate specialist training in Endodontology is available in Denmark; therefore, root canal treatment is almost exclusively performed by GDPs in private practice. The questionnaire was mailed, together with a letter guaranteeing confidential and anonymous processing of the data, and a stamped, coded return envelope. Nonresponders were identified by the code and approached by a second mail in March 2004. To the second-wave nonresponders phone calls were made.

The questionnaire asked for information regarding the age and gender of the responder as well as number of years in practice, employment status and the weekly number of working hours as well as the time devoted to endodontic treatments. The responder was asked to recall the last endodontic case they had undertaken and state the gender and age of the patient, the type of tooth treated, the reason for treatment and the pulpal diagnosis. In addition, the GDPs were asked to envisage root canal treatment of a mandibular molar and assess their confidence in making the access cavity preparation, providing an aseptic operating field (i.e. including the use of rubber dam), locating the canal orifices and instrumentation of the root canals. The assessments were made on 100-mm visual analogue scales (VAS), where end-points were marked as 'very easy' and 'very difficult', respectively. Furthermore, responders were asked to estimate the time taken to prepare the access cavity, perform mechanical root preparation and root filling, respectively, in a mandibular molar. The reports were categorized in five groups: ≤15, 16–30, 31–45, 46–60 and ≥61 min.

Statistical analysis

Summary statistics, including cross-tabulation tables, were carried out. ANOVA of the VAS-assessed confidence level was performed on the basis of mean values of each of the four questions. A stepwise model was applied. Model 1 addressed whether demographical factors such as gender, age and the year when dental qualification was obtained had any effect on the response pattern. Model 2 contained the variables employment status (clinic owner or associate), the number of clinical working hours per week, and the number of endodontic treatment sessions per week. Initially a model 1 analysis was performed followed by a step-by-step removal of nonsignificant variables. If significant variables were found, they were incorporated in model 2. Tests of independence were performed as Monte Carlo simulated exact tests using Digram (Kreiner 2003) for variables with categorical scales and with data not showing a normal distribution. Partial γ-coefficients (a nonparametric rank correlation, Upton 1999) were used to characterize the degree of association in these cases.

Results

The overall response rate was 79.2% ($n = 475$). Five questionnaires were returned blank and 18 were only partially completed. The major reason given for not responding was that the dentists felt too busy to complete the form. Also, 10 practitioners questioned the anonymity (the return envelope was coded) and did not want to take part in the study. The number of forms used in the final analysis was 452 (75.3%).

Fifty-three per cent of the responders were men. However, amongst younger dentists, a majority were women (Fig. 1). Seventy per cent of the GDPs were practice owners, and 88% worked 27 h or more per

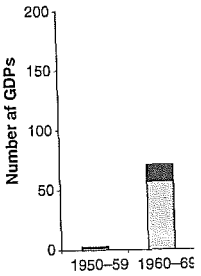

Figure 1 Distribution of qualification was obtain

week. Fifty-two perce endodontic treatment more than five.

The cases were m (55%, 95% CI: 50; 5 molars (60%, 95% majority, the pulp w (Table 2). Teeth with in 41% (95% CI: 36

Table 1 Distribution of

	Caries	De cr
Incisors	23	0
Pre-molar	73	7
Molar	152	52
No inf.	2	0
n (%)	250 (55)	59

[a]When pain could not b
[b]Other information.

Table 2 Distribution of

	Caries
HealtyPulp	0
Pulpitis	155
Pulp necr. –AP	31
Pulp necr. +AP	58
Root-filled –AP	0
Root-filled+AP	0
Other/no infor.	6
n (%)	250 (5

[a]When pain could not b
[b]Other information.

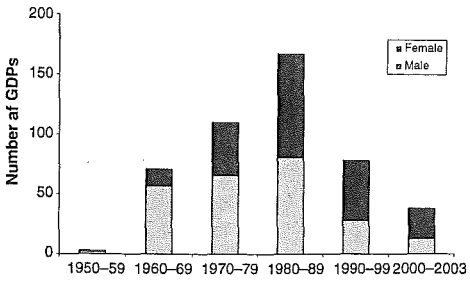

Figure 1 Distribution of gender and the year when dental qualification was obtained by the GDPs.

week. Fifty-two percent reported to have two to four endodontic treatment visits per week, and 28% had more than five.

The cases were most often associated with caries (55%, 95% CI: 50; 59%) and most treated teeth were molars (60%, 95% CI: 55; 65%) (Table 1). In a majority, the pulp was vital (54%, 95% CI: 49; 59%) (Table 2). Teeth with nonvital pulps were negotiated in 41% (95% CI: 36; 46%) and retreatments carried out in 2% (95% CI: 2; 2%). The typical patient was reported as being between 30 and 59 years of age (70%) (Table 3).

The confidence in performing root canal treatment varied amongst the GDPs (Table 4). The variation could not be explained by gender, years in practice or employment status, but GDPs working few hours with only one weekly endodontic treatment session found the negotiation of canals more difficult than colleagues spending ≥5 sessions with root canal problems per week (ANOVA, $P = 0.0385$). If mean VAS-values were compared, the creation of an aseptic working field (i.e. including the use of rubber dam) was regarded as the most difficult procedure (VAS 44) and preparation of the access cavity the easiest (VAS 24). However, the difference was not statistically significant.

When the root canal treatment of a mandibular molar was divided into access cavity preparation, mechanical preparation of the root canal and root filling, the GDPs reported spending most time with the canal preparation (Table 5). Females did use significantly more time than the men for any procedure, as expressed by the positive γ-coefficients (Table 5). Seventy per cent of the dentists reported that they needed

Table 1 Distribution of number of root filled teeth in relation to tooth type and the aetiology of the root canal treatment

	Caries	Dentine cracks	Pain[a]	Trauma	Defective restoration	Prosthetic retention	Inadequate seal	Old/large restoration	Apical radiolucency	[b]	*n* (%)
Incisors	23	0	6	21	3	11	3	0	0	1	68 (15)
Pre-molar	73	7	6	8	5	4	0	2	4	1	110 (24)
Molar	152	52	25	6	11	3	10	7	3	2	271 (60)
No inf.	2	0	0	0	0	0	0	0	0	1	3 (1)
n (%)	250 (55)	59 (13)	37 (8)	35 (8)	19 (4)	18 (4)	13 (3)	9 (2)	7 (2)	5 (1)	452

[a]When pain could not be placed in relation to the other reasons listed.
[b]Other information.

Table 2 Distribution of number of root filled teeth in relation to diagnosis and the aetiology of the root canal treatment

	Caries	Dentine cracks	Pain[a]	Trauma	Defective restoration	Prosthetic retention	Inadequate seal	Large restoration /crown	Apical radiolucency	[b]	*n* (%)
HealtyPulp	0	0	0	0	0	8	0	0	0	0	8 (2)
Pulpitis	155	45	17	8	4	2	2	2	0	2	237 (52)
Pulp necr. –AP	31	7	4	8	5	4	–	2	0	0	61 (14)
Pulp necr. +AP	58	7	16	19	9	2	2	5	7	1	126 (28)
Root-filled –AP	0	0	0	0	0	0	0	0	0	0	0
Root-filled+AP	0	0	0	0	0	0	9	0	0	0	9 (2)
Other/no Infor.	6	0	0	0	1	2	0	0	0	2	11 (2)
n (%)	250 (55)	59 (13)	37 (8)	35 (8)	19 (4)	18 (4)	13 (3)	9 (2)	7 (2)	5 (1)	452

[a]When pain could not be placed in relation to the other reasons listed.
[b]Other information.

Table 3 Distribution of number of root filled teeth in relation to age of the patient and the aetiology of the root canal treatment

	Caries	Dentine cracks	Pain[a]	Trauma	Defective restoration	Prosthetic retention	Inadequate seal	Old/large restoration	Apical radiolucency	[b]	*n* (%)
0–15 years	0	0	0	3	0	0	0	0	0	0	3 (1)
16–19 years	4	0	1	1	0	0	0	0	0	0	6 (1)
20–29 years	48	3	0	4	2	2	1	1	0		61 (14)
30–39 years	73	11	12	7	4	1	1	2	1	0	112 (25)
40–49 years	51	21	8	7	4	3	5	2	2	1	104 (23)
50–59 years	48	18	10	5	6	4	2	2	2	2	99 (22)
60–69 years	15	4	5	6	3	4	2	2	2	1	44 (10)
70–79 years	9	2	1	2	0	0	2	0	0	0	16 (4)
80+ years	0	0	0	0	0	4	0	0	0	0	4 (1)
No inf.	2	0	0	0	0	0	0	0	0	1	3 (1)
n (%)	250 (55)	59 (13)	37 (8)	35 (8)	19 (4)	18 (4)	13 (3)	9 (2)	7 (2)	5 (1)	452

[a]When pain could not be placed in relation to the other reasons listed.
[b]Other information.

	Preparation of access cavity	Negotiation of root canal orifices	Preparation of an aseptic working field	Root preparation
Male dentist				
VAS-values (mean ± SD)	23 ± 16	29 ± 18	44 ± 23	40 ± 20
Female dentist				
VAS-values (mean ± SD)	25 ± 17	31 ± 18	44 ± 22	40 ± 19

Table 4 Confidence scores as assessed by visual analogue scales, are presented in relation to the treatment of a mandibular molar. The end-points of the 100-mm VAS were marked as 'very easy' and 'very difficult', respectively

Table 5 Estimated time spent on treatment of a mandibular molar

Estimated time $n = 452$	≤15 min (%)	16–30 min (%)	31–45 min (%)	46–60 min (%)	≥61 min (%)	γ–coefficient (*P*-value)
Access cavity						
Men	213 (89)	24 (10)	0	3 (1)	0	$\gamma = 0.31$ ($P = 0.014$)
Women	173 (82)	34 (16)	3 (1)	2 (1)	0	
Mechanical root prep.[a]						
Men	31 (13)	142 (59)	50 (21)	14 (6)	2 (1)	$\gamma = 0.29$ ($P < 0.0005$)
Women	21 (10)	99 (47)	61 (29)	28 (13)	2 (1)	
Root filling						
Men	84 (35)	135 (56)	17 (7)	4 (2)	0	$\gamma = 0.20$ ($P = 0.010$)
Women	61 (29)	111 (52)	32 (15)	8 (4)	0	

[a]In two cases no information.

Table 6 Total estimated time for treatment of a mandibular molar

Total estimated time	≤45 min (%)	46–60 min[a] (%)	61–75 min (%)	76–90 min (%)	91–105 min[a] (%)	>105 min (%)
Number of GDPs $n = 452$	30 (7)	106 (23)	148 (33)	75 (17)	56 (12)	37 (8)

[a]In one case no information on estimated time in relation to mechanical root preparation.

more than 1 h to complete the treatment (Table 6). The median was 61–75 min. Positive correlations were observed between the time spent on treatment and the VAS-values in the confidence score regarding access cavity preparation (ANOVA; $P < 0.0001$), mechanical root canal preparation (ANOVA; $P < 0.0022$), as well as root filling (ANOVA; $P < 0.0261$).

Discussion

In the present study, the mailed questionnaire was accompanied by a confidential guarantee letter including a coded and stamped reply envelope. Nonresponders were first approached by a reminder card and finally by a telephone call (Tan & Burke 1997). The use

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of coded reply envelopes led to failed responses by at least 1.7% of the GDPs. The final response rate (75.3%) was regarded as sufficient to make valid conclusions (Parashos & Messer 2004).

The results of the present study provide some evidence that caries is still the main cause of pulp disease and thus endodontic treatment in the Danish population. This situation is valid for all age groups except the youngest one, in which traumatic injury was a major reason for root canal treatment (Table 3). In older patients with a high frequency of restored teeth, cusp fractures and dentinal cracks might be expected to challenge caries as the major reason of pulp injury, but these possibilities were not reported frequently. Reasons for caries still being the main cause for root canal treatment could be that the teeth that were previously extracted due to caries amongst Danish children (Poulsen & Malling Pedersen 2002) might now be candidates for root canal treatments. Seventy-nine per cent of root fillings were attributed to caries and pulp disease in the 20–29-year age group in the present study (Table 3). It could be speculated that the first operative interventions in these deep carious lesions have been postponed over the years, and perhaps take place in an increasing group of so-called 'drop-out' patients, who do not attend the dental service on a regular basis (Petersen *et al.* 2003). In addition, the long-time consequences of the overall reduced caries progression (Marthaler 2004) mean that now it takes longer time for a cavity to progress to a deep stage. The level of clinical symptoms such as pain might also be reduced as the progression is slow. Taken together, the caries lesion may also become a potential candidate for root canal treatment, even without the patient has taken notice of the problem. However, the increased focus on the procedures of caries management, involving an understanding of pulp-dentinal changes in relation to rapidly and slowly progressing deep carious lesions (Bjørndal & Kidd 2005), may in the future lead to treatment of deep caries lesions that preserve pulp health (Bjørndal & Reit 2005a,b). In accordance with earlier studies (Reit *et al.* 1993, Karlsson & Reit 1994), root canal treatment was reported to be undertaken in teeth with clinical symptoms (Table 2). Pulpitis was the dominating condition, particularly amongst patients between 20 and 40 years of age (Table 3).

Epidemiological surveys have observed apical periodontitis to be associated frequently in root filled teeth (Eriksen *et al.* 2002). Also, reports from Denmark and other countries have pointed out high frequencies of sub-standard root fillings (Kirkevang *et al.* 2001, Dugas *et al.* 2003). In spite of these facts, retreatments were rarely reported (2%) by the GDPs in the present study. It is obvious that the mere diagnosis of a periapical lesion in a symptom-free root filled tooth (even if the root filling is inadequate) will not motivate a retreatment decision (Kvist *et al.* 2004).

The present study confirms recent reports stating that root canal treatment is now the most common in molar teeth (Kirkevang *et al.* 2001). Sixty per cent of the GDPs completed their latest root filling in a molar tooth. It is obvious that, over the years, the spectrum of root canal treatment has changed. Molars are now extracted less often and are preserved with root canal treatment if indicated (Bjørndal & Reit 2004). Thus, contemporary endodontic treatment will often involve technically demanding cases. Therefore, the GDPs were asked to assess the difficulty of various technical aspects of a molar treatment. Considering the high frequency of inadequate root fillings, the scores were found to be surprisingly low. All mean values were situated in the 'easy' half of the scale (Table 4). The preparation of an aseptic working field was given the highest mean VAS-value, and approached 44 when compared with 40 for root canal preparation (no statistical difference). In Denmark, as in other countries, rubber dam is rarely used by GDPs as a part of an aseptic working field (Saunders *et al.* 1999a, Jenkins *et al.* 2001, Slaus & Bottenberg 2002, Bjørndal & Reit 2005c). To produce asepsis without the use of rubber dam is difficult; and as a majority of the treated cases have vital pulps, the risk of microbial contamination is high, which, in turn, might be an explanatory factor for the high rate of periapical lesions observed in root filled teeth.

Fifty-six per cent of the responders estimated the time to treat a mandibular molar at between 46 and 75 min. Mechanical root canal preparation was reported as being the most time-consuming procedure. Compared with other self-reported time evaluations, this is relatively rapid. In a Scottish sample (Saunders *et al.* 1999b), the treatment of a single-rooted tooth was estimated to take about 70 min. It has been suggested that the attitude of working rapidly within endodontics is associated with a low economic incentive (Basmadjian-Charles *et al.* 2004). The time-cost dilemma was also elaborated by McColl *et al.* (1999).

Gender influenced the reported time spent on root canal treatment. Female GDPs reported using significantly more time to prepare an access cavity and the root canals as well as filling the canals. The impact of gender was also found in another Danish sample, in which female GDPs completed teeth with vital and

nonvital pulps in significantly more visits than males (Bjørndal & Reit 2005c).

Conclusions

The present study has found that root canal treatment in Denmark was still most often associated with caries and pulpitis. Treatment was typically instituted in vital molar teeth. Even though apical periodontitis is frequent in root filled teeth, retreatments were rare. From a subjective point of view, root canal treatment was not evaluated as 'very difficult' and was carried out rapidly.

Acknowledgements

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Appendix III

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European Journal of Oral Sciences

Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy

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Less invasive excavation methods have been suggested for deep caries lesions. We tested the effects of stepwise vs. direct complete excavation, 1 yr after the procedure had been carried out, in 314 adults (from six centres) who had received treatment of a tooth with deep caries. The teeth had caries lesions involving 75% or more of the dentin and were centrally randomized to stepwise or direct complete excavation. Stepwise excavation resulted in fewer pulp exposures compared with direct complete excavation [difference: 11.4%, 95% confidence interval (CI) (1.2; 21.3)]. At 1 yr of follow-up, there was a statistically significantly higher success rate with stepwise excavation, with success being defined as an unexposed pulp with sustained pulp vitality without apical radiolucency [difference: 11.7%, 95% CI (0.5; 22.5)]. In a subsequent nested trial, 58 patients with exposed pulps were randomized to direct capping or partial pulpotomy. We found no significant difference in pulp vitality without apical radiolucency between the two capping procedures after more than 1 yr [31.8% and 34.5%; difference: 2.7%, 95% CI (−22.7; 26.6)]. In conclusion, stepwise excavation decreases the risk of pulp exposure compared with direct complete excavation. In view of the poor prognosis of vital pulp treatment, a stepwise excavation approach for managing deep caries lesions is recommended.

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Deep caries induces severe inflammatory reactions in the pulp and may cause pulp necrosis. When deep caries lesions are excavated, the dentin barrier may be broken and the healing of the pulp impaired. It has been suggested that a stepwise approach to caries excavation, as opposed to a direct complete excavation, would decrease the number of pulp exposures and accordingly enhance the possibilities for the pulp to heal (1, 2). A Cochrane review (3) found only two trials that compared stepwise excavation vs. direct complete excavation with respect to pulp exposure. MAGNUSSON & SUNDELL (1) found an advantage of stepwise excavation: only 15% of the pulps were exposed compared with 53% after complete excavation. Similar findings were reported by LEKSELL *et al.* (2) (18% vs. 40%). The teeth treated were either primary molars (1) or young permanent teeth in children (mean age 10 yr) (2). Whether these results are applicable to an adult population is unknown. Both trials used pulp exposure as the outcome measure and did not report on treatment of the exposed pulps or on sustained pulp vitality. Also, for a proper comparison between the outcomes of stepwise vs. complete caries excavation, randomized clinical trials are needed to improve the evidence concerning the treatment of deep caries (3–7).

The exposed pulp has been the subject of numerous studies, but well-designed clinical trials on the treatment of caries-exposed pulps in adult teeth are scarce (8). In a large cohort study with up to 12 yr of follow-up, NYBORG (9) reported 58% success in direct pulp capping with calcium hydroxide as the capping material in patients older than 15 yr of age. SHOVELTON *et al.* (10) showed that the 2-yr success rate following direct pulp capping varied between 50 and 80%, depending on the pulp condition and the materials used. Retrospective studies indicate that there is a difference in treatment success between the traumatically exposed pulp and the pulp exposed during caries excavation. For example, AL-HIYASAT *et al.* (11) found that direct capping of traumatically exposed pulps with calcium hydroxide was successful in 92% of treatments after a 3-yr follow-up

period, while only 33% of the treatments of caries-exposed pulps were classified as successes. A potential reason for treatment failure in the latter situation might be the introduction of infected dentin chips into the pulp during caries excavation, acting as nuclei for irreversible inflammation (12). It has been suggested that removing a few millimetres of the pulp (partial pulpotomy) might increase the healing potential (13). However, partial pulpotomy of pulps exposed as a result of caries has only been studied using young permanent teeth (13, 14) and no randomized clinical trials of direct pulp capping vs. partial pulpotomy in adult teeth can be found in the literature.

The two randomized clinical trials presented here were designed to test the effect of: (i) stepwise excavation vs. direct complete excavation of deep caries lesions in adults, using pulp exposure, 1-yr pulp vitality without apical radiolucency, and pain as the outcome measures; and (ii) direct capping vs. partial pulpotomy of pulps exposed as a result of caries, using 1-yr pulp vitality without apical radiolucency, and pain, as the outcome measures.

Material and methods

The excavation trial (i) was conducted as a centrally randomized, patient-blinded, multicentre trial with two parallel groups (Fig. 1) comparing the effect of stepwise excavation vs. direct complete excavation. Sample size calculation showed that 134 patients were needed in each group to detect a 20% difference in the success rate between stepwise excavation and direct complete excavation at a two-sided alpha level of 5% (type I error) and 90% power (type II error of 10%), when expecting 50% in the direct complete excavation group to retain pulp vitality without apical radiolucency after 1 yr. With an anticipated patient drop-out of 15%, the trial was planned to include at least 308 patients. Consecutive patients referred to two Danish centres (the Dental Schools at the University of Copenhagen and Aarhus University) and four Swedish centres (Karolinska Institute, Stockholm; Faculty of Odontology, Malmö; Uppsala Public Dental Service; and Gothenburg Public Dental Service) participated. Inclusion criteria were: ≥ 18 yr of age; a primary caries lesion radiographically involving 75% or more of the dentin; and the presence of a well-defined radiodense zone between the caries lesion and the pulp (Fig. 2). In patients who reported pain, the pain was provoked and confirmed by stimulation with cold or compressed air (pretreatment pain). Exclusion criteria were: prolonged unbearable pain and/or pain disturbing night sleep; no response to cold and electrical pulp testing; attachment loss > 5 mm; apical radiolucency; pregnancy; any systemic disease preventing enrolment; or lack of informed consent. Written informed consent was obtained from all the patients participating in the study.

The clinicians were trained in identifying eligible caries lesions using 15 radiographs representing different lesion depths. During the enrolment procedure potentially eligible teeth were compared to a scoring chart (Fig. 2). The allocation sequences for stepwise excavation vs. direct complete excavation (1:1) were computer generated, stratified for pain (yes or no), age (18–49 yr or ≥ 50 yr), and centre in blocks of six. The block size was unknown to the investigators. Concealed allocation was achieved through central telephone randomization (Copenhagen Trial Unit). One tooth was treated in each randomized patient. Patients were unaware of the treatment assignment, and all were seen in at least two treatment visits.

If the excavation procedure led to pulp exposure the patient was assessed for eligibility for the pulp capping trial (ii). The inclusion criteria were: the patient had participated in the excavation trial described in the section above; the pulp was exposed as a result of the excavation of caries

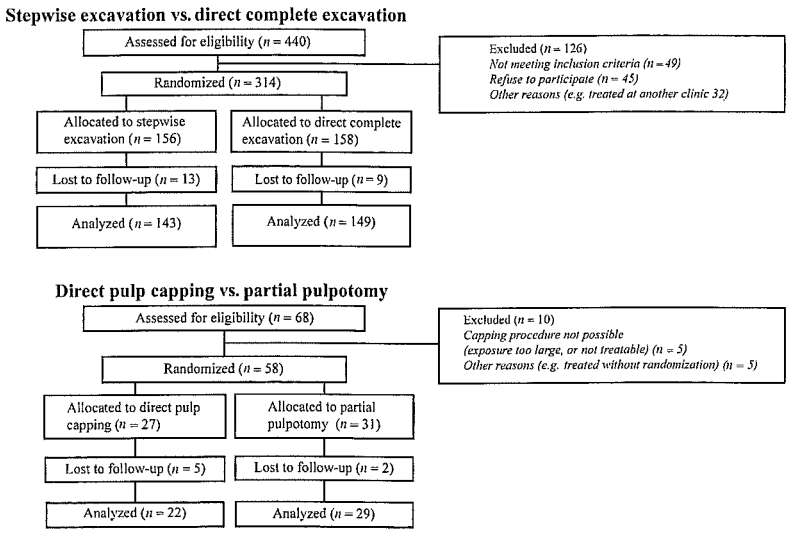

Fig. 1. Flow chart showing the number of patients according to enrolment, allocation, lost to followup, and final number of cases analyzed in the two trials.

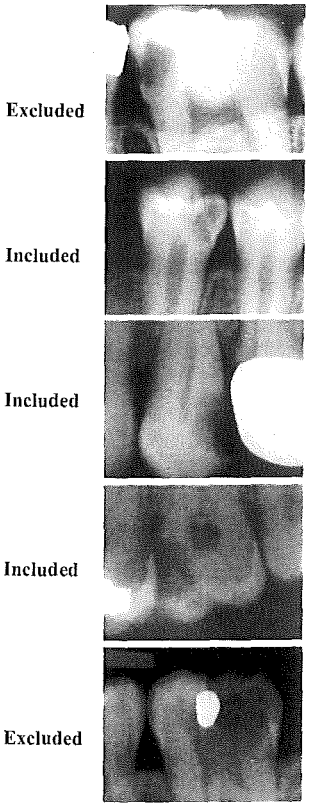

Fig. 2. The scoring chart used for the selection of cases is shown. Included teeth had caries lesions radiographically extending 75% or more into the dentin and walled off from the pulp by a well visible radiodense zone. A tooth was excluded if the caries lesion was either too small (as illustrated in the top) or too deep (bottom).

(mild pain could be present); and written informed consent had been given to take part. Exclusion criteria were: prolonged unacceptable pain or pain disturbing the night sleep; and pus draining from the exposed pulp. Eligible patients were centrally randomized to either direct pulp capping vs. partial pulpotomy using a similar randomization procedure as the one described for the excavation trial but only stratifying for pain (yes or no) (Fig. 1). The excavation trial (j.no: 03-004/03) and the pulp capping trial (j.no: 13-002/04) were approved by the joint Copenhagen and Frederiksberg ethics committees in Denmark and by the ethics committee at the Sahlgrenska Academy, University of Gothenburg, Sweden (j.no: 083-05), and was registered in the Danish Data Protection Agency (j.no: 2008-42-20329) and at http://www.ClinicalTrials.gov (NCT00187850 and NCT00187837). The trials were investigator initiated and investigator controlled.

Clinical procedures

The penetration depth of the lesion was assessed in bitewing radiographs (Insight IP22 film; Kodak, Stuttgart, Germany)

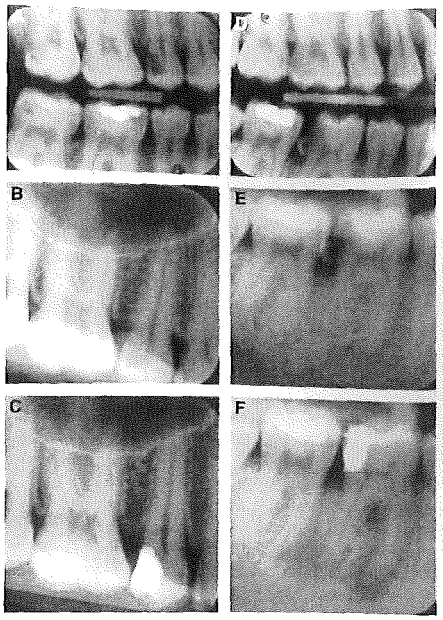

Fig. 3. A, B: Preoperative radiographs of a permanent upper right second premolar (stepwise excavation). At the 1-yr radiographical follow-up (C) the tooth was classified as a success (pulp vitality without apical radiolucency). D, E: Preoperative radiographs of a permanent lower right first molar (direct complete excavation). At the 1-yr follow-up (F) the tooth was classified as a failure (no pulp vitality with apical radiolucency).

(Fig. 3A,D). The penetration depth was expressed as the ratio between the maximum depth of the carious dentin (AB, Fig. 4) and the total dentin thickness (AC, Fig. 4), measured using computer software (Ppx View Pro version PRO 1.11.18; DeltaPix, Måløv, Denmark). The point A represented half the distance of the spread of the radiolucent carious dentin along the enamel–dentin junction. Point B was placed at the pulpal border of the radiolucent area, and C represented the border of the pulp. The difference between two repeated measurements [mean ± standard deviation (SD)] was 0.024 ± 0.601 mm for the distance AB and 0.001 ± 0.597 mm for the distance AC. To evaluate the periapical tissues (Fig. 3B,C,E,F) period-identical radiographs were obtained by means of a specific film holder (Super-Bite; KerrHawe, Bioggio, Switzerland). Pulp vitality was assessed using thermal methods (Green ENDO I.C.E; The Hygienic Corporation, Akron, OH, USA), or ethyl chloride (Rönnings Europa, Hässleholm, Sweden), and electrical pulp testing (Vitality Scanner Model 2006 or 2007; Analytic Technology, Redmond, VA, USA). The teeth were anaesthetized with Citanest Dental Octapressin (Dentsply, Weybridge, UK). The bulk of carious dentin was removed using a round bur followed by final excavation with hand instruments. The clinicians were calibrated before the trial was started. One of the investigators (L.B.) visited all centres and presented the guidelines for patient selection and clinical procedures.

In stepwise excavation the first excavation included removal of the superficial necrotic and demineralized dentin with complete excavation of the peripheral demineralized dentin (15), avoiding excavation close to the pulp. When a

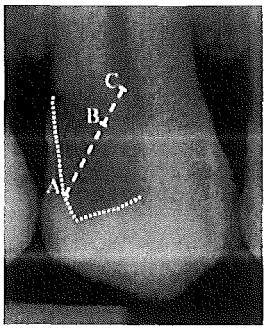

Fig. 4. The point A represents half the distance of the spread of the radiolucent carious dentin along the enamel-dentin junction (dotted line). Point B was placed at the pulpal border of the radiolucent area, and C at the border of the pulp. The ratio AB/AC defines the maximum penetration depth of the caries lesion.

temporary restoration could be properly placed no further excavation was carried out, leaving soft, wet, and discoloured dentin centrally on the pulpal wall. A calcium hydroxide base material (Dycal; DeTrey Dentsply, Skarpnäck, Sweden) was applied over the remaining carious dentin and the cavity was temporarily sealed with glass-ionomer (Ketac Molar; 3M ESPE, Glostrup, Denmark). After 8 to 12 wk, the cavity was re-entered and the final excavation was carried out leaving only central yellowish or greyish hard dentin (equal to the hardness of sound dentin, as judged by gentle probing). A calcium hydroxide base was applied and the cavities were restored with OptiBond Solo Plus (KerrHawe) and Herculite XRV (KerrHawe).

Direct complete excavation was completed during the first visit. Criteria for evaluating the remaining dentin were identical to those used at the second visit in the stepwise excavation group. Base material and a temporary restoration were placed as described above. At the second visit (8–12 wk later) the temporary restoration, but not the base material, was removed and replaced with a permanent restoration, as described above.

Direct pulp capping was performed after complete removal of carious dentin using hand excavation instruments (LM 533-534, LM 63-64, LM 631-641; LM-instruments, Parainen, Finland) in the final excavation, followed by isolation of the tooth with a rubber dam and cleaning with alcohol containing 5 mg ml^{-1} of chlorhexidine. The exposed pulp was irrigated with sterile saline. Following haemostasis (within 5 min) calcium hydroxide cement was applied (Dycal; DeTrey Dentsply, Sweden). The cement was covered with a temporary restoration (Ketac Molar; 3M ESPE). After 1 month the cavity was restored with OptiBond Solo Plus (KerrHawe) and Herculite XRV (KerrHawe). At the final restoration procedure a thin layer of the temporary restoration was left covering the pulp capping area to ensure that exposure to the oral environment was avoided.

The procedures and materials used for the partial pulpotomy were identical to those in the direct pulp capping group except that 1–1.5 mm of the pulp tissue (13) was removed using a high-speed round diamond bur under water spray coolant.

The treatment results were assessed after 1 yr. In the stepwise excavation trial the primary outcome measure was unexposed pulps with sustained pulp vitality without apical radiolucency (= success). Pulp vitality was defined as a positive response to thermal (cold) or electrical stimulation. Periapical radiolucency was diagnosed if the apical part of the periodontal ligament space was at least twice as wide as in other parts of the root and the lamina dura was absent. Two blinded observers independently examined the radiographs. Inter-examiner agreement in the determination of success or failure was judged as good (Kappa = 0.67). In 15 cases, the observers disagreed and they had to reach consensus. The consensus result was 12 successes and 3 failures. Patients who had to be treated with pulpectomy (because of unbearable pain) before the 1-yr follow-up were classified as failures.

Patients with mild-to-moderate pretreatment pain were included in the excavation trial, and the secondary outcome measure was the extent of pain relief on days 1 and 7 following excavation. The level of pretreatment pain was assessed just before treatment (Table 1) on the first visit using a 100 mm visual analogue scale (VAS) printed on paper ranging from 'no pain' to 'unbearable pain'. The patients were asked to make similar assessments at home on days 1 and 7 after excavation and to return the assessments by mail. Pain relief (secondary outcome measure) was defined as the difference in VAS scores (mm) between the pretreatment pain and pain on day 1 [median (mean)] and day 7 [median (mean)] after excavation. The tertiary outcome measure was pulp exposure during excavation.

In the pulp capping trial (Fig. 1), the primary outcome measure was pulp vitality without apical radiolucency.

Statistical analysis

The statistical investigator was unaware of the allocation codes. The non-Gaussian distributions of the VAS scorings were compared between the intervention groups using a non-parametric test (Mann–Whitney *U*-test). The mean ratio of the caries lesion depth was presented with 95% confidence interval (CI). The binary outcomes were analyzed by comparing the probability of success (Chi-square test) and by reporting the difference between intervention groups along with the 95% CI. In addition, binary logistic regression analysis (16) was performed to assess the effect of treatment, while adjusting for age, pretreatment pain, and treatment centre. Odds ratio (OR) estimates were presented with 95% CI. The level of significance (two-sided) was set to 0.05.

Results

We evaluated 440 patients for eligibility to participate in this study between February 2005 and April 2007. Of these patients, 126 were excluded because they did not meet the inclusion criteria, refused to participate, or underwent treatment at other clinics. Thus, 314 patients were randomized to stepwise excavation vs. direct complete excavation (Fig. 1). The baseline values of the demographic variables and VAS scorings of pretreatment pain are shown in Table 1, including the mean depth ratio of the caries lesions. The median number of days of the observation period was 476 (interquartile range 442–559) in the stepwise excavation group and 477 (interquartile range 434–524) in the direct complete excavation group.

Demographic

Variables
Men *n* (%)
Median age (yr) (IQR)*
Age < 50 yr *n* (%)
Type of tooth
Incisor/canine *n* (%)
Premolar *n* (%)
Molar *n* (%)
Lesion site
Approximal *n* (%)
Mean depth ratio of cari
Median pretreatment pai
Centre
Centre 1 *n* (%)
Centre 2 *n* (%)
Centre 3 *n* (%)
Centre 4 *n* (%)
Centre 5 *n* (%)
Centre 6 *n* (%)

CI, confidence interval;

Randomized (n = analyzed teeth)
Success
Pulp vitality without
Failures
Pulp exposure *n* (%)
Pulp vitality with api
No pulp vitality with
Unbearable pain* *n* (

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Considering only
pulps, 89.8% of
without apical rad
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not significant).

Table 1

Demographic variables and pretreatment pain assessments on a 100-mm visual analogue scale (VAS) at baseline

Variables	Stepwise excavation (n = 156)	Direct complete excavation (n = 158)
Men n (%)	63 (39.9)	69 (44.2)
Median age (yr) (IQR)*	29.0 (25.3–38.0)	29.0 (26.0–37.8)
Age < 50 yr n (%)	141 (89.2)	146 (93.6)
Type of tooth		
Incisor/canine n (%)	5 (3.2)	7 (4.4)
Premolar n (%)	70 (44.9)	58 (36.7)
Molar n (%)	81 (51.9)	93 (58.9)
Lesion site		
Approximal n (%)	151 (96.8)	151 (95.6)
Mean depth ratio of caries lesion (95% CI)	0.77 (0.75; 0.79)	0.77 (0.76; 0.78)
Median pretreatment pain (VAS) (IQR)	3.0 (0.0–26.0)	5.0 (0.0–30.0)
Centre		
Centre 1 n (%)	15 (9.6)	17 (10.8)
Centre 2 n (%)	29 (18.6)	26 (16.5)
Centre 3 n (%)	12 (7.7)	10 (6.3)
Centre 4 n (%)	3 (1.9)	6 (3.8)
Centre 5 n (%)	12 (7.7)	14 (8.9)
Centre 6 n (%)	85 (54.5)	85 (53.8)

CI, confidence interval; IQR, interquartile range.

Table 2

Primary outcome analysis of teeth at 1 yr of follow-up

Randomized (n = analyzed teeth)	Stepwise excavation (n = 143)	Direct complete excavation (n = 149)	Difference between groups (95% CI)	P-value
Success				
Pulp vitality without apical radiolucency n (%)	106 (74.1)	93 (62.4)	11.7 (0.5; 22.5)	0.044
Failures				
Pulp exposure n (%)	25 (17.5)	43 (28.9)	−11.4 (−21.3; −1.2)	0.030
Pulp vitality with apical radiolucency n (%)	2 (1.4)	2 (1.3)	0.1 (−3.5; 3.8)	0.665
No pulp vitality with apical radiolucency n (%)	2 (1.4)	4 (2.7)	−1.3 (−5.5; 2.8)	0.712
Unbearable pain* n (%)	8 (5.6)	7 (4.7)	0.9 (−4.8; 6.8)	0.934

*Resulting in pulpectomy.
CI, confidence interval.

The results from the excavation trial are summarized in Table 2. The stepwise excavation group had a significantly higher proportion of success (74.1%) at follow-up compared with the direct complete excavation group (62.4%) (P = 0.044). The difference was still significant when adjusted for the effect of age, pain, and centre (Table 3). The pulp was exposed in 25 teeth (17.5%) after the stepwise excavation procedure. In four of these teeth the pulp had already been unintentionally exposed at the first visit. In the direct complete excavation group the pulp was exposed in 43 teeth (28.9%). The estimated difference was 11.4% with a 95% CI of 1.2–21.3 (P = 0.030) (Table 2). This difference was also statistically significant when the analysis was adjusted for the effect of age, pain, and centre (Table 3). Considering only teeth remaining with unexposed pulps, 89.8% of these teeth retained pulp vitality without apical radiolucency following stepwise excavation vs. 87.7% after direct complete excavation (P = not significant).

Among patients with pretreatment pain in the excavation trial, we found no significant difference in pain relief [median (mean)] on day 1 (P = 0.41, Mann–Whitney U-test) between the stepwise excavation group [0.0 (−0.01)] and the direct complete excavation group [0.0 (−0.88)]. The level of pain relief on day 7 was similarly low and not significant (P = 0.88, Mann–Whitney U-test) between the stepwise excavation group [0.0 (−1.91)] and the direct complete excavation group [0.0 (−4.12)].

Patients with pretreatment pain were significantly less likely to show a successful treatment result at follow-up compared to those without pain, when adjusting for the effect of treatment, age, and centre (Table 3). Treatments of patients younger than 50 yr of age (median for the group 28 yr) were more likely to result in sustained pulp vitality without apical radiolucency than treatments of older patients (median for the group 58 yr); however, only borderline significance was noted (Table 3).

The ORs of pulp exposure differed among the centres, with centres 1 and 2 avoiding pulp exposure significantly

Table 3

Logistic regression analysis of the outcomes 'unexposed pulps with sustained vitality without apical radiolucency' at 1 yr of follow-up and 'pulp exposure' after excavation (n = 292)

	Unexposed pulps with sustained vitality without apical radiolucency		Pulp exposure	
Independent variables	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Intervention Ref: 'Direct com- plete excavation'	1.74 (1.03–2.94)	0.038	0.50 (0.27–0.90)	0.021
Age < 50 yr Ref: 'age ≥ 50 yr'	3.34 (0.98–6.22)	0.054	0.44 (0.15–1.30)	0.137
Pretreatment pain Ref: 'no pain'	0.48 (0.28–0.82)	0.007	2.38 (1.31–4.34)	0.005
Centre Ref: 'Centre 6'		0.076*		0.016*
Centre 6	1.00		1.00	
Centre 1	3.25 (1.12–9.46)	0.031	0.15 (0.03–0.71)	0.016
Centre 2	2.82 (1.25–6.36)	0.012	0.17 (0.05–0.53)	0.002
Centre 3	1.37 (0.50–3.71)	0.539	0.68 (0.23–2.07)	0.499
Centre 4	1.17 (0.29–5.30)	0.841	0.74 (0.13–4.23)	0.733
Centre 5	2.05 (0.71–5.97)	0.186	0.55 (0.17–1.75)	0.307

*Comparing all centres.
CI, confidence interval; OR, odds ratio; Reference.

Table 4

Primary outcome analysis of the pulp capping trial at 1 yr of follow-up

Randomized (*n* = analyzed teeth)	Direct pulp capping (*n* = 22)	Partial pulpotomy (*n* = 29)	Difference between proportions (95% CI)	*P*-value
Success				
Pulp vitality without apical radiolucency *n* (%)	7 (31.8)	10 (34.5)	−2.7 (−26.6; 22.7)	0.923
Failures				
No pulp vitality and apical radiolucency *n* (%)	1 (4.5)	2 (6.9)	−2.4 (−17.9; 15.5)	0.810
Unbearable pain* *n* (%)	14 (63.6)	15 (51.7)	11.9 (−14.8; 35.9)	0.573
No haemostasis* *n* (%)	0 (0)	2 (6.9)	−6.9 (−22.0; 8.8)	0.597

*Primary outcome assessment was no pulp vitality at follow-up as a result of pulpectomy.
CI, confidence interval.

more often (adjusted for the effect of treatment, age, and pain) (Table 3).

Of the 68 patients with exposed pulps it was possible to randomize 58 to direct pulp capping vs. partial pulpotomy (the pulp capping trial). Ten patients were excluded because it was not possible to perform either the randomization or the capping procedure (Fig. 1). The median number of days of the observation period was 416 (interquartile range 407 – 531) in the direct pulp capping group vs. 426 (interquartile range 390–530) in the partial pulpotomy group. The results from the pulp capping trial are summarized in Table 4.

The total proportion of teeth retaining pulp vitality without apical radiolucency at the 1-yr follow-up did not differ significantly between the direct pulp capping group and the partial pulpotomy group (31.8% vs. 34.5%) (Table 4). It should be noted that the majority of failed pulp treatments occurred as a result of pain (Table 4) because a number of patients received endodontic emergency treatment (pulpectomy) before the scheduled follow-up appointment.

Discussion

We observed significantly fewer pulp exposures after stepwise excavation (17.5%) than after direct complete excavation (28.9%) in adult teeth. Moreover, a significantly better success rate (74.1%) was found for stepwise excavation at 1 yr of follow-up vs. direct complete excavation (62.4%), when considering unexposed pulps with sustained vitality without apical radiolucency (Table 2). These results are similar to findings in studies on primary teeth and young permanent teeth (1, 2). The biological rationale for this difference could be that the first phase of stepwise excavation inactivates caries progression (15) and stimulates the formation of tertiary dentin (17), which over time makes carious dentin easier to remove without exposing the pulp at the final excavation. Such reactions might also be enhanced by placing a calcium hydroxide compound on the remaining carious dentin (1, 18). In our excavation trial we used 8–12 weeks as the treatment interval for the stepwise excavation and it could be speculated that a prolonged treatment

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interval might have induced more tertiary dentin and reduced the number of pulp exposures. However, LEKSELL *et al.* (2) found no difference in the frequency of pulp exposure between a group of patients treated within a shorter time interval (8–10 wk) and one treated within a longer time interval (11–24 wk). It might also be considered to avoid re-entry of the cavity (6). However, the recently recommended procedure of permanently leaving a small amount of carious dentin to arrest lesion progression and to prevent pulp exposure (19) has not been systematically evaluated in a randomized clinical trial, and merits further study (20).

In our excavation trial fewer pulp exposures were noted after direct complete excavation than previously reported: 40% by LEKSELL *et al.* (2) and 53% by MAGNUSSON & SUNDELL (1). Trials with inadequate allocation concealment may exaggerate the treatment effect (21, 22). Therefore, as concealment of allocation in both of the above studies was unclear (3), the treatment effects may have been overestimated. Another explanation might be that the operators in the present study performed a less invasive caries-excavation procedure than that carried out by LEKSELL *et al.* (2).

The statistically significant difference in pulp exposures between the centres may be caused by differences in depths or progression rates of the caries lesions. However, our analysis of lesion depths indicated that proper depths had been selected at all centres according to the scoring chart (Fig. 2). Other plausible reasons could be differences in technical skills, or random error.

Amongst the teeth with exposed pulps we found a low overall pulp survival (32.8%) at the 1-yr follow-up, which differs from the results reported by NYBORG (9) and SHOVELTON *et al.* (10) but is in accordance with the results reported by AL-HIYASAT *et al.* (11). It should be noted that the present study was carried out using teeth with deep caries lesions and that the actual health status of the pulps was unknown. In a majority of the failed cases the patient, within a few months, developed intensely painful symptoms that had to be treated by pulpectomy. This indicates that a deleterious pretreatment condition of the pulp, rather than micro-organisms entering the wound area via marginal leakage, caused the unsuccessful outcome.

At 1 yr of follow-up we found no statistically significant difference in the number of patients with pulp vitality without apical radiolucency between partial pulpotomy and direct pulp capping (Table 4). However, the relatively small number of pulp exposures makes the CIs wide, and definite conclusions concerning the choice of capping procedure cannot be made from our data. Further trials are required.

A calcium hydroxide material was used as wound dressing in both pulp capping interventions. High outcome rates for teeth with pulp exposures treated by partial pulpotomy (23), as well as direct pulp capping (24), have been reported in small observational studies using mineral trioxide aggregate (MTA). However, no significant difference was found in two randomized clinical trials comparing calcium hydroxide vs. MTA in young permanent molars with deep caries treated with partial pulpotomy (14) and in carious primary molars treated with direct pulp capping (25). Therefore, we do not expect our choice of calcium hydroxide cement as a wound dressing to have influenced the results negatively.

Pulp survival at follow-up amongst teeth with unexposed pulps was much higher than amongst teeth with exposed pulps (Table 4). This observation emphasizes the importance of maintaining an unbroken dentin barrier against the pulp. Leksell *et al.* (2) reported 1-yr pulp survival to be 100% in teeth with unexposed pulps. The lower frequency of pulp survival found in our study might indicate that we included patients with more severe caries and pulp inflammation by including patients with pretreatment pain. In our study the presence of pretreatment pain was significantly associated with treatment failure (Table 3).

Age of the patient tended to influence the treatment results. We observed that younger patients were associated with a higher proportion of vital pulps without apical radiolucency at follow-up than older patients. This is in accordance with an earlier observational study on stepwise excavation of deep caries lesions in a mixed population of children and adults (median age 24 yr), where a relatively high pulp survival (89%) was noted 3½–4½ yr later (26). A similar influence of the age of the patients on the treatment outcome is known from direct pulp capping. HØRSTED *et al.* (27) showed a higher pulp survival amongst younger patients compared with older patients in a long-term retrospective study of direct pulp capping.

In conclusion, the stepwise excavation group had a significantly higher proportion of unexposed pulps with sustained vitality without apical radiolucency compared with direct complete excavation of deep caries lesions in adult teeth. As the treatment of teeth with caries exposures had a lower pulp survival than teeth with unexposed pulps, a stepwise excavation procedure is preferable for the management of deep caries lesions.

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Appendix IV

Bjørndal L, Reit C (2005) The adoption of new endodontic technology amongst Danish general dental practitioners. *International Endodontic Journal* **38**, 52-8.

The adoption of new endodontic technology amongst Danish general dental practitioners

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Abstract

Bjørndal L, Reit C. The adoption of new endodontic technology amongst Danish general dental practitioners. *International Endodontic Journal*, **38**, 52–58, 2005.

Aim To assess the adoption of new endodontic technology in a population of Danish practitioners.

Methodology Members of the Copenhagen Dental Association ($n = 1156$) were approached with a questionnaire concerning the frequency of various endodontic procedures. Three options were available: often, occasionally and never. Responses were anonymous. The statistical analyses were performed as studies of association in two- or three-way contingency tables, and with Goodman–Kruskal's γ-coefficient as the basic tool chosen.

Results Only data from general practitioners (GPs) in private practice were analysed ($n = 956$). The response rate was 72%. NiTi hand instruments were often used to negotiate canals by 18%, whilst 10% often used NiTi rotary systems. Electronic apex locators were often employed by 15%. Nineteen per cent reported that warm gutta-percha was often used. A majority (53%) often spend two sessions to instrument a molar, and 20% often needed three or more sessions to finish the shaping phase. To complete a treatment of a nonvital case most practitioners reported to use at least three appointments. Only 4% frequently applied rubber dam.

Conclusions The adoption of new endodontic technology is at an early stage amongst Danish GPs. A new revised remuneration system might influence the rate of adoption, allowing the practitioners to act more rationally and produce a higher frequency of good-quality root fillings. Progress towards high quality endodontics might be hindered by the nonuse of rubber dam.

Keywords: adoption of technology, electronic apex locators, NiTi instruments, rubber dam, treatment sessions, warm gutta-percha.

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Introduction

In a recent study using a nationwide database, Bjørndal & Reit (2004) reported a 17% increase in the annual frequency of root fillings performed in Danish adults between 1977 and 2003. Thus, the need and demand for endodontic therapy does not necessarily appear to decrease in a population with a low prevalence of caries. However, endodontics is one of the most technically challenging clinical procedures and the quality of the treatment provided in general dental practice has been questioned. For example, in a radiographic examination of randomly selected individuals from Aarhus, Denmark, Kirkevang *et al.* (2000) observed that 59% of the root filled teeth had inadequate lateral seal and 40% displayed inadequate length. Furthermore, 52% of the treated teeth were associated with signs of apical periodontitis. These data are part of a body of evidence demonstrating, in most populations, a high frequency of technically defective root fillings, a high prevalence of periapical radiolucencies in root filled teeth, and a strong correlation between the two (Eriksen *et al.* 2002, Dugas *et al.* 2003).

Despite the high rate of substandard treatments reported, few studies have been concerned with factors

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that influence the quality of root canal treatment performed in general dental practice. It might be assumed that such factors will relate not only to the individual dentist (knowledge, attitudes and skills), but also to the context in which he or she works. For example, the remuneration system, time pressure, patient expectations, and inadequate equipment have been expressed by British dental practitioners to have bearing on treatment quality (McColl *et al.* 1999).

Within the last decade major technological breakthroughs have been made. The advent of nickel-titanium alloy and alternative methods to introduce gutta-percha were designed to simplify the procedure and thus improve the technical treatment results. Studies have shown the superiority of nickel-titanium files over conventional instruments to shape the root canal (Bishop & Dummer 1997, Park 2001, Schäfer & Lohmann 2002), and Molander *et al.* (2003) observed an increased frequency of good-quality root fillings when a group of Swedish practitioners were trained to use a NiTi rotary system. Furthermore, electronic apex locators are claimed to be more reliable than radiographs to identify the working length of the root canal (Pratten & McDonald 1996), and the recommendation today is that working length determination should be carried out using a combination of an apex locator and radiography (Hoer & Attin 2004). Finally, systems using warm gutta-percha are more rapid (Dummer *et al.* 1994, Gulabivala *et al.* 1998).

The concept of new technology is not limited to 'hardware' innovations, such as those mentioned above. The concept also include 'software' components such as ideas, notions and strategies (Brorson & Wall 1985). Historically endodontic treatment often was extended to encompass five, six or even seven appointments (Strindberg 1956). However, based on scientific studies the trend has been to reduce the number of appointments; new endodontic technology implies fewer sessions and often allows treatment in a single visit (Peters & Wesselink 2002, Kvist *et al.* 2004).

The idea of protecting teeth with rubber dam is widely accepted and advocated. However, studies indicate that most dentists abandon its use as soon as they enter practice (McColl *et al.* 1999, Jenkins *et al.* 2001). Therefore, rubber dam application cannot be regarded as an innovation but could be perceived as necessary in combination with the acceptance of, for example, new root canal instrumentation techniques.

Studies of the diffusion of widely accepted technologies have often found that, at first, only a few individuals (the so-called innovators) adopt the innovation. Following an early, relatively slow, phase that includes 10–20% of the potential adopters, the diffusion curve (Fig. 1) starts to climb, as more and more persons adopt the technology. Finally, the curve levels off to describe an s-form (Rogers 1983). The steepness of the curve will vary between innovations.

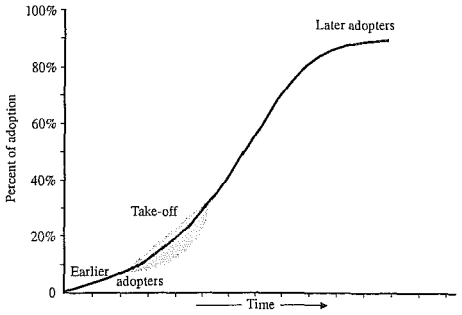

Figure 1 An s-shaped diffusion curve illustrating the typical development over time for the spread of an idea, practice, or object that is perceived as new by an individual (innovation). At first a group of earlier adopters appears, being about 10–25% of all potential users of the innovation in focus. Later on a so-called 'take-off' is noted when interpersonal networks become activated (modified from Rogers 1983).

There is little data available on the diffusion rate of new endodontic technology amongst general dental practitioners. Therefore, the aim of the present study was to (i) investigate the rate of adoption amongst a group of Danish general practitioners (GPs) and (ii) determine the factors associated with such an adoption.

Materials and methods

In January 2003 a questionnaire and an addressed return envelope were sent to all 1156 members of the Copenhagen Dental Association (CDA). The purpose of the anonymous survey was stated in an explanatory note. After 4 weeks all CDA members received a reminder. In addition, an announcement was attached to the website of the Danish Dental Association, and also placed in an issue of the Danish Dental Journal (Tandlaegebladet).

The first part of the questionnaire asked for information regarding gender, year of graduation, and the average number of root canal treatments performed per week. The second part of the questionnaire consisted of 14 questions concerned with the frequency of which

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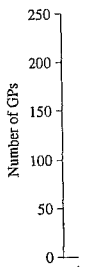

Figure 2 practition increased

various endodontic instruments, materials and procedures were used. In answering the questions the respondent had three options: *often*, *occasionally* and *never*. At present there is no postgraduate endodontic specialist programme in Denmark, therefore the information from the questionnaire did not contain information from trained endodontic specialists.

Statistical analysis

All statistical analyses were performed as studies of association in two- or three-way contingency tables. Most often the variables were ordered categorically and therefore the basic tool chosen was Goodman–Kruskal's γ-coefficient, which is an association measure similar to a correlation coefficient, with a positive value indicating a positive association and a negative value a negative association. Tests of independence were performed as Monte Carlo simulated exact tests using Digram (Upton 1999).

Results

By using different colours for the questionnaires it was possible to distinguish between forms returned by dentists in private and public practice. However, amongst the latter (mostly paediatric dentists and university staff) endodontic treatment was found to be infrequent and this group was excluded from the study. Thus, the total population included the 956 private practitioners within the CDA. Of these, 692 (72.4%) completed and returned the questionnaire.

Of the responders 50.4% were male; the distribution of gender and year of graduation is shown in Fig. 2. The relation between male and female dentists varied over time. Significantly more men were found in the earlier graduation groups and more women in the later ($\gamma = 0.49$; $P < 0.0005$). Forty-seven per cent of the practitioners reported a frequency of two to four endodontic treatments per week, and 17% completed more than five treatments per week.

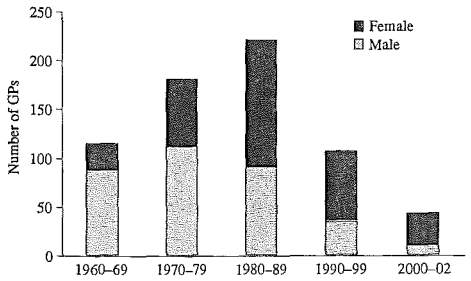

Figure 2 The distribution of male (▨) and female (■) general practitioners (GPs) is noted in relation to year of education. An increased number of females are observed from 1980 to 2002.

Instruments and technique

Most practitioners (75%) relied on conventional stainless steel files or reamers to shape root canals. Forty-two per cent often placed the instruments in a mechanical device (Endo-Lift; Kavo, Biberach, Germany). A similar proportion of dentists reported they combined stainless steel instruments with Gates-Glidden burs for coronal flare. NiTi hand instruments were often used by 18% of the responders, and by 13% in a crown-down fashion. NiTi rotary systems were fully adopted by 10% (Table 1).

Twenty-three per cent of Copenhagen dentists often incorporated electronic measurement to determine working length. Conventional root filling methods (mainly cold lateral condensation) served as standard for 81% of the practitioners, whilst 35% were clinically familiar with warm gutta-percha techniques, and 19% often used one or more of them (Table 1). About one-third of the dentists (36%) had no experience of any of the new techniques that were asked for in the questionnaire.

Rubber dam was irregularly used and only 4% applied it often; it was occasionally used by another 14%.

Number of treatment sessions

A majority of dentists often spent two sessions or more to complete the instrumentation of a molar tooth (Table 2). Few practitioners (4%) often handled nonvital cases in a single visit, whilst 28% often ended pulpectomies in one session.

Table 1 The adoption rate of new endodontic technology amongst 692 general dental practitioners

	Often (%)	Occasionally (%)	Never (%)
NiTi instrumentation	18	17	65
NiTi rotary	10	5	85
Electronic apex locator	23	19	67
Warm gutta-percha	19	16	65

Table 2 The frequency of number of visits used for endodontic treatment amongst 692 general dental practitioners

	Number of visits					
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	Oft. (%)	Occ. (%)	Oft. (%)	Occ. (%)	Oft. (%)	Occ. (%)
Instrumentation of a molar	40	24	53	37	20	46
Complete treatment of vital pulp cases	28	31	61	28	14	42
Complete treatment of necrotic pulp cases	5	12	47	32	53	36

Oft., often; Occ., occasionally.

Influence of gender

Males more frequently used electronic measurement devices than females ($\gamma = 0.36$; $P < 0.0005$), and performed more weekly root canal treatments ($\gamma = -0.27$; $P < 0.0005$). A tendency for males using fewer appointments to instrument a molar than females was observed ($\gamma = -0.12$; $P < 0.057$). In addition, females completed vital cases ($\gamma = -0.19$; $P < 0.004$) and nonvital cases ($\gamma = -0.24$; $P < 0.0005$) in significantly more visits than males.

Influence of graduation year

Dentists in the early education groups performed fewer endodontic treatment per week than dentists in the later group ($\gamma = 0.31$; $P < 0.0005$), who reported spending more time to instrument a molar ($\gamma = 0.13$; $P < 0.016$).

Influence of endodontic treatment frequency

The only slight significant correlation found was between responders performing an increased number of treatments per week and a more frequent use of electronic measurement devices ($\gamma = -0.15$; $P = 0.012$).

Technology cluster

The regular users of electronic measurement devices were observed to be regular users of NiTi hand instruments ($\gamma = 0.20$; $P = 0.002$), NiTi rotary systems ($\gamma = 0.47$; $P = 0.001$) and warm gutta-percha techniques ($\gamma = 0.32$; $P < 0.0005$). Frequent rubber dam application was correlated to the adoption of NiTi hand instruments ($\gamma = 0.24$; $P = 0.003$), NiTi rotary systems ($\gamma = 0.50$; $P < 0.0005$) and warm gutta-percha techniques ($\gamma = 0.29$; $P = 0.0005$).

The adoption of NiTi rotary systems ($\gamma = -0.23$; $P = 0.008$) and electronic measurement devices ($\gamma = -0.14$; $P = 0.013$) were correlated with fewer treatment sessions dedicated to instrumenting a molar tooth. The completion of treatment was accomplished in fewer visits when canals were obturated with warm gutta-percha techniques ($\gamma = -0.15$; $P = 0.012$), and if instrumentation had been carried out by either NiTi hand instruments ($\gamma = -0.12$; $P = 0.029$) or NiTi rotary systems ($\gamma = -0.25$; $P = 0.004$).

Discussion

In Denmark there is no recognized postgraduate specialist training in Endodontology, therefore endodontic treatment in Danish adults is almost exclusively performed by general dentists in private practice. The Danish Dental Association manages 3450 of the practitioners. Of these 956 (28%) are working in the Copenhagen area. The questionnaire was returned by approximately 72% of the Copenhagen dentists, which implies the population represented the dentists in the region. However, there might be differences in practice patterns between Danish dentists working in urban and rural areas and generalizations must be made with care.

Thirty-five per cent of the responders reported to have clinical experience of NiTi hand instruments. Data from other populations of dentists are scarce. However, amongst Flemish practitioners Slaus & Bottenberg (2002) and Hommez *et al.* (2003) found 47 and 50%, used NiTi hand files or reamers at least sometimes. Only 18% of the Copenhagen dentists often negotiated root canals with such instruments and 10% often used rotary NiTi instrumentation. In a recent Australian survey (Parashos & Messer 2004) rotary NiTi instrumentation were used by 22% of the GPs. Despite a substantial body of studies showing a superior quality of NiTi instrumentation over conventional, the

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Oft. (%)	Occ. (%)
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14	42
53	36

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Rogers (1983) suggested that the adoption rate of a technology might be explained by its perceived attributes. He proposed five characteristics to be used as a framework for analysis: relative advantage, compatibility, complexity, suitability for trials and observability. The concept of 'relative advantage' denotes the extent to which the technology is perceived as being better than the idea it supersedes. 'Compatibility' is the degree to which an innovation is perceived as consistent with the existing values, past experiences and needs of potential adopters. 'Complexity' marks the extent to which a technology is perceived as relatively difficult to understand and use. 'Trialability' is the extent to which an innovation may be experimented with on a limited basis. The fifth attribute 'observability' refers to the extent to which the results of a technology are visible to others. The 'relative advantage' has been found to be one of the best predictors of the rate of adoption of innovations (Rogers 1983, Molander *et al.* 1996). In a dental context the advantages may relate either to the patient or the dentist. Regardless of instrumentation technique endodontic treatment frequently relieves patients of pain. Persistent pathology is mostly asymptomatic, and, therefore, normally is detected by radiographic examination. Thus, only the dentist will in general 'observe' improved treatment quality. Subsequently, marketing has focused, not so much on health effects, as on enhancing the simplicity and the time-saving effects of using NiTi technology. However, amongst the Copenhagen practitioners a mechanical device is already used by 42%, a situation which might act as a barrier to the adoption of NiTi rotary systems.

The NiTi innovation obviously has a high 'compatibility' factor. However, in order to change from conventional to rotary instrumentation technique the 'trialability' and the 'complexity' aspects seem crucial. In a recent study of Swedish dentists Reit *et al.* (unpublished data) found significantly more individuals willing to adopt a rotary system when hands-on training was included in the educational package, as compared with just lectures and written information.

The use of warm gutta-percha appealed to a large proportion of the Danish dentists. One-third of the sample used it occasionally and 19% often. In comparison, warm techniques were found to be used by only 4% in a Flemish sample (Slaus & Bottenberg 2002).

Amongst general dentists negative attitudes towards root canal treatment have been reported. Slaus & Bottenberg (2002) found that only 34% of a sample of Flemish dentists actually liked doing endodontics. Root canal treatment is technically demanding and is often in general practice carried out under less than optimal conditions. For example, several studies have shown that the vast majority of dentists abandon the use of rubber dam as they enter general practice. In the present sample only 4% reported to use it often, whereas 14% of the responders were occasional users. In fact, it has been reported that 19% of a subpopulation of British generalists (Jenkins *et al.* 2001) and 3% of Flemish practitioners (Slaus & Bottenberg 2002) used rubber dam for endodontic purposes. In contrast, studies have shown that most patients prefer dental treatment to be carried out under the protection of rubber dam (Stewardson & McHugh 2002).

In the present sample treatment procedures were extended over several appointments. Of the Copenhagen dentists 53% frequently spent two sessions to instrument a molar and 20% often needed three or more appointments to complete the shaping. To complete the treatment of a nonvital case most practitioners often used at least three sessions. The observed nonuse of rubber dam and often prolonged and seemingly irrational treatment procedures might be due to time pressure resulting in short treatment sessions. Such pressure is often caused by restrictions imposed by the remuneration system. In Denmark the fee structure within the National Health Insurance (NHI) system has for many years not rewarded endodontic treatment quality, because it has been fixed at a relatively low level, with no relation to the time factor spent on the treatment. This aspect has been qualitatively analysed in the study by McColl *et al.* (1999) where in-depth interviews of general dental practitioners revealed that there was a dilemma between the time required for molar endodontic treatment and the fee offered by the National Health Service (NHS). However, in 1999 a new contract was introduced in Denmark (where the fixed fee for endodontics was abandoned) that has considerably decreased the time-cost dilemma. Therefore, general dental practitioners today have a remuneration system that could give adequate reward for quality, because an individual fee can be introduced reflecting the actual costs of equipment, time etc. As already outlined the remuneration system is only one aspect amongst many factors that affect the quality of root canal treatment performed in general dental practice. However, it might be an important baseline for improving endodontic care in Denmark. In the light of the new fee structures, Danish dentists were recently

motivated and encouraged to use rubber dam in order to produce high quality treatment (Bjørndal 2002).

The adoption of new endodontic instrumentation and filling techniques seemed to be associated neither with gender (only electronic measuring devices were more used by males) nor age (year of graduation) of the dentists. The latter might be explained by the very recent inclusion of NiTi technology in the curriculum of the Danish dental schools (Bjørndal *et al.* 2001). However, male dentists completed cases in fewer treatment sessions than female dentists, and young practitioners spent more appointments on the instrumentation of a molar than their more senior colleagues.

It has been proposed that the adoption of one technology may lead to the adoption of others that are closely related (Rogers 1983, Molander *et al.* 1996). Such a technology cluster was observed also in the present study. Several significant associations/correlations were found between the technologies, indicating that the front-runners and early adopters did not view the innovations in isolation. The adoption of NiTi technology seemed to influence the time spent per case. Use of rotary systems was significantly associated with less instrumentation sessions as well as fewer numbers of visits needed to complete a case. This was also noted in the Australian survey (Parashos & Messer 2004) where 80% of the users of rotary instrumentation reported a more rapid preparation of root canals.

Conclusions

According to Rogers' (1983) diffusion curve (Fig. 1) the adoption of new endodontic technology amongst Danish GPs is in an early phase. The adoption frequencies of the innovations varied between 10 and 30%, a position where a more rapid diffusion rate might be expected in the near future. A new Danish remuneration system might influence the rate of adoption but progress towards high quality endodontics might be hindered by the nonuse of rubber dam.

Acknowledgements

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Appendix V

Bjørndal L, Laustsen MH, Reit C (2007) Danish practitioners' assessment of factors influencing the outcome of endodontic treatment. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, **103**, 570-5.

Danish practitioners' assessment of factors influencing the outcome of endodontic treatment

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Objective. This investigation explored the hypothesis that among general dental practitioners (GDPs), the performance of root fillings of substandard quality might be associated with deficient knowledge of factors important to the outcome of endodontic treatment.
Study design. A questionnaire was mailed to 600 randomly selected GDPs. The influence of 24 factors on treatment outcome was assessed on 100 mm visual analog scales. A gold standard (GS) was established by an external group of researchers. Comparisons between the GDP response and the GS were analyzed using Wilcoxon tests.
Results. Despite large variation, the responses were significantly associated with sex, year of education, and exposure to endodontic treatment. Compared with the GS, the GDPs emphasized factors associated with clinical symptoms and underevaluated factors related to the microbial situation in the root canal.
Conclusions. The GDPs seemed to regard endodontics mainly to be a procedure to keep a patient free of symptoms.
(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:570-5)

Despite a declining caries prevalence in the Western world, endodontic treatment is still in great demand. In Denmark, Bjørndal and Reit[1] reported a 17% increase in the annual number of root fillings provided between 1977 and 2003. However, most population studies have observed high frequencies of substandard root-filling quality.[2-6] For example, in a Danish sample, Kirkevang et al.[5] found that 59% of root fillings showed signs of inadequate seal and 40% were not of optimal length. Studies have also shown a strong correlation between root-filling quality and treatment outcome.[6]

Factors that shape the quality of root canal treatment performed in general dental practice are not well known. It has been suggested that the use of inadequate equipment has bearing on the quality of treatment[7] and that the replacement of stainless steel hand files with nickel-titanium rotary instruments might be beneficial. In support of this notion, Molander et al.[8] reported an increased frequency of good quality root fillings when nickel-titanium rotary instruments were introduced to a group of Swedish general dental practitioners. It has also been proposed that not only "hardware" components of a technology, but also "software" parts like knowledge and attitudes, might influence the quality of the performance.[9] Hays et al.[10] proposed that insight and awareness of one's performance will influence clinical practice; in a study of physicians' clinical competence, they stated that doctors who perform poorly not always appear to be aware of how their performance compares with accepted practice, and that they are unaware of gaps in their knowledge.

When analyzing the forms of knowledge that the dental practitioner needs, Reit et al.[11] suggested the concepts "episteme," "techne," and "phronesis," introduced by Aristotle,[12] to be useful. Episteme corresponds with what might be described as theoretical-scientific knowledge. Techne is practical knowledge, but the concept encompasses not only the ability to do things, but also to understand what you are doing. Phronesis is the ability to think about practical matters and can be translated as "practical wisdom."

The first aim of the present study was to explore the status of significant endodontic epistemic knowledge, specifically the influence of prognostic factors on treatment outcome, among a representative sample of Danish general dental practitioners. Their responses to a questionnaire were compared with a "gold standard" obtained from a panel of selected experts within the field of endodontology. The second aim was to study the self-awareness of the practitioners in the area of their level of epistemic and technical knowledge.

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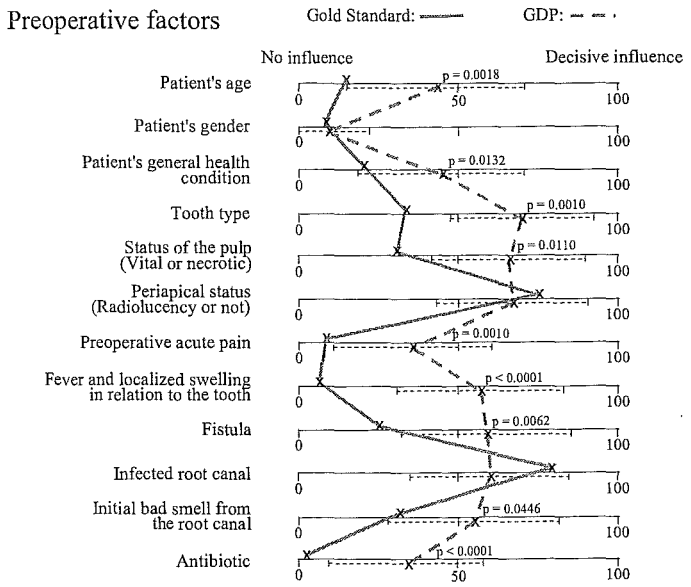

Fig. 1. The gold standard (GS) on preoperative factors affecting endodontic outcome compared with the general dental practitioners (GDP) group response. *P* values denote the significant results from the Wilcoxon tests.

MATERIAL AND METHODS

Questionnaire to general dental practitioners

To test the design of the questionnaire, 10 general dental practitioners (GDPs) were used as pilots. In January 2004, a revised questionnaire was sent to 600 Danish GDPs. The GDPs were selected from the roster of the Danish Dental Association, which at that time listed 3293 members. The selection was carried out at random, with the acceptance of the Danish Dental Association, with the database software program Microsoft SQL Server 2000 Standard Edition, version 8.0.534 (Microsoft, Bloomington, Minnesota). The questionnaire was mailed with a letter guaranteeing confidential and anonymous processing of the data and a stamped, coded return envelope. Nonresponders were approached by a second mail in March 2004. To the second-wave nonresponders, phone calls were made. The questionnaire asked about information regarding age and sex of the responder, years in practice, employment status, and the weekly number of working hours and endodontic treatment visits as earlier described.[13] The responder was asked to assess the influence of 24 factors on endodontic treatment outcome (Figs. 1-3). The assessments were made using 100 mm visual analog scales with "no influence" and "decisive influence" as end points. The GDPs were also asked to make a self-assessment of their level of various aspects of epistemic knowledge and technical skill graded as "excellent," "satisfactory," or "nonsatisfactory" (Table I).

Questionnaire to endodontic researchers (gold standard)

An expert panel was selected based on a PubMed search for "endodontics and treatment outcome." Ten persons fulfilled the criteria of authoring or coauthoring 3 papers within the last 14 years. Three researchers either had retired or had passed away. The remaining 7 individuals were mailed an identical set of questions concerning prognostic factors as described earlier. Each researcher reported his assessments without knowing the names of the other researchers. When answers were collected, the mean value and standard deviation of each factor was calculated. Like in the Delphi method,[14] this information was communicated to the experts, who were given a chance to change their initial response. After the second round of responses, mean values were recalculated and were regarded as a measure of group consensus and used as "gold standard."

Statistical analysis

A stepwise analysis of variance (ANOVA) was applied. Model 1 included whether demographic factors such as sex, age, and year of education had effect on the respond pattern. Model 2 contained the variables em-

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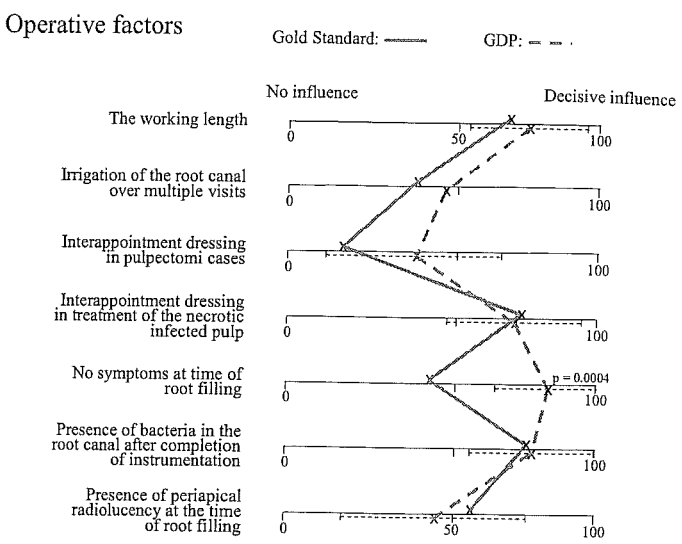

Fig. 2. The gold standard on operative factors affecting endodontic outcome compared with the GDP group response, using visual analog scale scores. *P* value denotes the significant results from the Wilcoxon tests.

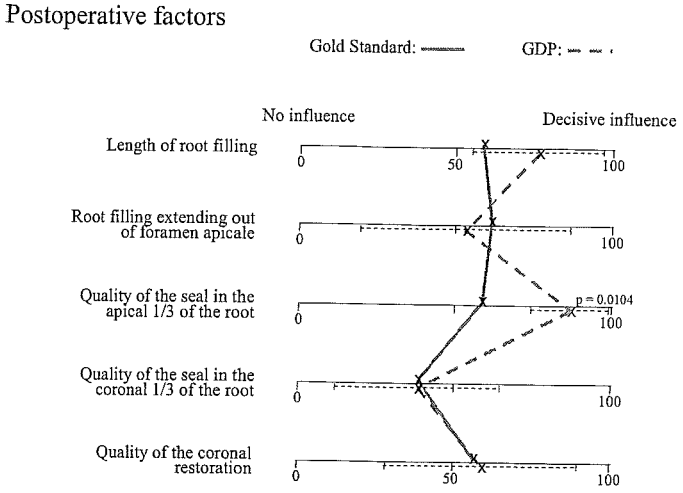

Fig. 3. The gold standard on endodontic outcome compared with the GDP group response in relation to postoperative factors, using visual analog scale scores. *P* value denotes results from the Wilcoxon tests.

ployment status (clinic owner or associate), number of clinical working hours per week, and number of endodontic visits per week. Firstly, model 1 was analyzed and followed by step-by-step removal of nonsignificant variables. If significant variables were found in model 1, they were incorporated into the analysis of model 2.

Tests of independence were performed as Monte Carlo simulated exact tests by using DIGRAM[15] for variables with categorical scales (e.g., age was grouped in 5 classes, the youngest being 23-32 years of age and the oldest 63-72 years of age) and for data not showing a normal distribution. Partial γ-coefficients (a nonpara-

Table I. The distribution of male and female general dental practitioners' self-assessments of level of endodontic knowledge and skills (N = 470)

	Excellent			*Satisfactory*			*Nonsatisfactory*			*No*
Endodontic topics	*Total (%)*	*M*	*F*	*Total (%)*	*M*	*F*	*Total (%)*	*M*	*F*	*influence*
Pulpal pathology	156 (34.9)	87	69	263 (58.8)	142	120 (1*)	28 (6.3)	7	21	23
Microbiology	39 (8.7)	14	25	225 (50.4)	127	97 (1*)	182 (40.8)	96	86	24
Clinical diagnostics	310 (68.9)	162	148	138 (30.7)	75	62 (1*)	2 (0.4)	1	1	20
Injecting local anesthesia	361 (80.0)	200	161	85 (18.8)	38	46	5 (1.1)	0	5	19
Emergency treatment	333 (74.8)	182	151	107 (42.0)	53	54	5 (1.1)	2	3	25
Root canal preparation procedure	182 (40.4)	109 (1*)	72	245 (54.3)	115	130	24 (5.3)	14	10	19
Root filling procedure	151 (33.5)	95 (1*)	55	273 (60.5)	135	138	27 (6.0)	19	8	19
Prognostic factors	114 (25.7)	70	44	296 (66.7)	150	145 (1*)	34 (7.7)	15	19	26

M, male; *F*, female.
*Number of responds not specified in relation to gender.

metric rank correlation[16]) were used to characterize the degree of association in these cases. The GDP group opinions and the gold standard were compared by Wilcoxon tests, because a normal distribution assumption was clearly rejected (significance level set at $P < .05$).

RESULTS

The overall response rate was 79.2% (N = 475). Five questionnaires were returned blank and 26 were only partially completed. The major reason given for not responding was that the dentists felt too busy to complete the form. In addition, 10 practitioners questioned the anonymity (the return envelope was coded) and did not want to take part in the study. Fifty-three percent of the responders were males. However, among younger dentists, a majority were females. Seventy percent of the GDPs were practice owners, and 88% worked 27 hours or more per week. Fifty-two percent reported to have 2 to 4 weekly endodontic visits and 28% had more than 5.

GDP responses on the prognostic factors

There was a large variation within almost all the GDP responses (Figs. 1-3). In general, the GDP group response assessed many preoperative factors as having an important influence on endodontic outcome with visual analog scale scorings >50. Tooth type was assessed by the GDP as the most influencing preoperative factor on endodontic outcome (Fig. 1). Results from the operative and postoperative factors are disclosed in Figs. 2 and 3.

Comparisons between the GDP group response and the gold standard

The GDP group response, in 9 of 12 preoperative factors, significantly overevaluated the influence on prognosis as compared with the gold standard (GS; Fig. 1). In contrast, the GS indicated a high influence for only 2 factors: periapical status and infected root canal (Fig. 1). The use of "antibiotic" had the least influence of all the preoperative factors according to the GS.

GDP group response and sex

Female GDPs assessed a significantly higher influence on endodontic outcome than males in relation to the following preoperative factors: tooth type (ANOVA, $P = .0067$), periapical status, fever and localized swelling in relation to tooth (ANOVA, $P = .0021$), and fistula (ANOVA; $P < .0001$). Females also assessed root filling extending out of the apical foramen as having a higher influence on outcome than males (ANOVA, $P = .0079$). The female GDPs agreed with the GS that periapical status influences the treatment outcome, whereas male GDPs had a significantly different group response than compared with the GS (Wilcoxon test, $P = .0426$).

GDP group response and age

Younger aged GDPs versus older scored a higher influence on treatment outcome as shown by the negative correlations in relation to status of the pulp ($\gamma = -0.16$; $P = .000$) and periapical status ($\gamma = -0.12$; $P = .02$). Moreover, younger GDPs also assessed a higher influence for use of interappointment dressing in relation to the treatment of necrotic infected pulp ($\gamma = -0.27$; $P = .000$) and the presence of bacteria in the root canal after instrumentation ($\gamma = -0.19$; $P = .004$).

GDP group response and weekly endodontic visits

GDPs with relatively more weekly endodontic visits increased the assessments of influence on the treatment outcome expressed as positive correlations in relation to status of the pulp ($\gamma = 0.12$; $P = .026$), periapical status ($\gamma = 0.23$; $P = .000$), and working length ($\gamma = 0.18$; $P = .009$). Moreover, GDPs having relatively

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GDP self-assessments of the level of endodontic knowledge and skills

In Table I, the self-assessment level of knowledge and clinical skills are displayed. The clinical skills were, in general, assessed by the vast majority of the GDPs as being excellent or satisfactory. The topic "microbiology" had the overall highest proportion of nonsatisfactory scores (~40%).

Correlation analysis of the GDP sex and level of endodontic knowledge and skills

Females as opposed to male GDPs did not find themselves at a satisfactory level concerning pulp pathology ($\gamma = 0.25$; $P < .010$), injecting local anesthesia ($\gamma = 0.23$; $P < .044$; given the same graduation year), mechanical root canal preparation ($\gamma = 0.29$; $P < .003$; given the same graduation year and age), root-filling procedure ($\gamma = 0.33$; $P < .0001$), and knowledge about prognostic factors ($\gamma = 0.23$; $P = .008$).

Correlation analysis of the GDP graduation year and level of endodontic knowledge and skills

The most recent educated GDPs found themselves at a satisfactory level concerning pulp pathology ($\gamma = -0.13$; $P = .023$) and microbiology ($\gamma = -0.30$; $P = .005$), whereas injecting local anesthesia ($\gamma = 0.30$; $P = .001$) and performing emergency endodontics ($\gamma = 0.40$; $P = .003$) were nonsatisfactory.

Correlation analysis of the GDP employment status and level of endodontic knowledge and skills

Practice owners as opposed to associates assessed a higher satisfactory level in relation to microbiology ($\gamma = -0.30$; $P = .005$), clinical diagnostics ($\gamma = -0.29$; $P = .005$), emergency treatments ($\gamma = -0.30$; $P = .029$), and injecting local anesthesia ($\gamma = -0.41$; $P = .000$).

Correlation analysis of the GDP weekly working hours and level of endodontic knowledge and skills

Knowledge of clinical diagnostic factors (irrespective of employment status) and prognostic factors were assessed higher by general dental practitioners working most hours per week than by GDPs working few hours per week ($\gamma = -0.19$; $P = .013$).

DISCUSSION

The present study was part of a series of investigations attempting to explore factors that shape the quality of endodontic treatment in general dental practice. It was understood that not only levels of techne but also of episteme will exert influence on clinical behavior. The idea tested was that there might be a distorted apprehension among Danish GDPs of which factors are important for the treatment outcome and that such a distortion might contribute to the acceptance of a high rate of low-quality root fillings and symptomless periapical lesions in root-filled teeth. A random sample of 600 Danish GDPs was addressed. Questionnaires that were possible to analyze were returned by approximately 75%, a rate high enough to make conclusions valid.[17]

The GDP group response was compared with a GS. The GS was created by a consensus procedure among 7 researchers who were assumed to have expert knowledge of the relevant literature. The highest number of significant differences between the GDPs and the GS were found among preoperative factors (Fig. 1). The GDPs did put weight on most of these factors, whereas the GS singled out 2 as the most influential: periapical status and root canal infection. In comparison with the GS, the GDPs seem to overevaluate the importance of clinical symptoms such as pain, swelling, and the presence of a fistula. The focus on clinical symptoms was also observed among the operative factors, where the evaluation of "no symptoms at the time of root filling" resulted in the only statistically significant difference in that group.

Results from other studies support the idea that treatment initiation as well as acceptance of treatment outcome in general practice, to a great extent, is related to the presence or not of clinical symptoms. In 2 Swedish samples, Reit et al.[18] and Karlsson and Reit[19] found that intracanal procedures most often were instituted to cure symptoms like pain and tenderness in vital and necrotic pulps. At the same time, retreatment of symptomless persistent periapical lesions in root-filled teeth was very rare. In concordance, Bjørndal et al.[13] reported that endodontic treatment in Denmark most often was carried out in carious painful vital molars. Teeth with symptomless pathological conditions were infrequently negotiated.

On the one hand, a high frequency of substandard root fillings has been registered in Denmark.[5] On the other hand, the present study showed that the Danish GDPs appreciated the importance of the technical root-filling quality for the outcome of the treatment (Fig. 3), and that 94% regarded their level of endodontic skill as either excellent or satisfactory (Table I). In other words, Danish GDPs seem to know what they should do, think

they are good at doing it, but often perform inadequately. In the terms of Hays et al.,[10] it might be suggested that these are signs of lack of insight, with insight defined as "an awareness of one's performance in the spectrum of medical practice." According to Hays et al.,[10] insight may be regarded as a combination of 3 related constructs: awareness of one's own performance, awareness of the performance of others, and a capacity to reflect on both of these measures. A complementary interpretation of data is that, since the focus of the Danish GDPs seems to be on the presence or not of clinical symptoms, even root-filling quality of low technical quality is accepted as long as it prevents such symptoms.

Within the GDP group, large interindividual variations were found. Sex, year of education, and exposition to endodontic treatment could explain parts of this variation. The women regarded factors like periapical status, fever, swelling, and fistula to have greater impact on treatment outcome than did the male respondents. Young practitioners gave higher scores to microbiologically related operative factors such as "presence of bacteria in the root canal after completion of the instrumentation" and "interappointment dressing in relation to the treatment of the infected pulp." As could be expected, the GDPs with a higher weekly exposure to endodontic treatment did not assess tooth type as so important to the outcome as those treating root canals on a more irregular basis.

When levels of episteme and techne were self-assessed by the practitioners, the grade "nonsatisfactory" was rarely used (Table I). However, 40.8% regarded their knowledge of microbiology not to be up to standard. Again, this supports the notion that Danish GDPs look on endodontics as not so much a measure of preventing or treating an infectious condition like periapical disease, but as a procedure to keep a patient symptom-free. As long as the treatment fulfills that goal, it seems widely accepted, even if the root filling is of low technical quality.

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Appendix VI

Bjørndal L, Reit C (2008) Endodontic malpractice claims in Denmark 1995-2004. *International Endodontic Journal* **41**, 1059-65.

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Endodontic malpractice claims in Denmark 1995–2004

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Abstract

Bjørndal L, Reit C. Endodontic malpractice claims in Denmark 1995–2004. *International Endodontic Journal*, **41**, 1059–1065, 2008.

Aim To study the reasons for and outcome of malpractice claims handled by the regional and national Danish Dental Complaint Boards (DCB) from 1995 to 2004. Specific attention was paid to endodontic claims. Three hypotheses were explored: endodontic malpractice claims are frequent, they are mostly due to technical shortcomings and male dentists are overrepresented.

Methodology The reasons for the claims were classified and assigned to at least one of 14 categories. Cases assigned to the 'endodontic treatment' category were further sub-categorized, and reasons for malpractice were examined. An age and gender analysis of dentists and complaining patients was performed only on data obtained from the endodontic cases.

Results Overall, 3611 malpractice claims were registered. In 43% of the cases the dentist was judged to be guilty of malpractice. In the majority of the appealed cases the original verdict was affirmed (62.2%) by the national DCB. After crown & bridge treatment (23%) endodontic treatment was the next frequent malpractice claim (13.7%), in which 'technical complications or incorrect treatment' was the most frequent sub-categorization (28.4%). Reasons for endodontic malpractice verdicts were related to root filling quality, the use of a paraformaldehyde product and instrument fracture. Male dentists were most often involved in an endodontic claim, and the majority of complainants were females.

Conclusions Endodontic malpractice claims were relatively common in Denmark. Perceived technical shortcomings dominated the patients' complaints concerning root canal treatment. Male dentists and female patients were overrepresented indicating a gender influence on aspects of the doctor-patient communication important for liability claims.

Keywords: complaints, endodontic malpractice, endodontics, gender, root canal treatment.

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Introduction

The technical quality of endodontic treatment provided by general dental practitioners (GDP) has received much attention from investigators, and in epidemiological surveys substandard root fillings have been reported in more than 50% of treated cases (Kirkevang *et al.* 2000, Eriksen *et al.* 2002, Segura-Egea *et al.* 2004, Loftus *et al.* 2005, Ridell *et al.* 2006). Since a strong correlation has been found between root filling quality and treatment outcome (in terms of periapical healing) there is an obvious need to understand the reasons why and also to influence the behaviour of GDPs. However, factors that shape the quality of root canal treatment performed in general dental practice are, at present, not well understood.

In a series of investigations the potential influence on treatment quality of the utilization of new technology (Bjørndal & Reit 2005), treatment indications (Bjørndal *et al.* 2006) and the level of theoretical knowledge (Bjørndal *et al.* 2007) have been studied amongst Danish GDPs. However, endodontic treatment quality

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from the patient's point of view as, for example, reflected in dental malpractice cases, has been dealt with only by a few authors. Dental malpractice claims have been reported to most frequently be associated with prosthodontic treatment (René & Öwall 1991, Hapcook 2006) but claims related to root canal procedures were very common and reached 14% in a Swedish sample (René & Öwall 1991) and 17% in a material from the US (Hapcook 2006). However, detailed information about the character of endodontic claims is sparse.

The present study was established to study reasons for and verdicts of dental malpractice claims in Denmark during a 10-year period (1995–2004). The study focussed on cases involving endodontic treatment and three hypotheses were explored.

(H1) Since the frequency of root canal treatment in Denmark has not decreased over the last decades (Bjørndal & Reit 2004) the number of endodontically related malpractice claims should be relatively high.

(H2) In Denmark root fillings are often of substandard technical quality (Kirkevang *et al.* 2000) and rarely performed with the use of rubber dam (Bjørndal & Reit 2005), resulting in a high frequency of persistent periapical inflammatory lesions. Furthermore, treatment of molars predominates (Kirkevang *et al.* 2000, Bjørndal *et al.* 2006) and there are few endodontic specialists to refer complicated cases to. Malpractice claims are expected to reflect this situation and to a substantial part be associated with the results of defective root fillings and technical treatment complications.

(H3) A malpractice claim might be perceived as a criticism of the dentist's competence and a sign of a break down in the communication with the patient. Levinson *et al.* (1997) found that physicians accused of malpractice practiced less so called patient-centred communication than physicians not involved in such situations. In a meta-analytic review Roter *et al.* (2002) focused on gender effects in the doctor-patient communication, and found that female primary care physicians were more frequently involved in communication that was considered patient-centred and allowed more time for the visits than their male colleagues did. It was assumed that this situation also should be reflected in dental practice, and therefore an overrepresentation of male dentists claimed for malpractice would be expected.

Materials and methods

Since 1983 dental malpractice cases in Denmark have been handled by 16 regional Dental Complaint Boards (DCB), each consisting of three dentists appointed by the Danish Dental Association and three laypeople appointed by the county National Health Insurance (NHI). The system has previously been described in detail by Schwarz (1988). Following a complaint from the patient and an explanation from the dentist the DCB gives a written statement, which includes a verdict of malpractice or no malpractice. If the board finds the dentist guilty of malpractice he or she must return the fee for the treatment to the patient. The DCB might also propose a settlement between the complainant and the dentist. In such a settlement the dentist in question accepts to cover the patients' expenses for additional dental treatment provided by another practitioner. Complaints might be rejected by the DCB, most often because of a time limitation rule (5 years). The dentist or the patient may appeal to a national board (NDCB). Besides three dentists and three laypeople the NDCB also includes a civil court judge. The NDCB might temper, affirm, intensify or reject the regional DCB judgment. If one of the parties still is dissatisfied the case can be brought to civil court. Permission to obtain access to the files of complaints was obtained from the NHI and the official data register system in Denmark. The files were investigated for a 10-year period (1995–2004) and all cases handled by the 16 regional as well as the national DCB were included. In 1999 the Danish dental insurance remuneration system was changed (Bjørndal & Reit 2005), which hypothetically could have an influence on the number and character of malpractice claims. Therefore, comparisons were made between the two 5-year periods 1995–1999 and 2000–2004.

The authors classified the complaints and assigned each case to at least one of the following categories: aesthetic dentistry, cariology, diagnostics, endodontic treatment, financial costs, implantology, informed consent, office records, oral surgery, pain (not endodontically related), periodontal treatment, preventive care, prosthodontics (crown & bridge and dentures). More than one category could be used in a single case.

Endodontic claims

Detailed information was only available for cases registrered between 1995 and 2002 (n = 517). Analysis and subcategorization was possible to conduct in 482 claims (93%). The subcategorization was done according to the following.

(1) *Technical complications or incorrect treatment.* 'Technical complications' occurred in the course of

treatment, *e.g.* perforation of the root, instrument fracture, side effects of medicaments or defective root filling quality. A case was assigned to the 'incorrect treatment' category when a problem was, as experienced by the patient, a direct result of the treatment, such as, symptoms of infection, tooth fracture, or postoperative pain.

(2) *Persistent pain*: Following treatment the patient was in pain for a subjectively unacceptable period of time.

(3) *Wrong treatment*: The patient believed that the wrong tooth has been treated or thought that a tooth has been treated for the wrong reason.

(4) *Prolonged treatment*: The treatment was extended over a long period of time, including several appointments, often leading to complications or extraction of a tooth.

(5) *Lack of information*: The patient was not informed of crucial steps in the diagnosis or the treatment.

(6) *Other reasons*: The main reason for complaint was not endodontic, but an 'unnecessary' root canal treatment was the result of a diagnostic or a nonendodontic treatment problem.

The sub-categorization procedure was carried out blind to the DCB decisions. For cases assigned to the 'technical complications/incorrect treatment' group the written motives of the DCB decisions were studied in detail with the intention of finding explicit or implicit verdict policies.

Age and gender analysis of dentists and complaining patients was performed only on data obtained from the endodontic cases. Such data could be collected from the 482 cases. Two local DCBs refused to reveal age data referring to ethical problems. According to age dentists were grouped into 'younger' and 'older', defined as below and above the mean age, respectively. The general distribution of number and gender of Danish GDPs was provided by the Danish Dental Association.

Statistical analysis

Summary statistics was carried out and comparisons were performed using χ^2 - or *t*-test. Level of significance was set to 0.05.

Results

For the 10-year period a total number of 3611 complaint cases were registered by the local DCBs. Forty-three percent of the claims resulted in a conviction of malpractice. About one third of the cases were referred to the NDCB. In a majority of these claims (62.2%) the verdict of the regional DCB was affirmed. No systematic difference was found between decisions made before and after the change in the dental remuneration system. Over the years only small variations in the annual number of registered claims were found; from a minimum of 11.1 per 100 000 patients to a maximum of 15.2 (Table 1). However, Copenhagen, the only big city area in Denmark, differed from the country as a whole with a mean of 24.7 reported cases per 100 000 patients.

Table 1 Annual number of dental malpractice complaints in Denmark and the county of Copenhagen

	Denmark		Copenhagen county	
Year	Total number	Complaints per 100 000 patients	Total number	Complaints per 100 000 patients
1995	331	12.1	71	24.8
1996	408	14.9	84	29.5
1997	340	12.3	50	17.2
1998	362	12.9	85	29.1
1999	308	11.1	39	13.4
2000	345	12.5	64	22.2
2001	372	13.5	72	25.0
2002	378	13.8	88	30.9
2003	412	15.2	86	30.3
2004	355	12.9	71	24.9
Total/mean	3611	13.1	710	24.7

Complaints were most frequently (23%) associated with crown & bridge therapy (Table 2). Claims concerning root canal treatment were the third most

Table 2 Number of malpractice complaints for different categories. More than one category could be used in a single case

	1995–1999		2000–2004	
Categories	Number	%	Number	%
Crown & Bridge	559	23.0	678	22.8
Dentures	372	15.3	302	10.2
Endodontic treatment	354	14.5	388	13.1
Diagnostics	308	12.7	355	11.9
Caries	237	9.7	380	12.8
Periodontal treatment	171	7.0	168	5.7
Implantology	109	4.5	51	1.2
Oral surgery	108	4.4	120	4.0
Informed consent	75	3.1	122	4.1
Other	61	2.5	110	3.7
Pain	33	1.4	166	5.6
Office records	19	0.8	91	3.1
Aesthetic dentistry	14	0.6	22	0.7
Preventive care	13	0.5	19	0.6
Financial cost	1	0.0	1	0.0
Total	2434	100.0	2973	100.0

frequent (14.5%) in the 1995–1999 period and the second most frequent (13.1%) in the 2000–2004 period.

Endodontic claims

In 50% of the 482 analysed endodontic cases the complaint were only limited to an endodontic problem, while the rest showed a combination of one or more further dental problems (data not shown). The 482 endodontic claims were most often classified as due to technical complications or incorrect treatment (28.4%) (Table 3). Table 4 displays a further elaboration of these 137 cases. In the 'technical complication' group problems related to the root filling quality predominated and in the 'incorrect treatment' group symptoms of persisting infection were the most common. In 108 cases (22.4%) an endodontic sub-categorization was not possible.

When the root filling quality was judged not to be optimal the dentist most often was found guilty of malpractice (Table 4). However, if the dentist had explained why it was not possible to reach the very best technical result, for example due to difficult root canal anatomy, he or she was not found guilty of malpractice.

Multi-rooted teeth were involved in 12 of 16 claims concerned with fractured instruments. The DCBs considered the dentist as guilty of malpractice if the canal anatomy was simple, the root filling around the instrument was defective, apical pathology was persistent or the patient was not informed. Some DCBs stated

Table 3 Endodontic complaints and the DCB decisions 1995–2002

	DCB decisions				
	Verdict of malpractice	No verdict of malpractice	Settlement	Rejection	Total *n* (%)
Technical complications or incorrect treatment	55	74	5	3	137 (28.4)
Other reasons	56	26	3	1	86 (17.8)
Persistent pain	24	39	1	–	64 (13.3)
Wrong treatment	11	37	2	–	50 (10.4)
Lack of information	11	10	–	–	21 (4.4)
Prolonged treatment	10	6	–	–	16 (3.3)
No data	12	21	69	6	108 (22.4)
Total	179	213	80	10	482 (100)

Table 4 Sub-categorization of 'technical complications' and 'incorrect treatments' and the DCB decisions (1995–2002)

	DCB decisions				
	Verdict of malpractice	No verdict of malpractice	Settlement	Rejection	Total *n* (%)
Technical complications					
Defective root filling (short, long, leaking, not all root canals root filled)	31	11	–	2	44 (32.1)
Separated instrument	5	10	–	1	16 (11.7)
Root perforation (following instrumentation or post-preparation)	8	1	–	–	9 (6.6)
Medicament related (all events after use of a paraform- aldehyde product)	4	–	–	–	4 (2.9)
Other complications (e.g. a foreign body in maxillary sinus, nerve damage)	–	10	2	–	12 (8.8)
Incorrect treatment					
Symptoms of infection	3	18	2	–	23 (16.8)
Tooth was weakened/fractured/extracted	1	10	1	–	12 (8.8)
Treatment related persistent pain	2	12	–	–	14 (10.2)
Incorrect treatment is stated but not further detailed	1	2	–	–	3 (2.2)
Total	55	74	5	3	137 (100.1)

that an instrument left in the canal could serve equally well as a conventional root filling and thus gave non malpractice verdicts. In no case was the presence or absence of rubber dam commented upon by the DCBs.

A significant ($P < 0.0005$; $\chi^2 = 22.911$) difference in malpractice verdicts was found between cases assigned to the *'technical complications'* group (malpractice frequency = 56%) and cases in the *'incorrect treatment'* group (malpractice frequency = 13.5%).

Age and gender of patients and dentists did seem to exert influence on the pattern of complaints. Male dentists were involved in 69% ($n = 331$) of the endodontically related complaints, which significantly differed ($P < 0.0005$; $\chi^2 = 15.189$) from the general proportion of male GDPs (57.8%) during the period. In contrast, the majority of complainants were women (71.0%, $n = 342$), which significantly differed ($P < 0.0001$; $\chi^2 = 77.543$) from the general proportion of females (50.8%) among patients who received root canal treatment within the same time period (Bjørndal & Reit 2004). The age (mean ± SD) of the female complainants (44.3 ± 14.3 year) was significantly lower ($P = 0.0327$; $t = 2.147$) than that of the male complainants (48.0 ± 12.4 year). Furthermore, the mean age of the female dentists involved in an endodontic complaint (47.6 ± 10.4 year) was significantly lower than that of the male dentists (53.0 ± 8.5 year) ($P < 0.0001$; $t = 5.598$). Female patients most often complained about treatments provided by older male dentists ($P = 0.0189$; $\chi^2 = 5.675$). The frequency of 'young' female dentists who received a malpractice claim was significantly higher than seen in the male dentist group ($P = 0.0098$; $\chi^2 = 6.672$). A borderline statistical significance indicated that younger female patients had a tendency to make complaints about older male dentists ($P = 0.043$; $\chi^2 = 4.172$).

Discussion

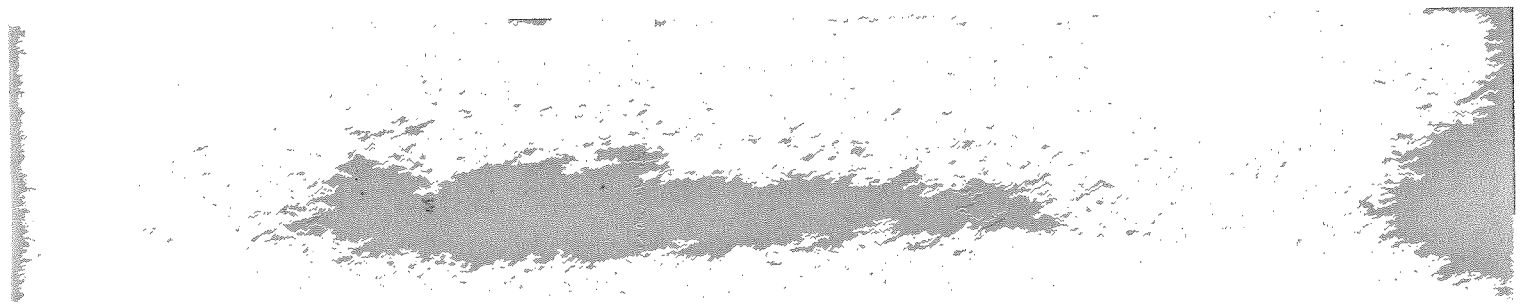
The present study includes all dental malpractice claims registered in Denmark between 1995 and 2004. However, the authors had no access to original material such as letters, office records and radiographs, but only the formal reports issued by the DCBs and the NDCB. The reports varied in quality and fullness, thus interpretation and categorization of the claims was sometimes difficult, a situation that might have biased the results of the investigation. In cases that concluded with a settlement between the patient and the dentist detailed information was often not found. In 77.6% ($n = 374$) of the 482 claims focused on root canal treatment (Table 3) the information was sufficient enough to make further categorization possible.

The annual number of dental malpractice claims as calculated per 100 000 patients was subjected to a very small variation over the investigated period in question. However, in the city area of Copenhagen the frequency of claims was well over the mean of Denmark taken as a whole (24.7 vs. 13.1, respectively). A similar difference between urban and rural areas was reported by René & Öwall (1991) in a study of Swedish malpractice cases.

In the first five years (1995–1999) of the investigated period 725 claims resulted in verdicts of malpractice, which corresponds to 4.2 annual malpractice cases per 1000 GDPs. In the second period there was an increase to 4.9 cases. In the US Milgrom *et al.* (1994) compared the years 1988 and 1992 and found an increase from 11 to 27 malpractice cases per 1000 dental practitioners. In Sweden René & Öwall (1991) studied the period from 1977 to 1983 and found no increase and only less than one malpractice case per 1000 dentists. However, the medico-legal systems vary between countries and direct comparisons are difficult to make.

In agreement with the findings of René & Öwall (1991) and Hapcook (2006) the dental malpractice claims most often concerned crown & bridge treatment (22.9%). However, as was proposed in H1, claims of endodontic malpractice were frequently received by the Danish DCBs. The proportion found in the present investigation (13.8%) corresponded to the Swedish and US samples.

In support of H2 a substantial part of the claims (28%) were associated with substandard root filling quality or technical treatment problems (Table 4). By comparing the verdicts and the written judgments of the DCBs in the 137 cases assigned to the 'technical complications/incorrect treatment' category, an attempt was made to find explicit or implicit verdict policies. The dentist was found to be guilty of malpractice in all claims when a paraformaldehyde product was used in the root canal, a situation which often resulted in severe bone and soft tissue damage. In eight of the nine cases in which a root was perforated, the dentist was also judged to be guilty. Malpractice was stated in 70.5% of the cases ($n = 31$) concerned with the root filling quality (Table 4). In the DCB reports reasons for malpractice verdicts were often that the root fillings were too short, had defective quality of seal, the canal was over filled as a result of over instrumentation and that not all canals were filled. However, if



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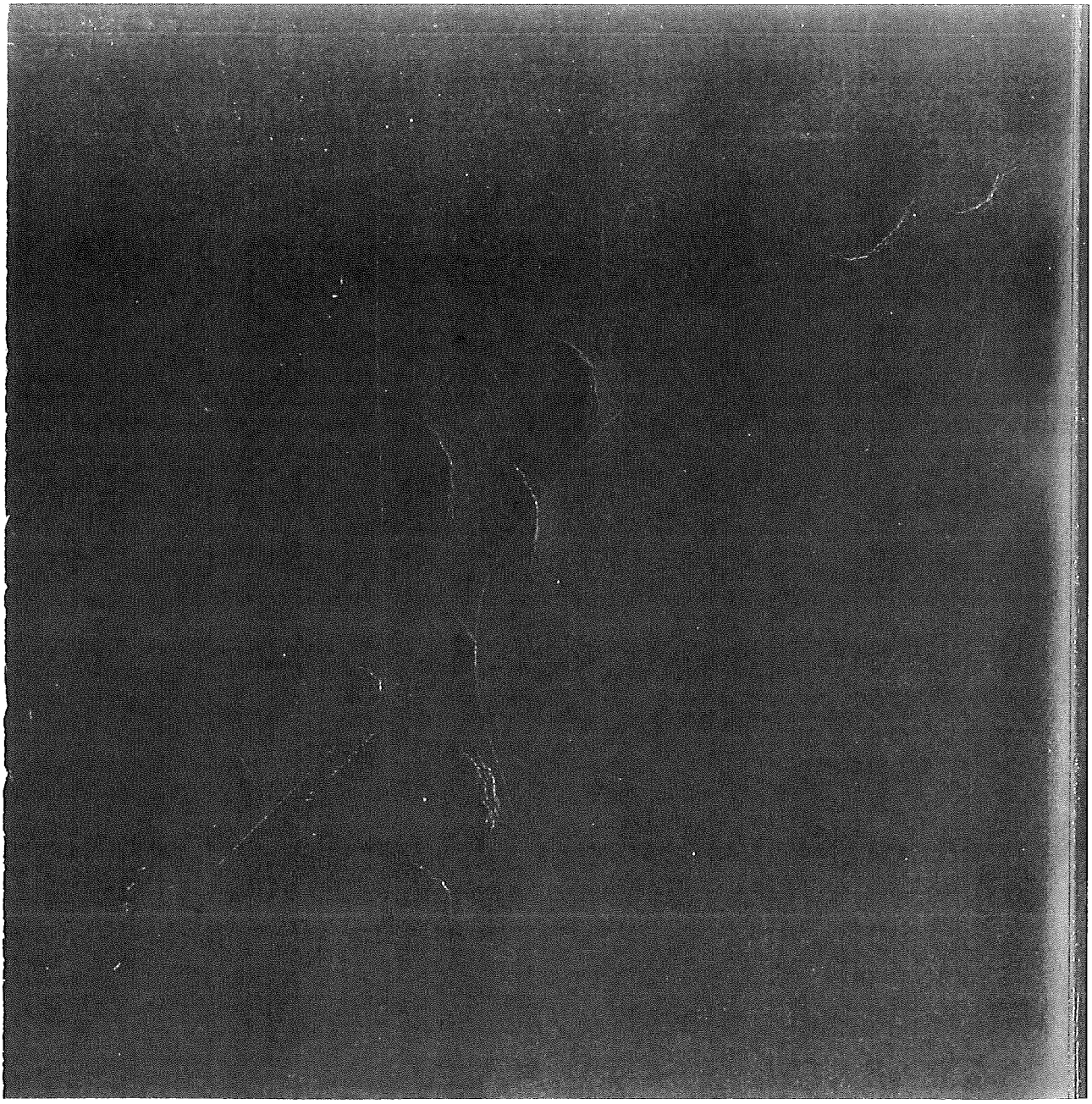

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