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2018
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QUALITY OF ROOT CANAL TREATMENT PERFORMED BY UNDERGRADUATE STUDENTS AT THE WITS ORAL HEALTH CENTRE

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Dentisry.

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Johannesburg, 2018

Declaration

I, A.alaali Mohamed Ehbesh, declare that this research report is my own work. It is being submitted for the degree of M.Sc. (Dent.) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

_____day of _____, 2018

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Abstract

Purpose: Following the changes to the undergraduate endodontic curriculum at the University of the Witwatersrand in 2012, there was a need to assess the impact of the changes on treatment outcomes. This study was an audit of root canal treatment performed by undergraduate students as shown in the postoperative radiographs. The study compared the root canal treatment performed by the 3rd, 4th and 5th undergraduate students.

Methods: Postoperative periapical radiographs of patients treated by undergraduate students, were examined to assess length, density, taper and iatrogenic errors. Two independent investigators were first calibrated, and thereafter assessed 299 endodontic cases that were performed by 3rd, 4th and 5th year students between 2013-2015 at the Wits Oral Health Centre.

Results: 68.9%, 73.6% and 70.9% were found for adequate length, acceptable density and acceptable taper of root filling respectively. The most acceptable length, density and taper results was by the 5th year students, while the lowest results were in the 4th year students. The iatrogenic errors were identified as 37.1% with ledge formation and canal transportation the most common.

Conclusion: The result of this study shows that the quality of root canal treatment performed by undergraduate students is similar to other studies conducted at various dental schools around the world. The change in the curriculum has been justified, although the study does point out some areas of concern. There was a notable increase in quality from 4th year to 5th year students, possibly due to using of rotary system and dental operating microscope.

Dedication

To my parents who have been my guidance, my wife who has supported me, and to all my brothers and friends for their support.

Acknowledgements

I wish to express my gratitude to:

My supervisors: Dr I. Munshi and Dr E. Patel.

To the Libyan Embassay in South Africa.

To the Libyan Education Ministry.

To all administrative staff at the WITS Oral Health Centre.

List of Abbreviations and Symbols

AC: Apical Constriction

CDJ: CementoDentinal Junction

AF: Apical Foramen

AP: Apical Periodontitis

AAE: American Association of Endodontists

ESE: European Society of Endodontology

NiTi: Nickel-Titanium

PTN: ProTaper Next files

Mx: Maxillary

Mn: Mandibular

LF: Left

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Root canal treatment is a complicated procedure that requires careful attention to detail and meticulous execution, in order to effectively clean and shape the root canals and to avoid any procedural errors that may impact treatment outcome. In order to be able to perform the treatment at a high standard of care, the training of dental students should be of a high quality.

Since the revised endodontic curriculum was instituted at the Wits School of Oral Health Sciences in 2012, no study has been done to assess the impact of the curriculum change on treatment outcomes. This study is an audit of the quality of root canal treatment performed by undergraduate students at the University of the Witwatersrand.

1.1 Quality guidelines in root canal treatment

The European Society of Endodontology (ESE) in 2013 expressed their concern that despite the tremendous technical advances in endodontics and the quality guidelines regarding endodontic treatment continue to exhibit displeasing technical results for endodontic treatment in European societies (De Moor et al., 2013).

The ESE 2013 guidelines quote several studies to prove that these results are a reflection of the achievement of the initial proficiency shown in undergraduate training where requirements remain variable (Eleftheriadis and Lambrianidis, 2005; Sonntag et al., 2008; Burke et al., 2009; Kelbauskas et al., 2009; Khabbaz et al., 2010). They also emphasised the necessity of ensuring that undergraduate practice is performed to a standard that confirms thorough understanding of the crucial factors that play a role in clinical outcomes

The ESE (1992, 1994, 2001, and 2006) reported a set of guidelines for undergraduate syllabi, to promote the advancement of high quality undergraduate dental teaching. According to these guidelines, the student is expected to possess the ability to perform nonsurgical

endodontic treatment on single and multi-rooted teeth. The guidelines also included the expectation that students should identify and know how to avoid any iatrogenic errors that might occur with conventional endodontic treatment (European Society of Endodontology, 1992; Wesselink, 1994; Lost, 2001; Loest, 2006).

Educational guidelines dictate that dental schools ensure the competence of each graduating student in the field of endodontics (Lynch and Burke, 2006). Eleftheriadis and Lambrianidis (2005) proposed that the assessment of technical outcomes of endodontic treatment and the detection of iatrogenic errors are based on the immediate postoperative radiographs. Consequently, the ESE (2006) advised that the quality of root canal filling should be assessed through postoperative radiographs (Loest, 2006).

1.2 The use of periapical radiographs in root canal treatment

Since its invention in 1895 by Roentgen, radiographs have been used for the diagnosis of dental diseases. Dr Otto Walkhoff produced the first radiograph for teeth just 14 days after Roentgen's publication (Forrai, 2007). While Dr C. Edmund Kells was the first to use intraoral radiographs in 1896. Periapical radiographs are the most commonly used x-rays in endodontic treatment. Periapical radiographs are used for preoperative diagnostic assessment, working length determination, master apical file fit, master cone and postoperative assessment of the quality of obturation.

Endodontic treatment success is often predicted by the quality of the root canal treatment, as depicted on postoperative radiographs. Although Siqueira (2001) agrees with this recommendation, he also cautions that the radiographic judgement of the root filling may not be indicative of root canal sealing. The author concluded that the major cause of failure of most well-treated endodontic treatment cases is due to persistence of infection. It should be recognised that periapical radiographs represent a two dimension image and have limitations, such as the superposition with adjacent tooth structures, especially in the region of the maxillary molars (Tamse et al., 1980; Ridao-Sacie et al., 2007).

Numerous studies have used postoperative radiographs to assess the quality of root canal treatment. Table 1.1 lists the studies that assessed the quality of endodontic treatment performed by undergraduate students by examining the postoperative radiographs. Although

there is considerable consistency among the studies listed, not all the studies used the same criteria.

Table 1. 1 The undergraduate students and cases samples of previous studies in different parts of the world.

Authors	Year	Students	Criteria	Country	Sample
Greene and Krell	1990	3rd year students	Ledge formation	USA	171 cases or 336 canals
Kapalas and Lambrianidis	2000	undergraduate clinic and endodontists	Ledge formation	Greece	626 root canals (367 by undergraduate students)
Barrieshi-Nusair et al.	2004	4th and 5th year	Length, density and taper	Jordan	542 teeth or 912 root canals
Eleftheriadis and Lambrianidis	2005	4th and 5th year	Length, density, ledge, perforations (root, furcation and strip) fractured instruments	Greece	620 root canals 388 teeth
Er et al.	2006	4th and 5th year	Length, density and taper	Turkey	1893 teeth or 3692 root canals
Lynch and Burke	2006	Undergraduate	Length and density	Ireland	100 single rooted teeth
Pettigrew et al.	2007	Undergraduate	Length, and presence of voids, fractured instruments and perforation	Scotland	100 single rooted teeth
Balto et al.	2010	4th and 5th year	Length, Density, Taper, ledge, gouging, zipping, apical transportation, fractured instruments, perforations (apical, root, strip and furcation), lack of straight-line access and missed canal	Saudi Arabia	550 teeth
Khabbaz et al.	2010	4th and 5th year	Length, density, ledge, fractured instruments, perforations (foramen and root)	Greece	1109 root canals or 759 teeth
Rafeek et al.	2012	Undergraduate	The length, presence of voids, taper, curvature of canal and fractured instruments	Trinidad	288 or 460 root canals
Román Richon et al.	2014	4th year students	Length, density and taper.	Spain	561 extracted teeth
Smadi et al.	2015	4th and 5th year	Length, density, taper, ledge, transportation and perforation	Jordan	213 teeth

1.3 Criteria used to determine the quality of root canal treatment

Various studies have shown that the outcome of root canal treatment is dependent on the technical quality of the root canal filling (Sjögren et al., 1990; Smith et al., 1993; Peak et al., 2001; Eleftheriadis and Lambrianidis, 2005). Other studies have also used the absence of voids and the length of root fillings as assessment criteria (Sjögren et al., 1990; Nieuwenhuysen et al., 1994; Farzaneh et al., 2004). Furthermore, Santos et al. (2010) considered the length, density and taper of root canal fillings in their assessment of the quality of root canal treatment, while Bołtacz-Rzepkowska and Pawlicka (2003) concluded that the radiographic technical quality of root canal treatment is more related to the health of the periapical area, rather than substandard root fillings.

Dubrow (1976) stated that the failure of endodontic treatment could be a consequence of inappropriate debridement of a root canal or result of poor technique during the procedure. Furthermore, Ramachandran Nair (2003) reinforced the view that the primary cause of postoperative apical periodontitis (AP) in well-treated teeth is due to the presence of microbial infection.

Saunders and Saunders (1994) concluded that coronal leakage is a common cause of endodontic treatment failure. Moreover, Kirkevang et al. (2000) and Segura-Egea et al. (2004) indicated that teeth with sufficient coronal restoration and root canal filling lengths are associated with a decreased prevalence of AP.

When examining postoperative radiographs, there are several criteria that are predictors of successful outcome in endodontic treatment. Some of these criteria are:

1- Length of root canal filling
2- Density of root canal filling
3- Taper of root canal preparation

1.3.1 The length of the root canal filling

The length of the root canal filling is one of the most important parameters that have been used to evaluate the quality of endodontic treatment. On postoperative radiographs, the length is determined by measuring the apical terminus of the obturation from the radiographic apex of the tooth. Zhong et al. (2008) have shown that microbes and their by-products are responsible for the failure of endodontic

treatment in teeth with inadequate length of condensed obturation material and a low density of the obturation. These microbes colonise the remaining unfilled space in the root canal and infect the periapical area and the root canal filling (Sjögren et al, 1990).

The classic theory of apical root anatomy is founded in three anatomical and histological landmarks in the apical region of a root: the apical constriction (AC), the cementodentinal junction (CDJ), and the apical foramen (AF) (Kuttler, 1955) as shown in Figure 1.1. The American Association of Endodontists (AAE) defined the apical foramen as the main apical opening of the root canal. The apical constriction was defined as the apical part of the root canal that has the thinnest width. The location of the apical constriction might differ, but is frequently 0.5-1.0mm short of the apical foramen (American Association of Endodontists, 2016).

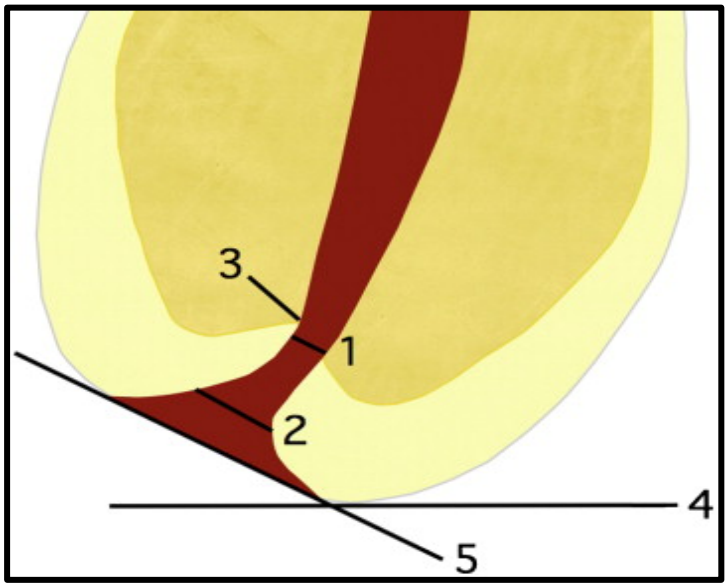


Figure 1. 1 Anatomical and histological apical structures

1. Apical constriction. 2. Apical foramen. 3. Cemento-dentinal junction junction.

4. Anatomical apex. 5. Radiographic apex.

[Source: Kuttler, 1955]

The AAE also defines the cementodentinal junction as the area where the cementum and dentin integrate; it is frequently used to represent the point at which the cemental surface ends at or close to the tooth apex; the location of the cementodentinal junction ranges between 0.5-3mm from the anatomical apex of root (American Association of Endodontists, 2016). It

was found that the cementodentinal junction is a meeting point between dentin and cementum in the root canal (Kuttler, 1955). The ESE suggested that the working length should be determined between 0.5–2mm from the radiographic apex (Loest, 2006).

The apical constriction is considered the smallest diameter part of the root canal (Kuttler, 1955). The apical constriction is used regularly by dentists as a reference point to apical termination of cleaning, shaping and filling of root canals. Kuttler (1955) stated that the cementodentinal junction is a meeting point between dentin and cementum in the root canal. Wu et al. (2000a) found that the apical constriction is regularly absent. Vertucci (2005) declared that the clinical determination of the morphology of the apical region is difficult. He also postulated that the presence of an apical constriction might be more theoretical than actual.

Kuttler (1955) mentioned that the apical foramen is offset 0.5-3.0mm from the anatomic apex. Dummer et al. (1984) found that the distance between the apex and apical foramen had greater variance between different tooth types (they compared maxillary and mandibular anterior teeth and premolars only), and they found the smallest distance was in maxillary incisors (0.7mm). While the largest distance was in premolars (around 2mm). The authors revealed that the total mean distance between root apex and foramen was 0.36mm.

Gutierreza and Aguayo (1995) concluded that the clinical determination of the opening of the apical foramen was practically unattainable due to the huge variations of distance between the root tip and foraminal openings, and because all the canals were deviated from the long axis of the root. The authors also concluded that the openings of the apical foramen can be found in different surfaces of the root.

Several studies have highlighted the controversy regarding the ideal working length. However, the general consensus, suggested by Sjögren et al, is that the root canal preparation and obturation should terminate between 0-2mm from radiographic apex. This is the guideline taught at the University and has thus been used in this study (Sjögren et al., 1990; Hayes et al., 2001; Hommez et al., 2002; Bołtacz-Rzepkowska and Pawlicka, 2003; Er et al., 2006; Eckerbom et al., 2007; Zhong et al., 2008; Tavares et al., 2009).

1.3.1.1 Effects of overfilling on the quality of root canal treatment

According to the AAE, overfilling of the obturation material is the extension of a semi-solid or solid core root canal material beyond the apical foramen (American Association of Endodontists, 2016). Sjögren et al. (1990) found that overfilling has no effect on the prognosis of endodontic treatment. Similarly, Halse and Molven (1987) stated that overfilling has little effect on the long-term healing as evaluated by postoperative radiographs.

Schaeffer et al. (2005) stated that extruded obturation material beyond the radiographic apex correlated with a decreasing prognosis of root canal treatment. Siqueira (2001) regards this as a cause of failure and overfilling is associated with intraradicular and /or extraradicular concomitant infections.

Sjögren et al. (1995) compared the tissue response of three varieties of gutta-percha by implanting them subcutaneously in guinea pigs. The authors found that large particles of gutta-percha did not provoke inflammation in the surrounding tissue and were well encapsulated, whereas the other types (fine particles of gutta-percha and dissolving particles of gutta-percha in resin-chloroform) caused an intense localised response characterised by the presence of multinucleated giant cells and macrophages. The authors then proposed that the aggregation of macrophages around the gutta-percha might be a significant feature leading to impaired healing of periapical lesions. In this study, overfilling is considered as an unfavourable criterion that can have a negative effect on the quality of endodontic treatment.

1.3.1.2 Role of over instrumentation

According to the AAE, over instrumentation refers to instrumentation of the root canal that extends beyond the apical foramen that leads to the loss of the apical constriction (American Association of Endodontists, 2016). Overfilling often occurs as a consequence of over instrumentation of the root canal. It affects the quality of root canal treatment by causing patient discomfort, due to the extrusion of possible irritating material beyond the root apex apex (Ricucci and Langeland, 1998). Yusuf (1982) found that 33% of periapical granulomas, in cases of endodontic or apicetomy failure, contained a foreign material such as: cementum, dentin chips, root filling material or amalgam. The author also found that evidence of root

filling material and amalgam were linked to a fibrous tissue reaction, while cementum and dentin chips were related to active inflammation.

A study conducted by Noiri et al. (2002) investigated the participation of extraradicular biofilm in refractory periapical periodontitis, using electronic microscopes. They studied eleven teeth, previously filled with gutta-percha points under the scanning electron microscope and found that bacterial biofilms were detected within the lesion at the extraradicular region. From which it was inferred that the extruded gutta-percha acted as a source of reinfection and that the body considered it as a foreign substance. In this study, overfilling has been considered as unacceptable.

1.3.1.3 Effect of underfilling on the quality of root canal treatment

According to the AAE, underfilling refers to the incomplete obturation of the root canal space, which subsequently results in voids (American Association of Endodontists, 2016). Ingle (1961) showed that the main reason for endodontic failure is inadequate canal instrumentation and incomplete obturation of the canal space. Chugal et al. (2003) stated that, with reference to teeth or roots with AP, a shortage of 1mm from the optimal working length increases the chance of failure of endodontic treatment by 14%. Underfilling has an indirect influence on the prognosis of endodontic treatment. In cases of insufficient canal instrumentation and incomplete obturation it may contain residual infected tissue (Lin et al., 2005). Underfilling results in voids in the apical region of the canal. Voids are considered to be critically important as they provide spaces for bacterial colonization.

Sjögren et al. (1990) agreed that underfilling has lower success rates than overfilling, due to the inability to clean the root canal to the advised working length. In contrast, Seltzer et al. (1963) stated that underfilling had a more favourable success rate, with 87.2%, than the flush and overfilling, which had success rates of 86.8% and 70.6%, respectively. Moreover, Akbar (2015) concluded that the most common failures of endodontic treatment occur in cases of underfilling followed by poorly filled canals. In this study, underfilling is defined as any root filling that is shorter than 2mm from the radiographic apex. It has been considered as unacceptable.

1.3.2 Effect of density of root filling on the quality of root canal treatment

The density of the root filling is another essential factor that influences the outcome or prognosis of endodontic therapy. Sjögren et al. (1990) stated that teeth that were retreated endodontically with adequate sealing had a higher success rate of 67% than inadequately sealed teeth, which only had a success rate of 31%. Chugal et al. (2003) concluded that a favourable prognosis of endodontic treatment was related to good density of root fillings, which is measured by the absence or presence of voids between the root canal fillings along the entire wall of the root canal In addition, voids can occur as a consequence of insufficient placement of the sealer (Mounce, 2008).

Boucher et al. (2002) used the presence of voids and the extent of root canal filling from radiographic apices as parameters to evaluate the outcome of endodontic treatment based on periapical radiographs. The aforementioned periapical radiographs are two-dimensional images of three-dimensional structures thus voids are inadequately represented in two dimensions. This suggests that the real size of the voids might be larger than their appearance on the radiographs.

Kirkevang et al. (2000) found that the presence of voids in root canal fillings have a substantial impact on the incidence of AP. Furthermore, Hommez et al. (2002) found that the incidence of AP had a 47.1% occurrence in samples of non-homogeneous root canal filling, and a 27.7% occurrence in samples of homogeneous root canal filling.

The radiograph is used to determine the quality of root canal treatment by qualifying the homogeneity of obturation, which depends on the absence or presence of voids (Khabbaz et al., 2010). Many studies used density as one of the parameters to assess the quality of root canal treatment (Tables 1.1 and 1.2). In this study, we considered the presence of voids in the root filling as unacceptable.

1.3.3 Taper of the root filling

The taper of the root canal filling is another parameter used to assess the quality of root canal treatment. The taper of the root canal is defined by Schilder (1974) as a continuous tapered funnel shape of the root canal system to enable cleaning and facilitate obturation.

Table 1. 2 Frequencies of length, acceptable density and acceptable taper of root canal filling in previous studies.

Authors	Year	Country	Results				
			Length			Density	Taper
			Adequate	Underfilling	Overfilling		
Barrieshi-Nusair et al.	2004	Jordan	61.3%	34.5%	4.2%	72.6%	85.3%
Eleftheriadis and Lambrianidis	2005	Greece	62.7%	7.4%	1.8%	82.6%	-
Er et al.	2006	Turkey	69.6%	17.4%	13%	53.2%	68.3%
Lynch and Burke	2006	Ireland	70%	21%	9%	90%	-
Pettigrew et al.	2007	Scotland	80%	5%	15%	80%	-
Balto et al.	2010	K.S.A	79.6% *	11.3%	9.1%	34.9%	59.6%
Rafeek et al.	2012	Trinidad	63.1%	24.3%	12.6%	27.6%	72.2%
Smadi et al.	2015	Jordan	61.5%	14.1%	24.4%	50.5%	56.1%

* Balto et al. 2010 defined the adequate length when root filling ends ≤2 mm from radiographic apex, and they also defined flush when root filling at the radiographic apex. Their result of 79.6% includes both adequate length and flush.

The ESE (2006) advised that in accordance with their criteria for acceptable endodontic treatment, the root filling has to be dense and consistently tapered (Loest, 2006). They recommend that the canal preparation should taper from the crown to the root apex. Santos et al. (2010) used the length, density and taper of the root canal filling in their assessment of the quality of root canal treatment.

Root canal taper is a reflection of shaping the root canals and not the obturation. Arvaniti and Khabbaz reported that there was no substantial difference in root canal cleanliness between the different tapers (0.04, 0.06 and 0.08) in root canals that were prepared to an apical size 30. They also found that the smear layer was not completely removed in the three taper sizes (Arvaniti and Khabbaz, 2011).

Zogheib et al. (2012) assessed the influence of different tapered preparation on the sealing ability of Real Seal 1 at the apical 5mm of the obturated canals using micro-CT for analysis. The results showed that the smallest taper size (0.04) had significantly greater volume of voids, while the large taper sizes (0.06 and 0.08) revealed fewer voids.

In this study we considered any inconsistent taper of canal preparation from crown to apex as unacceptable.

1.4 Influence of iatrogenic errors on the outcome of root canal treatment

In addition to the previously discussed criteria, root canal treatment may fail as a result of procedural errors, also referred to as iatrogenic errors.

1.4.1 Root curvature as a predisposing factor of iatrogenic errors

According to Schneider (1971), root canal curvature is classified as either straight (5° degrees or less), moderately curved (10° to 20° degrees) or severely curved (20° to 70° degrees). Anterior teeth have fewer curved roots when compared to posterior teeth, so the root curvature is also associated with location of the teeth.

The curvature of root canals is the most significant clinical factor correlating to ledge formation (Greene and Krell, 1990; Kapalas and Lambrianidis 2000). Eleftheriadis and Lambrianidis (2005) stated that curvature of the root canal is the most important clinical factor related to root perforation.

Suter et al. (2005) observed that curved root canals have a higher risk of fractured instruments than straight canals. The authors found that rotary instruments (nickel-titanium (NiTi) and Lentulo spiral) fractured more significantly in curved canals when compared to hand instruments. This was due to the increase in cyclic fatigue imposed on the rotary file in canals with greater curvature.

1.4.2 Types of iatrogenic errors

1.4.2.1 Ledge formation

The AAE (2016) defines the ledge as "an artificial irregularity created on the surface of the root canal wall that impedes the placement of instruments to the apex of an otherwise patent canal" (American Association of Endodontists, 2016).

Lambrianidis argues that ledges obstruct instrument access to the root apex, which further leads to inadequate root canal instrumentation and obturation. Thus the presence of ledges contributes to the incidence of periapical pathosis (Lambrianidis, 2009). It was found that the unfavourable prognosis of ledge in endodontic treatment is based on bacterial virulence in untreated apical areas of the root canal (Jafarzadeh and Abbott, 2007).

Ledges can be diagnosed from radiographs when the root filling material is shorter than 1mm from the initial working length or from the original curvature of the root canal (Eleftheriadis and Lambrianidis, 2005).

1.4.2.2. Zipping

According to the AAE, zipping is "a tear-drop shape that may be formed in the apical foramen during preparation of a curved canal when a file extends through the apical foramen and subsequently transports that outer wall" (American Association of Endodontists, 2016).

Elizabeth (2005) adds that stainless steel files, with sizes greater than 20, have a tendency to straighten the root canal curvature and can lead to the deviation from the original shape of the root canal. It has been shown, regardless of the file type, the incidence of zipping was significantly greater with an increase in file size, especially sizes 30 and 35 (Eldeeb and Boraas, 1985). Stainless steel (K-Flex) files preserved the original path of the curved root canals when compared to (NiTi) files (Esposito and Cunningham, 1995).

Zipping can be seen in radiographs when the apical end of obturated canals has an oval shape transporting the outer wall of the root canal curvature (Balto et al., 2010).

1.4.2.3. Canal transportation

Transportation was defined as “removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation” (American Association of Endodontists, 2016).

Wu et al. (2000b) found that canal transportation is associated with leakage along the root canal filling, while González Sánchez et al. (2012) indicated that apical transportation might encourage the concealment of debris and micro-organisms that remain due to improper cleaning of the root canal. Furthermore, apical transportation of intracanal leads to bacterial colonisation that is a factor associated with the occurrence of periradicular cysts in teeth after endodontic treatment (Pai et al, 2014).

In postoperative radiographs, canal transportation is seen as an extension of the root canal filling material towards the external canal curvature at the apical third (Balto et al., 2010).

1.4.2.4. Missed or untreated canal(s)

A missed or untreated canal is a root canal that is left without endodontic therapy. A root canal may go untreated due to lack of experience of the operator in identifying canals or due to canal blockages. In postoperative radiographs, missed or untreated canals are usually diagnosed (with horizontally angulated radiographs) when the root canal filling is not centred in the root and there is an associated radiolucency, which indicates the presence of another canal (Balto et al., 2010).

The presence of bacteria is considered a reason for failure of endodontic treatment when a canal is missed, since untreated canals or under-instrumented canals provides a favourable living environment for micro-organisms to grow in and cause infection to the periradicular tissues (Sjögren et al., 1997).

1.4.2.5 Fractured instrument(s)

Fractured instrument(s) refer to the occurrence of broken endodontic instruments within the root canal system or that extend beyond the root apex.

Suter et al. (2005) observed that straight canals have a lower incidence of fractured instruments than curved canals. They also found that the frequency of fractured instruments in the apical one-third is 41%, and is higher than the incidence in the middle and coronal thirds which are 32% and 20%, respectively. Gencoglu and Helvacioglu (2009) found that the root canal anatomy and location of the broken instrument influences the success of the fractured instrument removal.

Souter and Messer (2005) showed that files lodged at the coronal and middle third of the root canal can be removed without major complications. They also suggested that the removal of fractured instruments in the area beyond the curve should not be consistently attempted, because it leads to decreased strength of the root and subsequent perforation.

Fractured instrument is detectable on the postoperative radiograph when the fractured instrument appears within the root canal or the fractured tip protrudes through the root apex (Eleftheriadis and Lambrianidis, 2005).

1.4.2.6. Perforations

The AAE defined perforation as the "mechanical or pathologic communication between the root canal system and the external tooth surface" (American Association of Endodontists, 2016).

Mechanical perforation is an iatrogenic error that can occur at any level of the root canal system and the crown level due to misalignment of burs and inappropriate use of endodontic instruments (Harris, 1976). In contrast, non-iatrogenic perforation occurs as a consequence of caries or root resorption. Furthermore, perforations that occur coronal or apical to the epithelial attachment and crestal bone had a good prognosis while perforation occurs at the epithelial attachment and crestal bone had a poor prognosis (Fuss and Trope, 1996).

Perforations appear on postoperative radiographs when the obturating material is extruding through the root canal walls at any level of the root canal system (Khabbaz et al., 2010).

1.5 The motivation for this study

Several studies have been conducted in different parts of the world, where post-operative radiographic information was used to analyse the quality of root canal treatment performed

by undergraduate students. The purpose of evaluating the quality of root canal treatment is to help improve the skills of undergraduate students by modifying future endodontic educational programmes. It is also an excellent tool to evaluate current teaching practices. No such evaluations have been previously performed at the University of Witwatersrand Oral Health Centre.

CHAPTER 2

AIM AND OBJECTIVES

2.1 Aim

The aim of this study is to assess the quality of root canal treatment performed by undergraduate students at the Wits Oral Health Centre.

2.2 Objectives

1- To determine the quality of endodontic treatment performed by undergraduate students based on the periapical radiographs at Wits University over the past three years.

2- To compare the quality of root canal treatment performed between the 3rd, 4th and 5th year undergraduate student groups.

CHAPTER 3

METHODS AND MATERIALS

3.1 Sample size calculation

A margin of error of 0.05, confidence interval of 95% and an estimated acceptable length of root canal filling of 50.5 % as reported by Smadi et al. (2015) was also used for this study as reported by Smadi et al. (2015). A sample size of 196 will be sufficient.

Sample size formula: $n=Z^2 P (1-P) \div e^2$

Where n is sample size, P is estimated prevalence, e is margin of error and Z^2 is the confidence interval.

3.2 Methods and materials

This is a retrospective study, composed of 299 postoperative periapical radiographs of patients treated by 3rd, 4th and 5th year undergraduate dental students, at the School of Oral Health Sciences at the University of the Witwatersrand, between January 2013 and December 2015. The endodontic patients' radiographics were examined using a magnifying lens (2x magnification) and endodontic ruler in a dark room using a radiographic viewer. Twenty cases, not included in the study sample, were used to compare the inter-rater agreement between the two main investigators.

Ethical clearance and permission to conduct this study was obtained from the Human Research Ethics Committee and the Hospital Risk Assessment Committee respectively (Appendices A and B).

3.2.1 Quality of root canal treatment

The three main criteria assesed on the postoperative radiographs are:

1- Length of root fillings

A- Adequate: Root filling 0-2mm from radiographic apex.

B- Overfilling: Root root filling extends beyond radiographic apex.
C- Underfilling: Root root filling >2mm from radiographic apex.

2- Density of root fillings

A- Acceptable: No voids between root filling and root canal walls or in the root filling.
B- Unacceptable: Voids present between root filling and root canal walls or in the root filling.

3- Taper of root fillings

A- Acceptable: Consistent taper from the orifice to the root apex.
B- Unacceptable: Inconsistent taper from the orifice to the root apex.

3.2.2 Iatrogenic errors

The iatrogenic errors investigated on the postoperative radiographs were:

1- Ledge formation: When the root filling is shorter than 1mm from the initial working length or from the original curving of the canal.
2- Zipping: When the apical end of filled canals appears as ovate shaped transportation of the outer wall of the root canal.
3- Canal transportation: When the root canal filling material is placed external to the root canal curve at the apical third.
4- Missed/untreated canal(s): When an unfilled canal is detected on the periapical radiographs.
5- Fractured instrument(s): When the fractured instrument is visible inside the root canal or with its tip protruding into the periapical area.
6- Perforation: When there is extrusion of root canal filling material in any region beyond the root.

3.3 Statistical analysis

IBM SPSS 24.0 was used to analyse the results of this study. Cohen's Kappa was used to measure the inter-rater reliability of the root canal treatment variables between two clinicians. Descriptive statistics of frequency and percentages were used to summarise the results.

Inferential statistics using Fischer's exact test were used to determine the association between independent and dependent variables.

3.4 Inclusion and Exclusion criteria

3.4.1 Inclusion criteria

1- This study included all teeth endodontically treated by the 3rd , 4th and 5th undergraduate students, under supervision, from January 2013 until December 2015.
2- Teeth with complete root apices.
3- Patient files with postoperative radiographic records of good condition.
4- All permanent teeth (except the 3rd molars).
5- The root canal treatment must have been completed.
6- Postoperative radiographs must show a minimum of 2mm beyond the root apex.

3.4.2 Exclusion criteria

This study excluded patient records that showed any of following:-
1- Any radiographical deformity.
2- Patient files that had incomplete radiographic records eg. missing postoperative radiographs.
3-Any third molar teeth.
4- Any teeth with complex anatomy such as severe root canal curvature.
5- Root resorption (external or internal) prior to root canal obturation.
6- Root fracture.

CHAPTER 4

RESULTS

4.1 Inter-rater agreement

Twenty cases, not included in the study sample, were used to compare the inter-rater agreement between the two main investigators. The parameters that were used in this test were: length, density and taper of root canal filling. Cohen's Kappa was used to measure agreement (Table 4.1)

Table 4. 1 Measure of inter-rater agreement across the three assessed parameters.

	Cohen's Kappa
Length of filling	1.00
Density of filling	0.93
Taper filling	0.77

4.2 Results

385 cases were treated by the 3rd, 4th and 5th year dental students between January 2013 and December 2015. 86 cases were excluded from the study due to the following reasons: 32 cases did not have postoperative radiographs and 54 cases were incomplete. A total of 299 periapical radiographs of teeth treated by the 3rd, 4th and 5th year dental students between January 2013 and December 2015 were analysed. Table 4.2 depicts the distribution according to student year.

Table 4. 2 Distribution of cases according to student year.

Student year	N	%
Third year students	85	28.4
Fourth year students	106	35.5
Fifth year students	108	36.1
Total	**299**	**100**

4.2.1 Tooth location and position

153 (51.2%) of the teeth treated were anterior and 155 (51.8%) were maxillary teeth. The 3rd year students treated anterior teeth only, whilst 61.3% and 75% of the teeth treated by the 4th and 5th year group were posterior teeth (Table 4.3). The central incisors had the largest number in the sample (33.1%), while the lowest number was in canines (5.4%). The tooth predominately treated by 3rd year students was the central incisor, while for 4th year students, it was the 2nd premolar, whereas for the fifth year students, the highest number was the first molar (Table 4.3).

4.2.2 Number of roots and root curvature

The frequency of single rooted teeth was the highest (60.9%), while the frequency of teeth with three roots was the lowest (12.4%) as shown in Table 4.4. 58.5% of teeth treated by the 4th year students were single rooted teeth, while 47.2% of teeth treated by the 5th year students had two roots. On the other hand, 53.8% of the sample size of this study had moderately curved roots. 75.3% of teeth treated by the 3rd year students were straight rooted teeth, whereas 72.2% of teeth treated by the 5th year students had moderately curved roots (Table 4.4).

Table 4. 3 Tooth position and location.

Teeth characteristics		Third year		Fourth year		Fifth year		Total		P value
		N	%	N	%	N	%	N	%	
Tooth Type	Central incisor	47	55.3	27	25.5	26	24.1	100	33.1	<0.001
	Lateral incisor	29	34.1	9	8.5	-	-	37	12.7	
	Canine	9	10.6	6	5.7	1	0.9	16	5.4	
	1st premolar	-	-	17	16	8	7.4	25	8.4	
	2nd premolar	-	-	28	26.4	8	7.4	36	12	
	1st molar	-	-	14	13.2	38	35.2	53	17.7	
	2nd molar	-	-	5	4.7	27	25.0	32	10.7	
Teeth Location	Anterior	85	100	41	38.7	27	25	153	51.2	<0.001
	Posterior	-	-	65	61.3	81	75	146	48.8	
Teeth position	Maxillary	46	54.1	65	61.3	44	40.7	155	51.8	<0.001
	Mandibular	39	45.9	41	38.7	64	59.3	144	48.2	

Table 4. 4 Number of roots and root curvature.

	Third year		Fourth year		Fifth year		Total		p
	N	%	N	%	N	%	N	%	
Number of roots**									<0.001
Single	85	100	62	58.5	35	32.4	182	60.9	
Two roots	-	-	29	27.4	51	47.2	80	26.7	
Three roots	-	-	15	14.1	22	20.4	37	12.4	
Root curvature**									<0.001
Straight	64	75.3	44	41.5	30	27.8	138	46.2	
Moderate	21	24.7	62	58.5	78	72.2	161	53.8	

Level of significance, p<0.001**

4.2.3 Quality of the root canal obturation

The quality of the root canal filling was determined by reporting the length, density and taper of the root canal filling. Table 4.5 presents the frequencies of the quality of the root canal filling. The total number of canals with adequate length was 68.9%, while total acceptable density of root filling was 73.6%, and the total acceptable taper of root filling was 70.9% (Table 4.5).

The best adequate length and overfilling results were in the teeth treated by the 5th year students, while the worse overfilling result was in teeth treated by the 3rd year students. On the other hand, the best underfilling result was in teeth treated by the 3rd year students, whereas the worse adequate length underfilling results were in teeth treated by the 4th year students (Table 4.5).

The highest number of acceptable density of root canal filling was in teeth treated by the 3rd year students, while the lowest result was in teeth treated by the 4th year students. The highest acceptable taper of root canal filling was in teeth treated by the 5th year students, whereas the lowest result was in teeth treated by the 4th year students (Table 4.5).

4.2.3.1 Length of root filling

The total adequate length and underfilling results in anterior and maxillary teeth were better than posterior teeth and mandibular teeth respectively, (Figure 4.1). In contrast to that, the overfilling results of posterior and mandibular teeth were better than anterior and maxillary teeth respectively (Figure 4.1). With the exception of the adequate length in mandibular teeth treated by the 4th year students, adequate results in all tooth locations treated by all students' years was greater than 61%, while the total adequate length in all tooth locations was greater than 66%.

4.2.3.2 Acceptable density and taper of root filling

The acceptable density of root filling was greater than 63% in all tooth locations treated by all students (Figure 4.2). However, the total acceptable density of root filling in all tooth locations was greater than 68%, while the total acceptable taper of root filling was >56% in all tooth locations treated by all students (Figure 4.2).

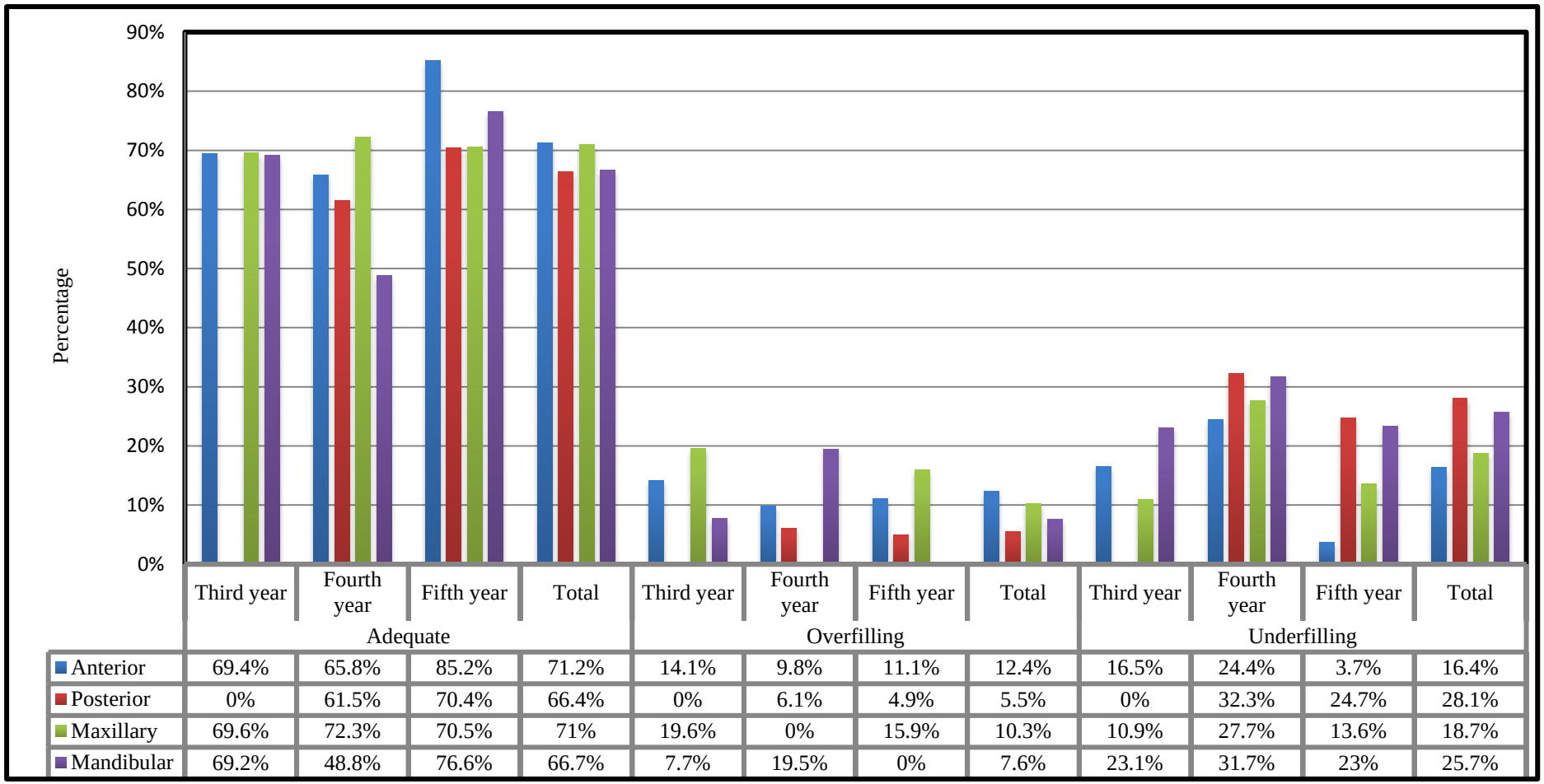
However, the total acceptable taper of root filling in all tooth locations was greater than 64%. The highest acceptable density and taper was in anterior teeth treated by the 5th year students, while the lowest acceptable density was in mandibular teeth treated by the 4th year students, whereas the lowest acceptable taper was in posterior teeth treated by the 4th year students (Figure 4.2).

Table 4. 5 Quality of the root canal obturation.

	Third year		Fourth year		Fifth year		Total	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Length of root canal filling								
Adequate	59	69.4	67	63.2	80	74.1	206	68.9
Overfilling	12	14.1	8	7.5	7	6.5	27	9
Under filling	14	16.5	31	29.2	21	19.4	66	22.1
Density of root canal filling								
Acceptable	68	80	73	68.9	79	73.1	220	73.6
Unacceptable	17	20	33	31.1	29	26.9	79	26.4
Taper of root canal filling								
Acceptable	64	75.3	66	62.3	82	75.9	212	70.9
Unacceptable	21	24.7	40	37.7	26	24.1	87	29.1

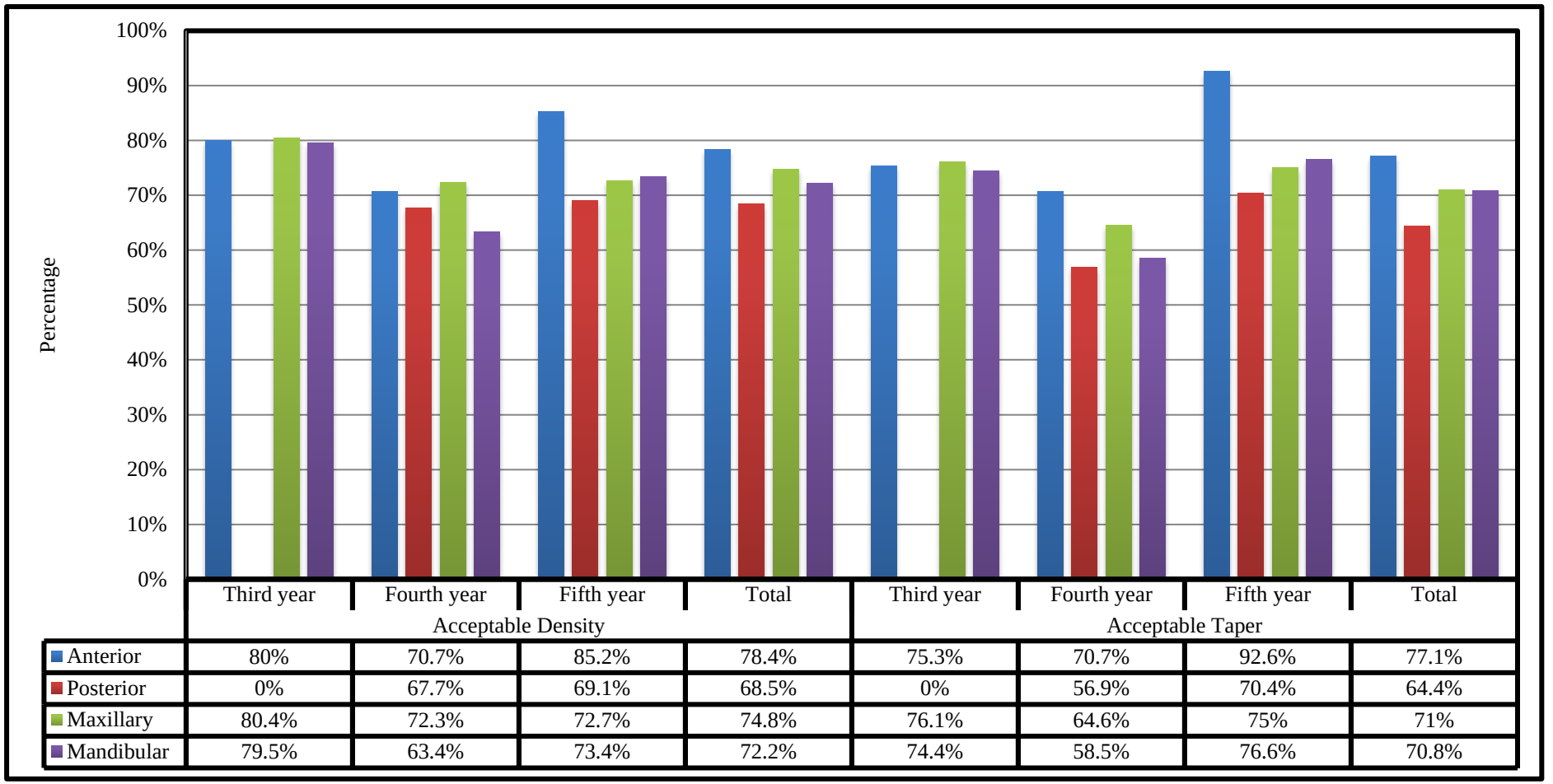
4.2.3.3 Total frequencies of length, density and taper of root filling according to tooth location and root curvature

The best adequate length (and lowest underfilling) results were in central incisors, while the worse adequate length and underfilling results were in second molars. In contrast to that, the better overfilling result was in second molars, while the worse result was in central incisors (Table 4.6). The adequate length and overfilling results were higher in teeth with straight roots than the teeth with moderately curved roots, whereas the frequency of underfilling was higher in teeth with moderately curved roots (Table 4.6).



	Adequate				Overfilling				Underfilling			
	Third year	Fourth year	Fifth year	Total	Third year	Fourth year	Fifth year	Total	Third year	Fourth year	Fifth year	Total
Anterior	69.4%	65.8%	85.2%	71.2%	14.1%	9.8%	11.1%	12.4%	16.5%	24.4%	3.7%	16.4%
Posterior	0%	61.5%	70.4%	66.4%	0%	6.1%	4.9%	5.5%	0%	32.3%	24.7%	28.1%
Maxillary	69.6%	72.3%	70.5%	71%	19.6%	0%	15.9%	10.3%	10.9%	27.7%	13.6%	18.7%
Mandibular	69.2%	48.8%	76.6%	66.7%	7.7%	19.5%	0%	7.6%	23.1%	31.7%	23%	25.7%

Figure 4. 1 Length of root canal filling.



	Acceptable Density				Acceptable Taper			
	Third year	Fourth year	Fifth year	Total	Third year	Fourth year	Fifth year	Total
Anterior	80%	70.7%	85.2%	78.4%	75.3%	70.7%	92.6%	77.1%
Posterior	0%	67.7%	69.1%	68.5%	0%	56.9%	70.4%	64.4%
Maxillary	80.4%	72.3%	72.7%	74.8%	76.1%	64.6%	75%	71%
Mandibular	79.5%	63.4%	73.4%	72.2%	74.4%	58.5%	76.6%	70.8%

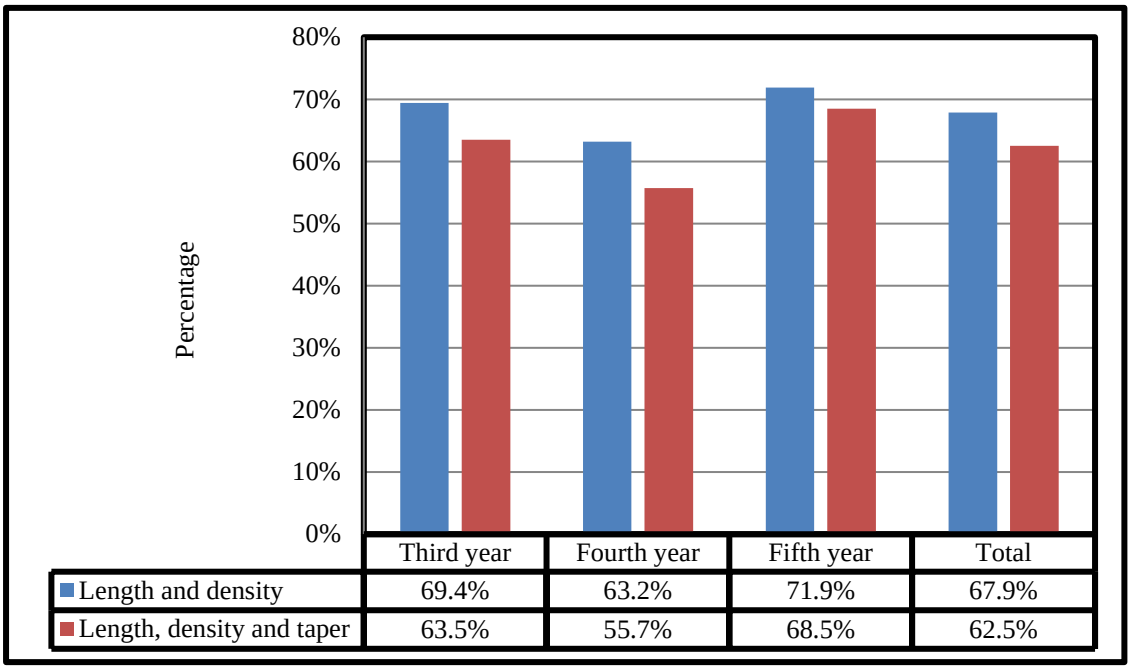
Figure 4. 2 Acceptable density and taper of root canal filling.

The highest acceptable density and taper of root canal filling result was in central incisors, while the lowest density and taper was in second molars. The acceptable density and taper was higher in teeth with straight roots than in teeth that had moderately curved roots (Table 4.6).

4.2.3.4 Acceptable root canal filling

An acceptable root canal filling is based on the length and density or length, density and taper of the filling (Figure 4.3). Acceptable root filling based on the length and density were greater than 63% in all years. However, the treatment performed by the 5th year students (71.9%) was the highest acceptable root filling when compared to the 3rd year students (69.4%) and the 4th year students (63.2%).

Acceptable root canal filling based on the length, density and taper were greater than 55% in all student years. However, the teeth treated by the 4th year students were the least acceptable result (55.7%) when compared to the 5th year (68.5%) and 3rd year (63.5%), as shown in Figure 4.3.



	Third year	Fourth year	Fifth year	Total
Length and density	69.4%	63.2%	71.9%	67.9%
Length, density and taper	63.5%	55.7%	68.5%	62.5%

Figure 4. 3 Acceptable root canal filling.

Table 4. 6 Total frequencies of length, density and taper of root filling according to tooth location and root curvature.

		Tooth type														Root curvature				Total	
		Central incisor		Lateral incisor		Canine		First Premolar		Second Premolar		First molar		Second molar		Straight		Moderate			
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Length	Adequate	76	76	23	62.2	10	62.5	18	72	25	69.4	35	66	19	59.4	108	78.3	98	60.9	206	68.9
	Overfilling	15	15	2	5.4	2	12.5	2	8	3	8.3	2	3.8	1	3.1	17	12.3	10	6.2	27	9
	Underfilling	9	9	12	32.4	4	25	5	20	8	22.2	16	30.2	12	37.5	13	9.4	53	32.9	66	22.1
Density	Acceptable	85	85	24	64.9	11	68.8	20	80	24	66.7	34	64.2	20	62.5	117	84.8	103	64	220	73.6
	Unacceptable	15	15	13	35.1	5	31.3	5	20	12	33.3	19	35.8	12	37.5	21	15.2	58	36	79	26.4
Taper	Acceptable	85	85	23	62.2	10	62.5	19	76	23	63.9	34	64.2	18	56.3	120	87	92	57.1	212	70.9
	Unacceptable	15	15	14	37.8	6	37.5	6	20	13	36.1	19	35.8	14	43.8	18	13	69	42.9	87	29.1

4.2.3.5. Association between the quality of root canal filling and year of study

Table 4.7 shows the results of the association between year of study and the quality of the root canal filling measured by the length, density and the taper of root canal filling.

The Fischer's exact test was used to examine the association between year of study and the quality of root canal filling. The test revealed that there was no significant association between the year of study and all the measures of quality of the root canal filling ($p>0.05$).

Table 4. 7 Association between students' year of study and the quality of root canal filling.

	Fischer's Exact Test
Length of canal filling	0.09
Density of root canal filling	0.22
Taper of root canal filling	0.06

Level of significance, $p<0.05$*.

4.2.4 Iatrogenic errors

The iatrogenic errors measured were ledge formation, presence of zipping, canal transportation, missed or untreated canals, fractured instruments and perforation. The overall and the student year specific frequency of the presence and absence of iatrogenic errors are outlined in Tables 4.8– 4.10.

4.2.4.1 Total iatrogenic errors

The most common iatrogenic errors in this study were ledge formation and canal transportation, while the least iatrogenic error was missed or untreated canal(s), as shown in Table 4.8. The most common of iatrogenic errors in teeth treated by the 3rd year students was zipping and canal transportation, while in teeth treated by the 4th year students was ledge formation, whereas it was zipping for 5th year students (Table 4.8).

4.2.4.2 Total iatrogenic errors according tooth location and position

With the exception of perforation which was equal in maxillary and mandibular teeth, while the perforation was higher in anterior teeth than posterior teeth, the frequency of iatrogenic errors was greater in mandibular and posterior teeth than maxillary and anterior teeth, respectively, as shown in Table 4.9.

4.2.4.3 Presence of iatrogenic errors according to students and location of teeth

With the exception of missed or untreated canal(s) and fracture instrument(s) the incidence of iatrogenic errors in teeth treated by the 4^{th} year students were higher in mandibular teeth than maxillary teeth, while in teeth treated by the 5^{th} year students the all iatrogenic errors were higher in mandibular teeth than maxillary teeth with exception of perforation as shown in Table 4.10.

There was no significant difference in the iatrogenic errors shown by the students between the year of study ($p>0.05$).

4.2.4.4 Total absence and presence of iatrogenic errors

The overall absence of iatrogenic errors in all students' years in this study was 62.9% (Figure 4.4). The highest absence of iatrogenic errors was in teeth performed by the 5^{th} year students (64.8%), while the least absence of iatrogenic errors was in teeth performed by the 4^{th} year students (60.4%).

4.2.4.5 Presence of iatrogenic errors according to tooth type and root curvature

With the exception of perforation, the highest presence of other iatrogenic errors was in second molars, while the highest presence of perforation was in canines (Table 4.11). In addition to that, the presence of iatrogenic errors with exception to perforation was higher in teeth with moderately curved roots than straight roots; in contrast to that, the presence of perforation was higher in teeth with straight roots than teeth with moderately curved roots (Table 4.11).

Table 4. 8 Total iatrogenic errors.

	Third year		Fourth year		Fifth year		Total		P
	N	%	N	%	N	%	N	%	
Ledge formation									0.17
Present	20	23.5	40	37.7	27	25	87	29.1	
Absent	65	76.5	66	62.3	81	75	212	70.9	
Zipping									0.35
Present	23	27.1	19	17.9	28	25.9	70	23.4	
Absent	62	72.9	87	82.1	80	74.1	229	76.6	
Canal transportation									0.62
Present	23	27.1	28	26.4	27	25	87	29.1	
Absent	62	72.9	78	73.6	81	75	212	70.9	
Missed or untreated canal(s)									1.00
Present	-	-	-	-	1	0.9	1	0.3	
Absent	85	100	106	100	107	99.1	298	99.7	
Fractured instrument(s)									0.11
Present	-	-	-	-	3	2.8	3	1	
Absent	85	100	106	100	105	97.2	296	99	
Perforation									0.16
Present	12	14.1	8	7.5	7	6.5	27	9	
Absent	73	85.9	98	92.5	101	93.5	272	91	

Level of significance, $p<0.05$*

Table 4. 9 Total iatrogenic errors according tooth location and position.

	Anterior		Posterior		Maxillary		Mandibular	
	N	%	N	%	N	%	N	%
Ledge formation								
Present	36	23.5	51	34.9	43	27.7	44	30.6
Absent	117	76.5	95	65.1	112	72.3	100	69.4
Zipping								
Present	35	22.9	35	24	33	21.3	37	25.7
Absent	118	77.1	111	76	122	78.7	107	74.3
Canal transportation								
Present	35	22.9	43	29.5	39	25.2	39	27.1
Absent	118	77.1	103	70.5	116	74.8	105	72.9
Missed or untreated canal(s)								
Present	-	-	1	0.7	-	-	1	0.7
Absent	153	100	145	99.3	155	100	143	99.3
Fractured instrument(s)								
Present	-	-	3	2.1	1	0.6	2	1.4
Absent	153	100	143	97.9	154	99.4	142	98.6
Perforation								
Present	18	11.8	9	6.2	14	9	13	9
Absent	135	88.2	137	93.8	141	91	131	91

Table 4. 10 Presence of iatrogenic errors according to student and location of teeth.

	Anterior		Posterior		Maxillary		Mandibular	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Ledge formation								
Third year students	20	23.5	-	-	11	23.9	9	23.1
Fourth year students	14	34.1	25	38.5	22	33.8	18	43.9
Fifth year students	6	22.2	21	25.9	10	22.7	17	26.6
Zipping								
Third year students	23	27.1	-	-	13	28.3	10	25.6
Fourth year students	10	24.4	11	16.9	9	12.3	12	29.3
Fifth year students	9	33.3	19	23.5	13	29.5	28	43.8
Canal transportation								
Third year students	23	27.1	-	-	13	28.2	10	25.6
Fourth year students	11	26.8	17	26.1	14	21.5	14	34.1
Fifth year students	8	29.6	19	23.5	13	29.5	15	23.4
Missed or untreated canal(s)								
Third year students	-	-	-	-	-	-	-	-
Fourth year students	-	-	-	-	-	-	-	-
Fifth year students	-	-	1	1.2	-	-	1	1.6
Fractured instrument(s)								
Third year students	-	-	-	-	-	-	-	-
Fourth year students	-	-	-	-	-	-	-	-
Fifth year students	-	-	3	3.7	1	2.3	2	3.1
Perforation								
Third year students	12	14.1	-	-	9	19.6	3	7.7
Fourth year students	3	7.3	5	7.7	-	-	8	19.5
Fifth year students	3	11.1	4	4.9	5	11.4	2	3.1

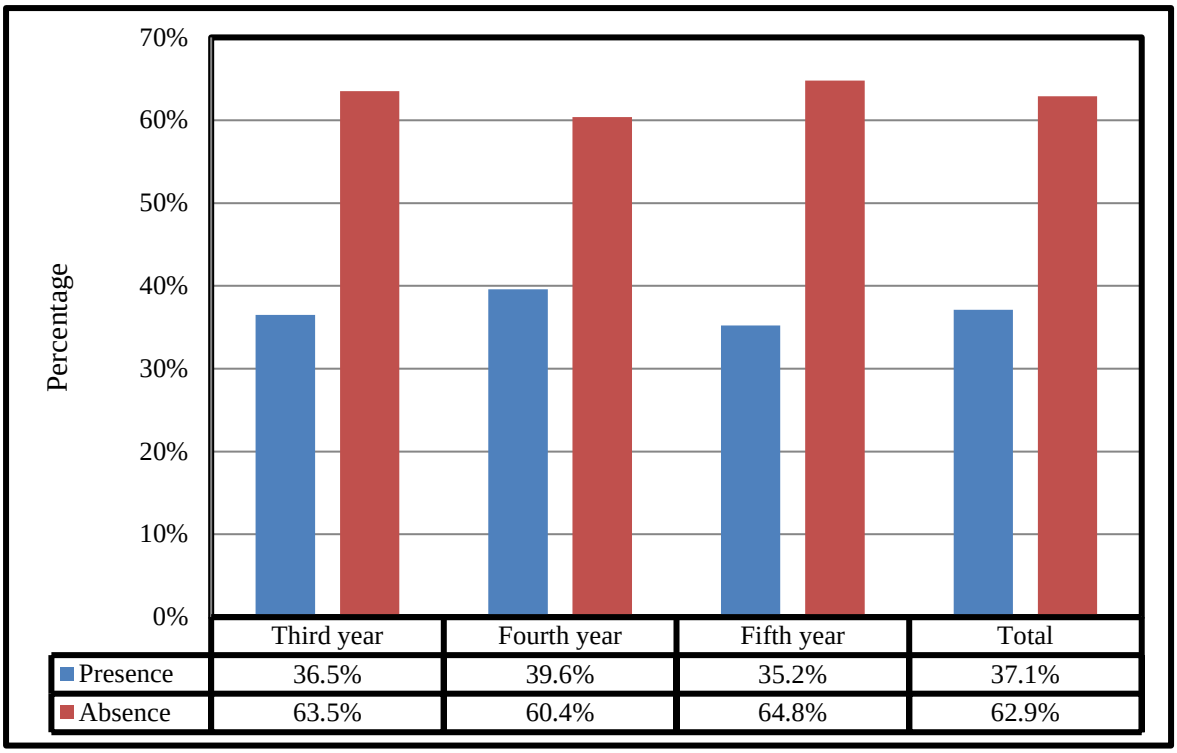


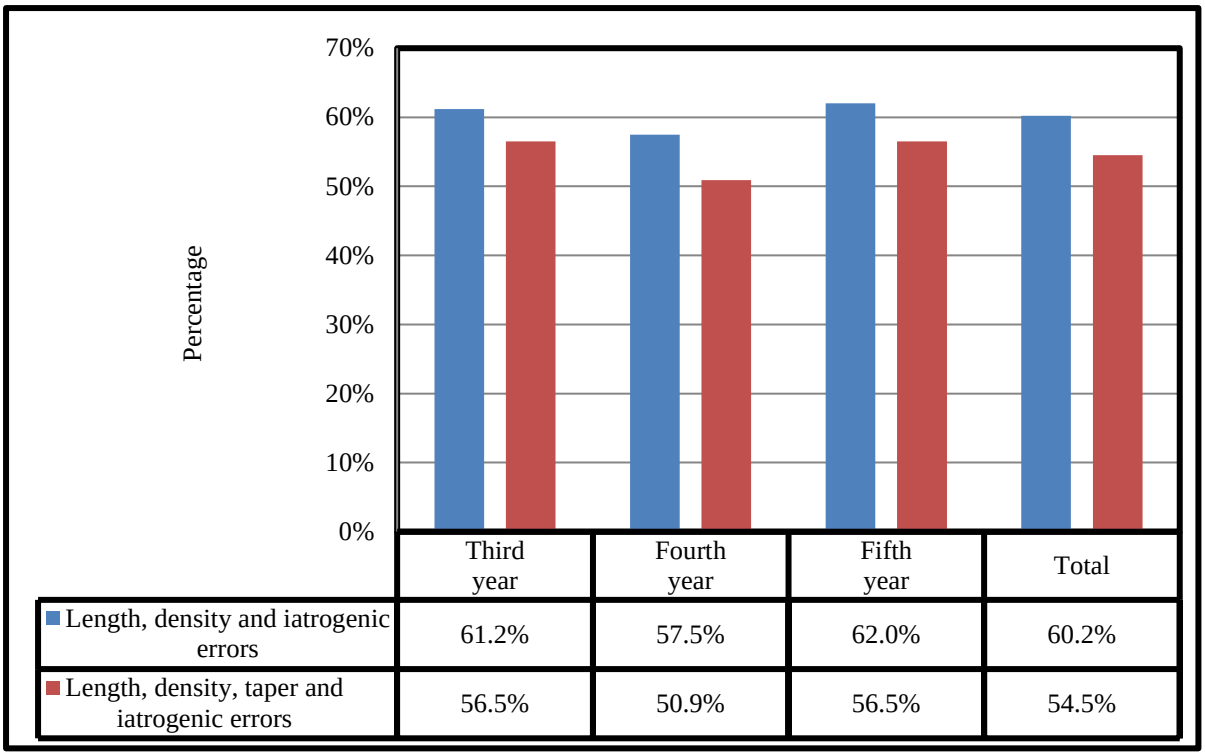
Figure 4. 4 Total absence and presence of iatrogenic errors.

4.2.5 Overall acceptable quality of root canal filling and presence of iatrogenic errors

The acceptable quality of root canal filling based on acceptable length and density without iatrogenic errors was greater than 57% in all student years, while the best acceptable result was in teeth treated by the 5th year students (62%), as shown in Figure 4.5. On the other hand, the acceptable quality based on acceptable length, density and taper without iatrogenic errors was greater than 50% in all student years, the lowest result was in teeth treated by the 4th year students (50.9%).

Table 4. 11 Presence of Iatrogenic errors according to teeth types and root curvature.

	Tooth type														Root curvature				Total	
	Central incisor		Lateral incisor		Canine		First Premolar		Second Premolar		First molar		Second molar		Straight		Moderate			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Ledge	16	16	15	40.5	5	31.2	5	20	9	25	18	34	19	59.3	35	25.4	52	32.3	87	29.1
Zipping	24	24	8	21.6	3	18.8	4	16	6	16.7	11	23.4	14	36.8	27	19.7	43	26.7	70	23.4
Canal transportation	21	21	10	27	4	25	5	20	8	22.2	15	31.9	15	46.9	37	26.8	50	31.1	87	29.1
Missed or untreated canal(s)	-	-	-	-	-	-	-	-	-	-	-	-	1	2.6	-	-	1	0.6	1	0.3
Fractured instrument(s)	-	-	-	-	-	-	-	-	-	-	1	2.1	2	5.3	-	-	3	1.9	3	1
Perforation	12	12	2	5.4	4	25	2	8	3	8.3	3	5.7	1	3.1	15	10.9	12	7.5	27	9



	Third year	Fourth year	Fifth year	Total
Length, density and iatrogenic errors	61.2%	57.5%	62.0%	60.2%
Length, density, taper and iatrogenic errors	56.5%	50.9%	56.5%	54.5%

Figure 4. 5 Overall acceptable quality of root canal filling and presence of iatrogenic errors.

CHAPTER 5

DISCUSSION

A new undergraduate curriculum was implemented in 2012 at the University of Witwatersrand, whereby the endodontic undergraduate preclinical course began in the second year, instead of the third year. Several changes were made to the didactic and clinical teaching schedule. The time allotted to the undergraduate endodontic courses is shown in Table 5.1.

Table 5. 1 The allocation for undergraduate endodontic course at WITS University as from 2012.

Student year	Second year	Third year	Fourth year	Fifth year	Total
Lectures / Tutorials	08	16	16	10	50
Preclinical hours	44	12	4	0	60
Clinical hours	0	20	60	60	140
Total	52	48	80	70	250

The 2nd year students have to complete endodontic treatment of four extracted teeth (two anterior and two premolars). The first two teeth (one anterior and one premolar) are treated under supervision; while the latter two teeth are assessed with the marks contributing toward the student's grade. Third year students have a preclinical and clinical components to their course. During the preclinical training, the students must complete two molar endodontic treatments. The absolute minimum clinical quota for undergraduate students at Wits Oral Health Centre is shown in Table 5.2. All clinical requirements (quota) of the 3rd, 4th and 5th year students have to be completed by the penultimate month of their final year of study.

Table 5. 2 The minimum clinical quota for undergraduate students at Wits School of Oral Health Sciences.

Procedure	Quota			Cumulative quota
	Third year	Fourth year	Fifth year	
Single-rooted teeth	2	2	1	5
Dual-rooted teeth	0	2	2	4
Multi-rooted teeth	0	2	2	4
Re-treatment	0	0	1	1
Use of microscope - molar tooth*	0	0	1	1

* Means that the microscope must be used to perform one of the molar endodontic treatments

Endodontics is not recognised as an independent dental speciality in South Africa. For this reason, the undergraduate endodontic course is taught by general dental practitioners and prosthodontists. The staff: student ratio is 1:7 for preclinical teaching and 1:5 for clinical teaching.

The preclinical staff: student's ratio at Wits University was greater than described by Lynch and Burke (2006) (1:8), Pettigrew et al. (2007) (with 1:12), and Smadi et al. (2015) (with 1:15). The preclinical hours at Wits University is 60 hours, which is greater than studies done by Lynch and Burke (2006) at University Dental School and Hospital, Cork was (48 hours), Pettigrew et al. (2007) at Glasgow Dental Hospital and School was (32 hours) and Rafeek et al. (2012) at the University of the West Indies was (54 hours), while it was less than the study by Smadi et al. (2015) at the University of Jordan was (56 hours). The allotted hours for lectures and tutorials over the four endodontic course years totalled 50 hours which was greater than the study done by Rafeek et al. (2012) (15 hours).

In addition to the above, the clinical staff: student's ratio at Wits University (1:5) was greater than Barrieshi-Nusair et al. (2004) at Jordan University of Science and Technology (with 1:6), Eleftheriadis and Lambrianidis (2005) at Aristotle University of Thessaloniki (with 1:8), Lynch and Burke (2006) (1:8), Pettigrew et al. (2007) (with 1:12 for 5th year), Balto et al. (2010) at King Saud University (1:7 for 4th year and 1: 2 for 5th year), Rafeek et al. (2012) at

the University of the West Indies was (1:10) and Smadi et al. (2015) at the University of Jordan was (1:12).

At the Wits University School of Oral Health Sciences, standard endodontic protocol in the 3rd and 4th years includes the step-back preparation and lateral condensation obturation techniques. Stainless steel K-files with a triangular cross section are used. A 1% sodium hypochlorite irrigation solution is advocated, and all files and cones are ISO 2% tapered. Topseal is the root canal sealant of choice. The 5th year students predominantly utilise rotary instrumentation for canal preparation. ProGlider files are used for glide path preparation followed by Protaper Next (PTN) files. The endodontic clinical protocol specifies certain radiographs that should be taken during and after every root canal treatment. Thus, no additional radiographs were required for this retrospective study. Teeth were excluded from the study when these radiographs were unreadable or unavailable. Standard endodontic protocol is that all endodontic readiographs be taken using an Endo Rinn® instrument, at a preset exposure to ensure image quality.

The European Society of Endodontology (1992) recommended that students have to perform endodontic treatment on uncomplicated teeth (single and multirooted), and they have to be familiar with problems encountered in complicated endodontic treatments. The ESE, in their definition of uncomplicated treatment, include that the tooth curvature is less than 15° from the axis of the roots. The 3rd year students treated only the anterior teeth, 75.3% of them were straight, while the 4th year students treated posterior teeth (61.3%) for the first time in the clinic, of which 58.5% were moderately curved teeth. These differences in the complexity of cases between the different student groups explain why the result of the 3rd year students in general was better than the 4th year students. There was a significant difference in the number of roots and root curvature of the teeth treated between the 3rd, 4th and the 5th year students ($p<0.001$).

5.1. Discussion of the results per student's year

5.1.1 Third year students

85 of the 299 teeth (28.4%) performed by the 3rd year students (Table 4.2) were assessed. These were all single rooted teeth, 75.3% of them were straight, while 24.7% were moderately curved (Table 4.4).

The third year students had the lowest percentage of underfilled canals than the 4th and 5th year students (16.5%, 29.2% and 19.4% respectively). Yet interestingly, the 3rd year students had the highest number of overfilled canals than the 4th and 5th year students (14.1%, 7.5% and 6.5% respectively). Because they only treated anterior teeth with relatively wider and straight canals, they had little difficulty at finding the full length. However, a possible explanation for their high rate of overfilling is their inexperience and their inability to confine the instrumentation to within the canal. Thus, the high rate of overfilling could be due to overinstrumentation.

The underfilling result in maxillary teeth treated by 3rd year students was better than in mandibular teeth (Figure 4.1). In contrast to that, the overfilling result was better in mandibular teeth than in maxillary teeth due to overinstrumentation in the large canals of maxillary teeth.

The density and taper of maxillary teeth treated by the 3rd year students was better than in the mandibular teeth (Figure 4.2). The simple explanation for this is the relative difference in the size of the canals; that maxillary teeth have larger canals than the mandibular teeth.

In teeth treated by the 3rd year students, there were no missed or untreated canal(s) and fractured instrument(s) in either mandibular or maxillary teeth (Tables 4.8 and 4.10). This student group also had the lowest prevalence of ledge formation. This was expected as all teeth were single rooted, had large single canals, and 75.3% of treated teeth had straight roots. In addition, iatrogenic errors in maxillary teeth treated by the 3rd year students were higher than mandibular teeth (Table 4.10); this may have occurred due to the high number of maxillary teeth treated by the 3rd year students (54.1%), as shown in Table 4.3.

Pruett et al. (1997) discussed the relationship between the degrees of root curvature, the relative stiffness of the endodontic instruments and the incidence of iatrogenic errors. They stated that the smaller the radius of canal curvature, the greater the stress placed on the endodontic instruments which may also be a significant factor clinically contributing to instrument breakage and canal transportation. In this study, the iatrogenic errors in teeth treated by 3rd year students were higher than the teeth treated by the 5th year students (Figure 4.4). This decrease in the prevalence of iatrogenic errors with time (from 3rd to 5th year) is related to the experience gained by the students. The results of zipping and perforation were the highest in 3rd year students, among all students' years (Table 4.8); and again, this is explained by a relative lack of experience.

5.1.2 Fourth year students

Although the students are exposed to treating premolars and molar teeth in their preclinical exercises in the second and third year, their first clinical exposure to multirooted teeth is in the fourth year. In this study, 35.5% of the teeth assessed were treated by the 4th year students as shown in Table 4.2.

With the exception of overfilling, the results of the main criteria assessed in this study (length, density and taper) show that the fourth year students produced the lowest quality rating among all student years (Table 4.5). This was attributed to the inexperience of the students in treating posterior teeth. Moreover, 61.3% of teeth treated by the 4th year students were posterior teeth (Table 4.3). In this study, 58.5% of teeth treated by the 4th year students had moderately curved roots, while 41.5% of the teeth had two and three roots (Table 4.4.). In addition to using manual preparation techniques, the fourth year students also used rotary endodontic techniques with NiTi files for the first time.

The 4th year group had a lower degree of overfilling when compared to the 3rd year group, but a higher degree of overfilling when compared to the 5th year group. Anterior teeth treated by the 4th year students displayed a higher prevalence of adequate length, underfilling, acceptable density and taper when compared to posterior teeth (Figures 4.2 and 4.3).

Unexpectedly, the 4th year students showed no missed or untreated canal(s) and fractured instrument(s) (Tables 4.8 and 4.10). The frequencies of other iatrogenic errors in maxillary teeth treated by the 4th year students were lower than in mandibular teeth (Table 4.10). This may have occurred due to the variation of morphology between the maxillary and mandibular teeth, even though 61.3% of the treated teeth were maxillary teeth. With the exception of zipping and canal transportation, the frequencies of other iatrogenic errors in anterior teeth were lower than the posterior teeth.

The presence of ledges in teeth treated by the 4th year students was the highest when compared to the 3rd and 5th year students (37.7%, 23.5% and 25% respectively) as shown in Table 4.8. This finding was attributed to the inexperience of the 4th year students to posterior endodontic treatment which constituted 63.1% of teeth treated by this group. In contrast to the above, the presence of zipping and canal transportation in teeth treated by the 4th year students was the lowest among all student years. The presence of perforation was lower than

the 3rd year students, but higher than the 5th year students; again relative to student experience.

5.1.3 Fifth year students:

Fifth year BDS students at Wits University treat the anterior and posterior teeth. In this study, 75% of treated teeth by the 5th year students were posterior teeth while 25% were anterior teeth. In this study, 36.1% of all the teeth assessed were treated by the 5th year students as shown in Table 4.2. 72.2% of teeth had moderately curved roots, while 67.6% of the teeth were multirooted teeth (Table 4.4).

The 5th year students had the best adequate length and overfilling results than the 3rd and 4th year students (74.1%, 69.4% and 62.3%). This finding highlighted the experience of this student cohort over other years. However, the underfilling results of the 3rd year students were better than the 5th year students (Table 4.5). This occurrence was due to the fact that 72.2% of treated teeth by the 5th year students were moderately curved, while 75.3% of treated teeth by the 3rd year students were straight and single rooted teeth (Table 4.4). In addition, 75% of the teeth treated by the 5th year students were posterior teeth (Table 4.3).

The presence of ledges, missed or untreated canal(s) and fractured instrument(s) in anterior and maxillary teeth treated by the 5th year students were better than posterior and mandibular teeth respectively (Table 4.10). The presence of zipping and canal transportation in mandibular teeth was higher than maxillary teeth. Unexpectedly, the presence of zipping and canal transportation in posterior teeth was lower than in anterior teeth. However, the overall absence of iatrogenic errors in all teeth treated by the 5th year students was 64.8% (Figure 4.4). The presence of canal transportation and perforation in teeth treated by the 5th year students had the best results over other students (Table 4.8).

The possible explanation for the improved results of the 5th year group was that, in addition to the use of loupes that all students also used, they also had the training and the opportunity to use the dental microscope. Furthermore, the 5th year cohort had the choice between manual and rotary systems, which together with their experience, accounts for the superior finding for this group.

5.2. Comparison of results of this study and previous studies

5.2.1 Quality of root canal filling

5.2.1.1 Length of root canal filling

5.2.1.1.1 Adequate length

The total adequate length in this study was 68.9%. The results of previous studies are shown in Table 5.3. However, the sample of studies by Lynch and Burke (2006) and Pettigrew et al. (2007) were only single rooted teeth; they also had a lower number of posterior teeth (single rooted premolars) than anterior teeth.

The adequate length result of this study were better in anterior teeth than posterior teeth (Figure 4.1), similar to the study by Rafeek et al. (2012). The adequate length in this study was higher in maxillary teeth than the mandibular teeth (Figure 4.1) similar to studies by Er et al. (2006) and Rafeek et al. (2012) (Table 5.4). In this study, the central incisors had the highest adequate length, while the highest adequate lengths in previous studies are shown in Table 5.4.

5.2.1.1.2 Overfilling

The total overfilling of this study was 9%, which was higher than the studies by Er et al. (2006), Pettigrew et al. (2007), Rafeek et al. (2012) and Smadi et al. (2015), while the results of other studies is shown in Table 5.3. The overfilling in this study tends to occur more often in anterior teeth than posterior teeth (Figure 4.1) similar to the study by Rafeek et al. (2012) (Table 5.4). This is probably due to the size of root canal, which is wider in anterior teeth, because all anterior teeth have a single root canal.

The overfilling in this study occurred in maxillary teeth rather than mandibular (Figure 4.1) as in studies by Er et al. (2006) and Rafeek et al. (2012) (Table 5.4). This could be attributed to naturally larger canals of maxillary teeth, which are prone to overinstrumentation by inexperienced operators. In this study, the central incisors had the highest overfilling result, while the highest adequate lengths reported in previous studies are shown in Table 5.4.

5.2.1.1.3 Underfilling

The total underfilling was 22.1%, which was better than underfilling results of studies by Barrieshi-Nusair et al. (2004) and Rafeek et al. (2012) (Table 5.3). These studies had more posterior teeth when compared to anterior teeth, which led to an increase in the amount of underfilling. On the other hand, 53.8% of teeth in this study had moderately curved roots.

The total underfilling results of this study were better in anterior teeth than in posterior teeth. This occurred due to the difference in complexity between the anterior and posterior teeth, since the anterior teeth were single rooted and less curved. The underfilling in this study occurred more in mandibular teeth, as in the study by Barrieshi-Nusair et al. (2004) (Table 5.4), because in general, the mandibular canals are narrower than the maxillary canals. The highest underfilling result in this study was in the second molar, while the highest underfilling results in previous studies are shown in Table 5.4. With the exception of studies by Lynch and Burke (2006) and Pettigrew et al. (2007), there seems to be a higher prevalence of underfilling in molar teeth.

5.2.1.2 Density of root filling

The acceptable density of this study was 73.6%, while the acceptable density results of previous studies are shown in Table 5.3. The acceptable density in this study was higher in anterior teeth than posterior teeth. On the other hand, the acceptable density of maxillary teeth was higher than mandibular teeth, similar to the study by Rafeek et al. (2012) (Table 5.4).

In this study, the highest acceptable density was in central incisors, while highest acceptable density in previous studies is shown in Table 5.4. On the other hand, the acceptable density in teeth treated by the 5th year students was better than in teeth treated by the 4th year students, similar to study by Balto et al. (2010). Again, this result is relative, due to the difference in clinical experience between the different student groups.

5.2.1.3 Taper of root filling

The acceptable taper of this study was 70.9% (Table 4.5), while the acceptable taper results of previous studies are tabulated in Table 5.3. The acceptable taper of this study was higher in straight teeth (87%) than in teeth with moderately curved roots (57.1%) (Table 4.6), similar

to the results of studies by Barrieshi-Nusair et al. (2004), Er et al. (2006) and Rafeek et al. (2012).

The acceptable taper of anterior teeth in this study was higher than the posterior teeth (Figure 4.2); as in the study Rafeek et al. (2012). On the other hand the acceptable taper of maxillary teeth in this study was slightly higher than the mandibular teeth, while in the study by Rafeek et al. (2012), there was no significant difference. In this study, the highest acceptable taper of root filling was in central incisors (Table 4.6), while highest acceptable taper in previous studies are shown in Table 5.4.

In this study, the acceptable taper in teeth treated by the 5th year students was better than in teeth treated by the 4th year students. In contrast to that, the study by Balto et al. (2010) showed the adequate taper in the teeth treated by the 4th year students was better than the 5th year students.

5.2.1.4 Total acceptable root canal filling

5.2.1.4.1 Total acceptable root filling based on the length and density of root filling

The total acceptable root canal filling of this study, based on the length and density, was 67.9% (Figure 4.4). This result was higher than the studies by Eleftheriadis and Lambrianidis (2005), in which their result was 55.3% and Khabbaz et al. (2010) at 54.8%. In this study, the total acceptable root filling based on the length and density in teeth treated by the 5th year students was higher than in teeth treated by the 4th year students, similar to the study by Khabbaz et al. (2010). This result is attributed to the difference in clinical experience between student groups.

5.2.1.4.2 Total acceptable root filling based on the length, density and taper of root filling

The total acceptable root filling based on the length, density and taper was 62.5%, which was better than the studies by Barrieshi-Nusair et al. (2004) (47.4%), Er et al. (2006) (33%) and Smadi et al. (2015), which was 29.2%. In this study, the total acceptable root filling based on the length, density and taper in teeth treated by the 5th year students was higher than in teeth treated by the 4th year students, similar to the study by Balto et al. (2010). In contrast to that, in the study by Smadi et al. (2015), the adequate root canal filling was higher in the 4th year students than the 5th year students.

Table 5. 3 Frequencies of length, acceptable density and acceptable taper of root canal filling in previous studies.

Authors	Year	Country	Results				
			Length			Density	Taper
			Adequate	Underfilling	Overfilling		
Barrieshi-Nusair et al.	2004	Jordan	61.3%	34.5%	4.2%	72.6%	85.3%
Eleftheriadis and Lambrianidis	2005	Greece	62.7%	7.4%	1.8%	82.6%	-
Er et al.	2006	Turkey	69.6%	17.4%	13%	53.2%	68.3%
Lynch and Burke	2006	Ireland	70%	21%	9%	90%	-
Pettigrew et al.	2007	Scotland	80%	5%	15%	80%	-
Balto et al.	2010	K.S.A	79.6% *	11.3%	9.1%	34.9%	59.6%
Rafeek et al.	2012	Trinidad	63.1%	24.3%	12.6%	27.6%	72.2%
Smadi et al.	2015	Jordan	61.5%	14.1%	24.4%	50.5%	56.1%
Current study	2017	R.S.A	68.9%	22.1%	9%	73.6%	70.9%

* Balto et al. 2010 defined adequate length when root fillings that end ≤2 mm from radiographic apex, and defined flush as root fillings that end at the radiographic apex. Their result of 79.6% includes both adequate length and flush.

Table 5. 4 The highest frequency of length, acceptable density and acceptable taper in previous studies according to tooth type, arch and location

		Barrieshi-Nusair et al. 2004	Er et al. 2006	Lynch and Burke 2006	Pettigrew et al. 2007	Balto et al. 2010	Rafeek et al. 2012	Smadi et al. 2015	Current study
Adequate length	**Tooth**	Mx Incisors	Mn Premolars	Mn Lateral incisors	Mx 2nd premolar and Mn 1st premolar	Incisors	Mx Canines	Mx Anteriors	Central incisors
	Arch	-	Maxillary	-	-	-	Maxillary	-	Maxillary
	Location	-	-	-	-	-	Anterior	-	Anterior
Overfilling	**Tooth**	Mx Canines	Mn Incisors	Mx Lateral incisors	Mn Central Incisor	Molars	Mn Incisors	Mx Molars	Central incisors
	Arch	-	Maxillary	-	-	-	Maxillary	-	Maxillary
	Location	-	-	-	-	-	Anterior	-	Anterior
Underfilling	**Tooth**	Mn Molars	Mn Molars	Mx 2nd Premolars	Mn Lateral incisor	Molars	Mx Molars	Mn Molars	2nd Molar
	Arch	Mandibular	-	-	-	-	-	-	Mandibular
	Location	-	-	-	-	-	-	-	Posterior
Density	**Tooth**	Mx Canines	Mx Canines	Mx Lateral, Mn Central and Lateral	Mn Central, lateral and Canines	Canines	Mn Incisors	Mx Anteriors	Central incisors
	Arch	-	-	-	-	-	Maxillary	-	Maxillary
	Location	-	-	-	-	-	No significant	-	Anterior
Taper	**Tooth**	Mn Canines	Mx Incisors	-	-	Canines	Mn Incisors	Mx Anteriors	Central incisors
	Arch	-	-	-	-	-	No significant	-	Maxillary
	Location	-	-	-	-	-	Anterior	-	Anterior

Mx: Maxillary, Mn: Mandibular, LF: Left

5.2.2 Iatrogenic errors

5.2.2.1 Ledge formation

The presence of ledges in this study was 29.1%. This result was lower than studies by Greene and Krell (1990) and Kapalas and Lambrianidis (2000) as shown in Table 5.5, noting that their sample consisted of molar teeth only. On the other hand, it was lower than the results of studies by Eleftheriadis and Lambrianidis (2005), Balto et al. (2010) and Smadi et al. (2015). In the study by Eleftheriadis and Lambrianidis (2005), 43.5% of ledges were in molar root canals and 33.9% were in premolar root canals, whereas in the study by Balto et al. (2010) 32.7% occurred in molar teeth and 34.7% in premolar teeth. The study by Smadi et al. (2015) had only 18.8% in molar teeth and 40.8% in premolars.

The presence of ledges in this study was higher in posterior teeth than the anterior teeth similar to previous studies (Table 5.6). Kapalas and Lambrianidis (2000) and Greene and Krell (1990) concluded that in addition to teeth number and the canal location, the curvature of the root canal is the most important factor that affects incidences of ledge formation. Kapalas and Lambrianidis (2000) also found ledges were the highest in severely curved canals (58.2%), while the lowest frequency of ledges was in straight canals (25.5%).

The presence of ledges in this study was higher in mandibular teeth than the maxillary teeth , similar to the study by Smadi et al. (2015) (Table 5.6). This could be attributed to the naturally smaller mandibular teeth canals and large maxillary teeth canals. We found that the frequency of ledges was higher in molar teeth which is similar to previous studies (Table 5.6). This is possibly due to the greater complexity of molar teeth when compared to other teeth which include: the location, number of canals and curvature of root canals.

Greene and Krell (1990) found that the root canals with curvatures $\geq 20°$ were ledged more than 56% and root canals with curvatures $\leq 10°$ were seldom ledged. In the study by Kapalas and Lambrianidis (2000), the ledging occurred in 58.2% of severely curved root canals, 56.4% in moderately curved root canals, and 25.5% in straight canals, while in the study by Eleftheriadis and Lambrianidis (2005), the ledging occurred in 58.4% of severely curved root canals, 40.4% in moderately curved, and 5.9% of straight root canals. This study is consistent with the previous studies that the incidence of ledging increases with the degree of curvature of the canal.

5.2.2.2 Zipping

The presence of zipping in the present study was 23.4%, which was less than the study by Balto et al. (2010), as shown in Table 5.5. In this study, zipping occurred more in posterior teeth than anterior teeth (Table 4.9), similar to the findings of Balto et al. (2010), as shown in Table 5.6. On the other hand, the occurrence of zipping in this study was higher in mandibular teeth than in maxillary teeth. In the study by Balto et al. (2010), zipping occurred in one molar tooth while in this study, the highest incidence of zipping was in the second molar teeth. In addition to that, the presence of zipping in this study was higher in moderately curved teeth (26.7%) than straight ones (19.7%), as shown in Table 4.11. Hence, we found that zipping tends to occurred more in posterior teeth than the anterior teeth and increases with canal curvature.

5.2.2.3 Canal transportation

The presence of canal transportation in the present study was 29.1%, while the results of previous studies are shown in Table 5.5. The study by Balto et al. (2010) used the term apical transportation. The presence of canal transportation in the present study was higher in posterior teeth than anterior teeth, similar to the study by Balto et al. (2010) as shown in Table 5.6.

Furthermore, the presence of canal transportation in the present study was higher in mandibular teeth than in maxillary teeth (Table 4.9); this could be attributed to the naturally smaller mandibular teeth canals and large maxillary teeth canals. Canal transportation in the present study was higher in moderately curved teeth (31.1%) than in straight teeth (26.8%), as shown in Table 4.11. The greatest incidence of canal transportation in the present study was in second molar teeth, while greatest incidences of canal transportation in previous studies are shown in Table 5.6. As expected, we found that canal transportation tends to occur more in posterior teeth than in anterior teeth.

In this study, the presence of canal transportation in teeth treated by the more experienced 5^{th} year students was lower than in teeth treated by the 4^{th} year students. On the contrary, the study by Balto et al. (2010) showed the presence of canal transportation in teeth treated by the 4^{th} year students was lower than in teeth treated by the 5^{th} year students.

5.2.2.4 Missed or untreated canal(s)

The presence of missed or untreated canal(s) in this study was 0.3%, which was lower than the study by Balto et al. (2010), as shown in Table 5.5. There was a single case of a missed canal in a second mandibular molar in a case performed by a 5th year student. This correlated with the study by Balto where missed canals also occurred in molar teeth.

5.2.2.5 Fractured instrument(s)

The presence of fractured instrument(s) in this study was identified in only three molar teeth, making 1% of the study and were all done by the 5th year students, while the presence of fractured instrument(s) in previous studies is shown in Table 5.5. The presence of fractured instrument(s) in the present study occurred only in posterior teeth. Suter et al. (2005) stated that curved root canals have a higher risk of fractured instruments than straight canals. In contrast to the present study, Balto et al. (2010) found that the incidence of fractured instrument(s) was higher in anterior teeth than in posterior teeth.

The presence of fractured instrument(s) in the present study was higher in mandibular teeth than maxillary teeth. The highest presence of fractured instrument(s) in the present study was in second molar teeth, while the incidence in previous studies is shown in Table 5.6.

5.2.2.6 Perforation

The presence of perforation in this study was 9%, while the results of previous studies are shown in Table 5.5. The presence of perforation in this study was higher in anterior teeth than in posterior teeth (Table 4.9). This is contrary to the findings by Balto et al. (2010), in which the presence of perforation was higher in posterior teeth than the anterior teeth. Eleftheriadis and Lambrianidis (2005) stated that the curvature of root canals is the most significant clinical factor correlating to root perforation and ledge formation.

On the other hand, there is no difference in the presence of perforation in this study between maxillary and mandibular teeth as shown in Table 4.9. The greatest incidence of perforation in the present study was in canine teeth, while the greatest incidences of perforation in previous studies are shown in Table 5.6.

5.2.2.7 Total presence of iatrogenic errors

In this study, the presence of iatrogenic errors was 37.1% (Figure 4.4). This result was higher than the study by Khabbaz et al. (2010) at 31.2%. This could be related to the difference in which iatrogenic errors are reported between the two studies. On the other hand, the frequency of iatrogenic presence of this study was higher in the 4th year students than the 5th year students, similar to the study by Khabbaz et al. (2010). The other studies did not show the total presence of iatrogenic errors.

5.2.3 Overall acceptable quality of root canal filling and absence of iatrogenic errors

Although the presence of iatrogenic errors has an effect on the total acceptable quality of root canal filling, the presence of iatrogenic errors sometimes did not lead to failure of endodontic therapy.

5.2.3.1 Overall acceptable quality of root canal treatement based on the length and density filling and absence of iatrogenic errors

The overall acceptable quality of root canal treatment based on the length and density filling and absence of iatrogenic errors in this study was 60.2% (Figure 4.5) which was less than the studies by Lynch and Burke (2006) with 70% and Pettigrew et al. (2007) with 63%.

5.2.3.2 Overall acceptable quality of root canal treatement based on the length, density and taper filling and absence of iatrogenic errors

The total acceptable quality of root canal treatement based on the length, density and taper filling and absence of iatrogenic errors in this study was 54.5% (Figure 4.5) which was better than the study done by Balto et al. (2010) (22.7%). This result may have occurred due to the study by Balto et al. (2010) using more types of iatrogenic errors than our study (Table 1.1). In the study by Rafeek et al. (2012), the result was 10.1% of teeth, but they added the absence of fractured instruments to adequate length and taper as they reasoned that all treatment was directly supervised by the endodontist.

Table 5. 5 Presence of iatrogenic errors in previous studies.

Authors	Year	Country	Results					
			Ledge	Zipping	Canal transportation	Missed canals	Fractured instrument(s)	Perforation
Greene and Krell	1990	U.S.A	46%	-	-	-	-	-
Kapalas and Lambrianidis	2000	Greece	51.5%*	-	-	-	-	-
Eleftheriadis and Lambrianidis	2005	Greece	24.8%	-	-	-	0.3%	Root = 2.7 %, Strip = 0.2% and furcation = 0.2%
Lynch and Burke	2006	Ireland	-	-	-	-	Not detected	Not detected
Pettigrew et al.	2007	Scotland	-	-	-	-	Not detected	1%
Balto et al.	2010	K.S.A	13.6%	0.2%	7.3%	1.5%	0.5%	Apical =6.7%, Root = 1.5% Strip = 1.5% and Furcation = 0%
Khabbaz et al.	2010	Greece	54.8%**	-	-	-	0.9%**	Root = 11.8%, ** Foramen = 32.6% **
Rafeek et al.	2012	Trinidad	-	-	-	-	1.5%	-
Smadi et al.	2015	Jordan	5.2%	-	7.6 %	-	-	1.9%
Current study	2017	R.S.A	29.1%	23.4%	29.1%	0.3%	1%	9%

* The result for undergraduate students

** The results of this study was out of root canals with iatrogenic errors

Table 5. 6 The highest frequency of iatrogenic errors in previous according to tooth type, arch and location

		Greene and Krell 1990	Kapalas and Lambrianidis 2000	Eleftheriadis and Lambrianidis 2005	Balto et al. 2010	Rafeek et al. 2012	Smadi et al. 2015	Current study
Ledge	**Tooth**	LF Mx 2nd Molars	LF Mn 2nd Molar		Molars	-	Mx Molars	2nd Molars
	Arch	-	Sample was left Mx and Mn Molars only	-	-	-	Mandibular	Mandibular
	Location	Sample was Molars only		Posterior	Posterior	-	Posterior	Posterior
Zipping	**Tooth**	-	-	-	Molar	-	-	2nd Molars
	Arch	-	-	-	-	-	-	Mandibular
	Location	-	-	-	Posterior	-	-	Posterior
Canal transportation	**Tooth**	-	-	-	Premolars	-	Mn Molars	2nd Molars
	Arch	-	-	-	-	-	-	Mandibular
	Location	-	-	-	Posterior	-	-	Posterior
Missed canals	**Tooth**	-	-	-	Molars	-	-	2nd Molar
	Arch	-	-	-	-	-	-	Mandibular
	Location	-	-	-	-	-	-	Posterior
Fractured instrument(s)	**Tooth**	-	-	-	Canine	Molar	-	2nd Molar
	Arch	-	-	-	-	-	-	Mandibular
	Location	-	-	-	-	Posterior	-	Posterior
Perforation	**Tooth**	-	-	Root = Molars	Apical = Molars, Root and Strip = Premolar,	-	Mx Molars	Canine
	Arch	-	-	-	-	-	-	Equal
	Location	-	-	-	Posterior	-	-	Anterior

Mx: Maxillary, Mn: Mandibular, LF: Left

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The results of this study are similar to other studies conducted at various dental schools around the world. The change in the curriculum has been justified, although the study does point out some areas of concern. There was a tendency for third year students to overfill due to overinstrumentation of anterior teeth, and so the introduction of apex locators may assist in avoiding these errors.

The fourth year students produce the lowest quality of endodontic treatment in the clinic, possibly because of their inexperience in treating molar teeth. The incidence of iatrogenic errors like ledges, zipping and canal transportation were greater in posterior teeth and increased with greater canal curvature. The 5th year students had better results, because of their relative experience and the opportunity to use dental operating microscopes.

The incidence of underfilling was more prevalent in posterior teeth, while the incidence of acceptable density and taper of root filling was more in anterior and maxillary teeth, respectively. The result of this study showed that the frequency of iatrogenic errors were greater in mandibular and in posterior teeth. The only exception being perforation which was equal in maxillary and mandibular teeth, while this was higher in anterior teeth.

Recommendations

Endodontic teaching should further emphasise the importance of length control during endodontic treatment and more stringent steps may be necessary during clinical supervision of third year students. Simillary, techniques to overcome the difficulties of treating curved canals in posterior teeth must be emphasised to fourth and fifth year students to decrease the incidences of iatrogenic errors in teeth treated by these student cohorts.

Limitations

A major limitation of this study was the use of 2-D radiographic images for quality anaylsis. These lack the bucco-palatal and bucco-lingual dimensions and may mask root filling errors

in this plane by superimposing anatomical structures. Whilst, Cone beam computed tomography would have allowed for superior analysis, this was a retrospective study of convention endodontic treatment in the polyclinics of the Wits Oral Health Centre where such imaging is not routine for each patient.

REFERENCES

Akbar, I., 2015. Radiographic Study of the Problems and Failures of Endodontic Treatment. *International Journal of Health Sciences*, 9(2), pp.111-18.

American Association of Endodontists, 2016. Glossary of Endodontic Terms. [Online] Available at: http://www.nxtbook.com/nxtbooks/aae/endodonticglossary2016/ [Accessed 28 August 2017].

Arvaniti, I.S. and Khabbaz, M.G., 2011. Influence of Root Canal Taper on its Cleanliness: a Scanning Electron Microscopic Study. *Journal of Endodontics*, 37(6), pp.871-74

Balto, H., Al Khalifah, S.H., Al Mugairin, S., Al Deeb, M. and Al-Madi, E., 2010. Technical Quality of Root Fillings Performed by Undergraduate Students in Saudi Arabia. *International Endodontic Journal*, 43(4), pp.292-300.

Barrieshi-Nusair, K., Al-Omari, M. and Al-Hiyasat, A., 2004. Radiographic Technical Quality of Root Canal Treatment Performed by Dental Students at the Dental Teaching Centre in Jordan. *Journal of Dentistry*, 32(4), pp.301-07.

Bołtacz-Rzepkowska, E. and Pawlicka, H., 2003. Radiographic Features and Outcome of Root Canal Treatment Carried out in the Łódź Region of Poland. *International Endodontic Journal*, 36(1), pp.27-32.

Boucher, Y., Matossian, L., Rilliard, F. and Machtou, P., 2002. Radiographic Evaluation of the Prevalence and Technical Quality of Root Canal Treatment in a French Subpopulation. *International Endodontic Journal*, 35(3), pp.229-38.

Burke, F., Lynch, C., Ní Ríordáin, R. and Hannigan, A., 2009. Technical Quality of Root Canal Fillings Performed in a Dental School and the Associated Retention of Root-Filled Teeth: A Clinical Follow-up Study over a 5-Year Period. *Journal of Oral Rehabilitation*, 36(7), pp.508-15.

Chugal, N.M., Clive, J.M. and Spångberg, L.S., 2003. Endodontic Infection: Some Biologic and Treatment Factors Associated with Outcome. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 96(1), pp.81-90.

De Moor, R., Hülsmann, M., Kirkevang, L.L., Tanalp, J. and Whitworth, J., 2013. Undergraduate Curriculum Guidelines for Endodontology. *International Endodontic Journal*, 46(12), pp.1105-14.

Dubrow, H., 1976. Silver Points and Gutta-percha and the Role of Root Canal Fillings. *The Journal of the American Dental Association*, 93(5), pp.976-80.

Dummer, P.M., McGinn, John H. and Rees, D.G., 1984. The Position and Topography of the Apical Canal Constriction and Apical Foramen. *International Endodontic Journal*, 17(4), pp.192-198

Eldeeb, M.E. and Boraas, J.C., 1985. The Effect of Different Files on the Preparation Shape of Severely Curved Canals. *International Endodontic Journal*, 18(1), pp.1-7.

Eleftheriadis, G. and Lambrianidis, T., 2005. Technical Quality of Root Canal Treatment and Detection of Iatrogenic Errors in an Undergraduate Dental Clinic. *International Endodontic Journal*, 38(10), pp.725-34.

Elizabeth, M., Saunders 2005. Hand Instrumentation in Root Canal Preparation. *Endodontic Topics*, 10(1), pp.163-67.

Er, O., Sagsen, B., Maden, M., Cinar, S. and Kahraman, Y., 2006. Radiographic Technical Quality of Root Fillings Performed by Dental Students in Turkey. *International Endodontic Journal*, 39(11), pp.867-872.

Eckerbom, M., Flygare, L. and Magnusson, T., 2007. A 20-Year Follow-up Study of Endodontic Variables and Apical Status in a Swedish Population. *International Endodontic Journal*, 40(12), pp.940-48.

Esposito, P.T. and Cunningham, C.J., 1995. A Comparison of Canal Preparation with Nickel-Titanium and Stainless Steel Instruments. *Journal of Endodontics*, 21(1), pp.173-76.

European Society of Endodontology, 1992. Undergraduate Curriculum Guidelines for Endodontology. *International Endodontic Journal*, 25(3), pp.169-72.

Farzaneh, M., Abitbol, S. and Friedman, S., 2004. Treatment Outcome in Endodontics: the Toronto Study. Phases I and II: Orthograde Retreatment. *Journal of Endodontics*, 30(9), pp.627-33.

Forrai, J., 2007. History of X-ray in Dentistry. *Revista De Clínica E Pesquisa Odontológica*, 3(3), pp.205-11.

Fuss, Z. and Trope, M., 1996. Root Perforations: Classification and Treatment Choices Based on Prognostic Factors. *Dental Traumatology*, 12(6), pp.255-64.

Gencoglu, N. and Helvacioglu, D., 2009. Comparison of the Different Techniques to Remove Fractured Endodontic Instruments from Root Canal Systems. *European Journal of Dentistry*, 3(2), pp.90-5.

González Sánchez, J.A., Duran-Sindreu, F., de Noé, S., Mercadé, M. and Roig, M., 2012. Centring Ability and Apical Transportation after Overinstrumentation with ProTaper Universal and ProFile Vortex Instruments. *International Endodontic Journal*, 45(6), pp.542-51.

Greene, K.J. and Krell, K.V., 1990. Clinical Factors Associated with Ledged Canals in Maxillary and Mandibular Molars. *Oral Surgery, Oral Medicine, Oral Pathology*, 70(4), pp.490-97.

Gutierreza, J.H. and Aguayo, P., 1995. Apical Foraminal Openings in Human Teeth: Number and Location. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 79(6), pp.769-77.

Halse, A. and Molven, O., 1987. Overextended Gutta-percha and Kloroperka N-ö Root Canal Fillings: Radiographic Findings after 10-17 Years. *Acta Odontologica Scandinavica*, 45(3), pp.171-77.

Harris, W.E., 1976. A Simplified Method of Treatment for Endodontic Perforations. *Journal of Endodontics*, 2(5), pp.126-34.

Hayes, S.J., Gibson, M., Hammond, M., Bryant, S.T. and Dummer, P.M.H., 2001. An Audit of Root Canal Treatment Performed by Undergraduate Students. *International Endodontic Journal*, 34(7), pp.501-05.

Hommez, G., Coppens, C. and De Moor, R., 2002. Periapical Health Related to the Quality of Coronal Restorations and Root Fillings. *International Endodontic Journal*, 35(8), pp.680-89.

Ingle, J.I., 1961. A Standardized Endodontic Technique Utilizing Newly Designed Instruments and Filling Materials. *Oral Surgery, Oral Medicine, Oral Pathology*, 14(1), pp.83-91.

Jafarzadeh, H. and Abbott, P.V., 2007. Ledge Formation: Review of a Great Challenge in Endodontics. *Journal of Endodontics*, 33(10), pp.1155-62.

Kapalas, A. and Lambrianidis, T., 2000. Factors Associated with Root Canal Ledging during Instrumentation. *Dental Traumatology*, 16(5), pp.229-31.

Kelbauskas, E., Andriukaitiene, L. and Nedzelskiene, I., 2009. Quality of Root Canal Filling Performed by Undergraduate Students of Odontology at Kaunas University of Medicine in Lithuania. *Stomatologija*, 11(3), pp.92-96.

Khabbaz, M., Protogerou, E. and Douka, E., 2010. Radiographic Quality of Root Fillings Performed by Undergraduate Students. *International Endodontic Journal*, 43(6), pp.499-508.

Kirkevang, L.L., Ørstavik, D., Hörsted-Bindslev, P. and Wenzel, A., 2000. Periapical Status and Quality of Root Fillings and Coronal Restorations in a Danish Population. *International Endodontic Journal*, 33(6), pp.509-515.

Kuttler, Y., 1955. Microscopic Investigation of Root Apexes. *The Journal of the American Dental Association*, 50(5), pp.544-52.

Lambrianidis, T., 2009. Ledging and Blockage of Root Canals during Canal Preparation: Causes, Recognition, Prevention, Management, and Outcomes. *Endodontic Topics*, 15(1), pp.56-74.

Lin, L.M., Rosenberg, P.A. and Lin, J., 2005. Do Procedural Errors Cause Endodontic Treatment Failure? *The Journal of the American Dental Association*, 136(2), pp.187-93.

Lost, C., 2001. Undergraduate Curriculum Guidelines for Endodontology. *International Endodontic Journal*, 34(8), pp.574-80.

Loest, C., 2006. Quality Guidelines for Endodontic Treatment: Consensus Report of the European Society of Endodontology. *International Endodontic Journal*, 39(12), pp.921-30.

Lynch, C. and Burke, F., 2006. Quality of Root Canal Fillings Performed by Undergraduate Dental Students on Single-Rooted Teeth. *European Journal of Dental Education*, 10(2), pp.67-72.

Mounce, R.E., 2008. Current Philosophies in Root Canal Obturation. Tulsa, OK.: *Pennwell Publications*, pp.1-11.

Nieuwenhuysen, J., Aouar, M. and D'hoore, W., 1994. Retreatment or Radiographic Monitoring in Endodontics. *International Endodontic Journal*, 27(2), pp.75-81.

Noiri, Y., Ehara, A., Kawahara, T., Takemura, N. and Ebisu, S., 2002. Participation of Bacterial Biofilms in Refractory and Chronic Periapical Periodontitis. *Journal of Endodontics*, 28(10), pp.679-83.

Pai, A.V., Shrikrishna, S.B. and Shah, N., 2014. Surgical Management of Overfilled Gutta-percha and Root Capping with Mineral Trioxide Aggregate in a Young Patient. *Journal of Interdisciplinary Dentistry*, 4(3), p.148.

Peak, J., Hayes, S., Bryant, S. and Dummer, P., 2001. Endodontics: The Outcome of Root Canal Treatment. A Retrospective Study within the Armed Forces (Royal Air Force). *British Dental Journal*, 190(3), pp.140-44.

Petersson, K., Hasselgren, G. and Tronstad, L., 1985. Endodontic Treatment of Experimental Root Perforations in Dog Teeth. *Dental Traumatology*, 1(1), pp.22-28.

Pettigrew, L.K., Jauhar, S., Lynch, C.D., Savarrio, L., Carrotte, P. and Hannigan, A., 2007. An Audit of the Quality of Root Canal Treatments Performed by Undergraduate Dental Students on Single-Rooted Teeth in Glasgow Dental Hospital and School. *The European Journal of Prosthodontics and Restorative Dentistry*, 15(2), pp.72-76.

Pruett, J.P., Clement, D.J. and Carnes, D.L., 1997. Cyclic Fatigue Testing of Nickel-titanium Endodontic Instruments. *Journal of Endodontics*, 23(2), pp.77-85.

Rafeek, R.N., Smith, W.A., Mankee, M.S. and Coldero, L.G., 2012. Radiographic Evaluation of the Technical Quality of Root Canal Fillings Performed by Dental Students. *Australian Endodontic Journal*, 38(2), pp.64-69.

Ramachandran Nair, P., 2003. Non-microbial Etiology: Foreign Body Reaction Maintaining Post-treatment Apical Periodontitis. *Endodontic Topics*, 6(1), pp.114-34.

Ricucci, Langeland, 1998. Apical Limit of Root Canal Instrumentation and Obturation, Part 2. A Histological Study. *International Endodontic Journal*, 31(6), pp.394-409..

Ridao-Sacie, C., Segura-Egea, J.J., Fernández-Palacín, A., Bullón-Fernández, P. and Ríos-Santos, J.V., 2007. Radiological Assessment of Periapical Status using the Periapical Index: Comparison of Periapical Radiography and Digital Panoramic Radiography. *International Endodontic Journal*, 40(6), pp.433-40.

Román Richon, S., Faus Matoses, V., Alegre Domingo, T. and Faus Llácer, V., 2014. Radiographic Technical Quality of Root Canal Treatment Performed Ex Vivo by Dental Students at Valencia University Medical and Dental School, Spain. *Medicina Oral, Patología Oral Y Cirugía Bucal*, pp.e 93–97.

Santos, S.M.C., Soares, J.A., Costa, G.M., Brito-Júnior, M., Moreira, A.N. and de Magalhães, C.S., 2010. Radiographic Parameters of Quality of Root Canal Fillings and Periapical Status: A Retrospective Cohort Study. *Journal of Endodontics*, 36(12), pp.1932-37.

Saunders, W. and Saunders, E., 1994. Coronal Leakage as a Cause of Failure in Root Canal Therapy: A Review. *Dental Traumatology*, 10(3), pp.105-08.

Schaeffer, M.A., White, R.R. and Walton, R.E., 2005. Determining the Optimal Obturation Length: A Meta-Analysis of Literature. *Journal of Endodontics*, 31(4), pp.271-74.

Schilder H., 1974. Cleaning and Shaping the Root Canal. *The Dental Clinics of North America*, 18, pp.269-96.

Schneider, S.W., 1971. A Comparison of Canal Preparations in Straight and Curved Root Canals. *Oral surgery, Oral medicine, Oral pathology*, 32(2), pp.271-75.

Segura-Egea, J.J., Jiménez-Pinzón, A., Poyato-Ferrera, M., Velasco-Ortega, E. and Ríos-Santos, J.V., 2004. Periapical Status and Quality of Root Fillings and Coronal Restorations in an Adult Spanish Population. *International Endodontic Journal*, 37(8), pp.525-30.

Seltzer, S., Bender, I. and Turkenkopf, S., 1963. Factors Affecting Successful Repair after Root Canal Therapy. *The Journal of the American Dental Association*, 67(5), pp.651-62.

Siqueira, J., 2001. Aetiology of Root Canal Treatment Failure: Why Well-Treated Teeth Can Fail. *International Endodontic Journal*, 34(1), pp.1-10.

Sjögren, U., Hägglund, B., Sundqvist, G. and Wing, K., 1990. Factors Affecting the Long-Term Results of Endodontic Treatment. *Journal of Endodontics*, 16(10), pp.498-504.

Sjögren, U., Sundqvist, G. and Nair, P., 1995. Tissue Reaction to Gutta-percha Particles of Various Sizes when Implanted Subcutaneously in Guinea Pigs. *European Journal of Oral Sciences,* 103(5), pp.313-21.

Sjögren, U., Figdor, D., Persson, S. and Sundqvist, G., 1997. Influence of Infection at the Time of Root Filling on the Outcome of Endodontic Treatment of Teeth with Apical Periodontitis. *International Endodontic Journal*, 30(5), pp.297-306.

Smadi, L., Hammad, M. and El-Ma'aita, A., 2015. Evaluation of the Quality of Root Canal Treatments Performed by Dental Undergraduates: Is There a Need to Review Preclinical Endodontic Courses? *American Journal of Educational Research*, 3(12), pp.1554-58.

Smith, C., Setchell, D. and Harty, F., 1993. Factors Influencing the Success of Conventional Root Canal Therapy—a Five-Year Retrospective Study. *International Endodontic Journal*, 26(6), pp.321-33.

Sonntag, D., Bärwald, R., Hülsmann, M. and Stachniss, V., 2008. Pre-Clinical Endodontics: a Survey Amongst German Dental Schools. *International Endodontic Journal*, 41(10), pp.863-68.

Souter, N.J. and Messer, H.H., 2005. Complications Associated with Fractured File Removal Using an Ultrasonic Technique. *International Endodontic Journal*, 31(6), pp.450-52.

Suter, B., Lussi, A. and Sequeira, P., 2005. Probability of Removing Fractured Instruments from Root Canals. *International Endodontic Journal*, 38(2), pp.112-23.

Tamse, A., Kaffe, I. & Fishel, D., 1980. Zygomatic Arch Interference with Correct Radiographic Diagnosis in Maxillary Molar Endodontics. *Oral Surgery, Oral Medicine, Oral Pathology,* 50(6), pp.563-65.

Tavares, P.B., Bonte, E., Boukpessi, T., Siqueira, J.F. and Lasfargues, J.J., 2009. Prevalence of Apical Periodontitis in Root Canal–Treated Teeth from an Urban French Population: Influence of the Quality of Root Canal Fillings and Coronal Restorations. *Journal of Endodontics,* 35(6), pp.810-13.

Vertucci, F.J., 2005. Root Canal Morphology and its Relationship to Endodontic Procedures. *Endodontic Topics*, 10(1), pp.3-29.

Walia, H., Streiff, J. and Gerstein, H., 1988. Use of a Hemostatic Agent in the Repair of Procedural Errors. *Journal of Endodontics*, 14(9), pp.465-68.

Wesselink, P.R., 1994. Consensus Report of the European Society of Endodontology on Quality Guidelines for Endodontic Treatment. *International Endodontic Journal*, 27(3), pp.115-24.

Wu, M.-K., Wesselink, P.R. and Walton, R.E., 2000a. Apical Terminus Location of Root Canal Treatment Procedures. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 89(1), pp.99-103.

Wu, M.-K., Fan, B. and Wesselink, P.R., 2000b. Leakage along Apical Root Fillings in Curved Root Canals. Part I: Effects of Apical Transportation on Seal of Root fillings. *Journal of Endodontics*, 26(4), pp.210-16.

Yusuf, H., 1982. The Significance of the Presence of Foreign Material Periapically as a Cause of Failure of Root Treatment. *Oral Surgery, Oral Medicine, Oral Pathology*, 54(5), pp.566-74.

Zhong, Y., Chasen, J., Yamanaka, R., Garcia, R., Kaye, E.K., Kaufman, J.S., Cai, J., Wilcosky, T., Trope, M. and Caplan, D.J., 2008. Extension and Density of Root Fillings and Postoperative Apical Radiolucencies in the Veterans Affairs Dental Longitudinal Study. *Journal of Endodontics*, 34(7), pp.798-803.

Zogheib, C., Naaman, A., Medioni, E. and Arbab-Chirani, R., 2012. Influence of Apical Taper on the Quality of Thermoplasticized Root Fillings Assessed by Micro-Computed Tomography. *Clinical Oral Investigations*, 16(5), pp.1493-98.

Appendix A: Hospital Risk Assessment Committee Permission

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Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

29 June 2016
Person No: 1096693
PAG

Mr AM Ehbesh
308 san fransisco
10 park lane
park town
2193
South Africa

Dear Mr Ehbesh

Master of Science in Dentistry: Approval of Title

We have pleasure in advising that your proposal entitled *Quality of root canal treatment performed by undergraduate students at the Wits Oral Health Centre* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

Appendix B: Ethical Clearance

R14/49 Dr A.Alaali Mohamed Ehbesh

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160409

NAME: (Principal Investigator)	Dr A.Alaali Mohamed Ehbesh
DEPARTMENT:	School of Oral Health Wits Oral Health Centre University of the Witwatersrand
PROJECT TITLE:	Quality of Root Canal Treatment Performed by Undergraduate Students at the Wits Oral Health Centre
DATE CONSIDERED:	06/05/2016
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr I Munshi and Dr E Patel
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	01/06/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/2nd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated,from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review in April and will therefore be due in the month of April each year.

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix C1: Codes of Data Capture Sheets

Criteria	Code	Code meaning
Case number	**CN**	
Year of Treatment	**YT1**	if the case treated in 2013
	YT2	if the case treated in 2014
	YT3	if the case treated in 2015
Study year	**SY1**	the case treated by 3rd undergraduate students
	SY2	The case treated by 4th undergraduate students
	SY3	The case treated by 5th undergraduate students
Sex	**F**	for Female
	M	for Male
Tooth / Teeth type	**CEN**	Central incisor
	LAI	Lateral incisor
	CAN	Canine
	1PM	1st Premolar
	2PM	2nd Premolar
	1ML	1st Molar
	2ML	2nd Molar
Tooth location	**ANT**	if the tooth is anterior
	POS	if the tooth is posterior
	MAX	if the tooth is maxillary
	MAN	if the tooth is mandibular
Length of root filling	**LF1**	if the length of root filling is 0-2mm from root apex
	LF2	if the length of root filling is beyond radiographic apex
	LF3	if the length of root filling is >2mm from root apex
Density of root filling	**DF1**	No voids beteween the root canal walls and root canal filling
	DF2	if there is voids beteween the root canal walls and root canal filling
Taper of root filling	**TF1**	if the root canal system is suffient taper
	TF2	if the root canal system is insuffient taper
Ledge formation	**LD1**	if there is no ledge formation
	LD2	if there is ledge formation
Zipping	**ZP1**	if there is no zipping
	ZP2	if there is zipping
Canal transportation	**CTP1**	if there is no canal transportation
	CTP2	if there is canal transportation
Missed / untreated canal	**MUC1**	if there is no missed or untreated canal
	MUC2	if there is missed or untreated canal
Fractured instruments	**FRI1**	if there is no fractured instruments
	FRI2	if there is fractured instruments
Perforations	**PER1**	if there is no perforation
	PER2	if there is perforation

Appendix C2: Data Capture Sheet 1

Data Capture Sheet 1																		Paper Number ……
CN	**YT1**	**YT2**	**YT3**	**SY1**	**SY2**	**SY3**	**M**	**F**	**CEN**	**LAI**	**CAN**	**1PM**	**2PM**	**1ML**	**2ML**	**ANT**	**POS**	**MAX**	**MAN**

Appendix C3: Data Capture Sheet 2

Data Capture Sheet 2														Paper Number ……					
CN	**LF1**	**LF2**	**LF3**	**DF1**	**DF2**	**TF1**	**TF2**	**LD1**	**LD2**	**ZP1**	**ZP2**	**CTP1**	**CTP2**	**MUC1**	**MUC2**	**FRI1**	**FRI2**	**PER1**	**PER2**

Appendix D Plagiarism Report

1096693:Quality_of_root_canal_treatment_performed_by_undergraduate_students_at_the_wits_oral_health_centre_2017.docx

by A.alaali Ehbesh

Submission date: 19-Dec-2017 10:28AM (UTC+0200)
Submission ID: 897967569
File name: undergraduate_students_at_the_wits_oral_health_centre_2017.docx (1.21M)
Word count: 18128
Character count: 105668

1096693:Quality_of_root_canal_treatment_performed_by_un..

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