Scientific Research Report

Treatment Outcome and Root Canal Preparation Techniques: 5-Year Follow-Up

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ARTICLE INFO

Article history:
Received 21 February 2022
Received in revised form 11 August 2022
Accepted 16 August 2022
Available online 22 September 2022

Key words:
Manual instrumentation
Root canal treatment
Rotary instrumentation
Tooth survival
Treatment outcome

ABSTRACT

Objective: This study aims at comparing treatment outcome and tooth survival of root canal–filled teeth following manual vs rotary instrumentation techniques over a 5-year period.

Methods: This was a single-centre study conducted as a follow-up to a short-term parallel-arm randomised controlled noninferiority trial in which root canal treatment was performed on teeth using either rotary or manual instrumentation. Patients were monitored at post 6-month, 1-year, 4-year, and 5-year review periods by blinded evaluators. Treatment outcome was categorised as favourable, uncertain, and unfavourable (employing European Society of Endodontology categorisation based on strict clinical and radiographic criteria), and 5-year tooth survival was determined by assessing whether tooth was in situ in the oral cavity or extracted. The Kaplan–Meier method and log rank test evaluated tooth survival. P value <.05 was considered statistically significant.

Results: Ninety of 120 treated teeth were assessed in 37 men and 40 women with mean age of 30.6 ± 10.99 years. Treatment outcome was significantly more favourable in the rotary group compared to the manual group at post 6-month (P = .021) and 1-year (P = .043) review periods. The differences in favourable outcome (P = .498) and tooth survival (P = .296) between the 2 groups were, however, not significant at the 5-year review period.

Conclusions: The rotary instrumentation technique was shown to be more effective in resolving clinical symptoms and promoting periapical healing after the post 6-month and 1-year review compared to the manual instrumentation technique; however, both groups had similar favourable outcomes and survival rates after an extended 5-year review period.

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Introduction

The aim of root canal treatment (RCT) is to eliminate inflamed and infected pulpal tissue, thus providing an environment that promotes healing, and arrests the progression of periapical pathology. Periapical healing encourages the long-term retention of functional, endodontically treated teeth.1–4

Outcomes of RCT are of significant interest in endodontics. Dental clinicians must possess the right skill and judgement during endodontic outcome assessment to determine whether RCT is successful. Endodontic success is determined after a root-filled tooth has been subjected to different functional activities over time. Evaluating such success requires the adoption of specific criteria. Notably, overlapping criteria have been employed in different studies.5–8 The inconsistency in endodontic success classification, varying from consideration of a symptomless and clinically functional tooth to strict radiographic healing, has led to misdiagnosis and unnecessary re-treatment. The differences in success rates reported in the literature have been attributed to varying durations of postoperative review, criteria used to categorise outcome, radiographic evaluation, and clinical experience.2

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https://doi.org/10.1016/j.identj.2022.08.008
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The European Society of Endodontology (ESE) has set out guidelines using both clinical and radiographic parameters to categorise treatment outcomes as “favourable,” “uncertain,” and “unfavourable” after a minimum of 4 years’ monitoring. It has been recommended that endodontic success should be evaluated based on the assessment of the dentist (objective) and the patient (subjective). The dentist’s assessment involves both clinical and radiographic review. The patient’s assessment centres on tooth survival, which focuses on the tooth being asymptomatic and functional in the dentition, which—though it is an insufficient biological goal of treatment—is satisfactory for the patient. Tooth survival as a measure of endodontic success refers to the tooth being present in the oral cavity 12 months or more after initial RCT, whereas a failure is recorded if the tooth is extracted at any time following treatment. The long-term survival following RCT is of high priority and focus in modern tooth conservation.

Few retrospective studies have evaluated the impact of recent advancements in canal preparation techniques on endodontic success. Therefore, to ascertain endodontic success in relation to preparation techniques, there is the need for extended patient follow-up for continued assessment of root-filled teeth for a minimum of 4 years according to ESE recommendations. This study was thus conducted to determine endodontic success at 5 years post-RCT; short-term results were previously published. Two measures—treatment outcome as categorised by the ESE and tooth survival over a 5-year review period—were employed in the evaluation sequel to use of either manual or rotary instrumentation techniques during RCT.

**Material and methods**

This present study is a follow-up to a previous randomised controlled noninferiority trial (2 parallel-group design) conducted at the Restorative Dental Clinics, Lagos University Teaching Hospital, Nigeria, after obtaining institutional ethical approval with assigned numbers for the trial and follow-up study (ADM/DCST/HREC/1684 and ADM/DCST/HREC/APR/3096, respectively, accessed at Pan African Clinical Registry with registration number PACTR201804003323280). This follow-up study follows Consolidated Standards of Reporting Trials (CONSORT) guidelines. The CONSORT flow diagram and checklist are provided as supplementary materials.

**Eligibility criteria of prior clinical trial**

Participants recruited were consecutive adult patients who presented between April 2014 and March 2015, met the inclusion criteria for single-visit RCT, and signed a written consent. Inclusion criteria were anterior, premolar, or first molar teeth (maxillary or mandibular) with no pain or mild to moderate preoperative pain; diagnosed with irreversible pulpitis, nonvital with no periapical involvement, uncomplicated coronal fracture, or apical periodontitis not exceeding 2 × 2 mm periapical radiolucency. Teeth with severe pain; weeping canals, or periapical abscess; periodontally compromised teeth; teeth with calcified canals, external and internal root resorption; excessively curved roots; unrestorable teeth; cases of RCT retreatment; as well as uncooperative and medically compromised patients (ASA Physical Status Classification III and beyond) were excluded from the study.

**Sample size determination and randomisation**

This study was a follow-up of a previous study and followed on the calculated sample size of 28 teeth per group using the formula for comparing 2 independent proportions by Varkevisser et al based on a previous study by Wei et al. Alpha-error was set at 0.05 and power was set at 80%. Considering that single- and multi-rooted teeth were included and to compensate for attrition, the required sample size per group was increased to 60.

The randomisation process was performed by 2 endodontists in training. After each participant met the inclusion criteria, the tooth was randomly assigned into either of the 2 groups (by picking out of 120 concealed envelopes, each containing a tagged slip). Patients who required RCT for multiple teeth but not more than 2 teeth, one each on the left and right sides, had them randomly assigned to ensure objectivity and to maintain an equal sample size.

**Intervention and postoperative assessment of the prior clinical trial**

Comprehensive history and examination, electric pulp tests, tooth percussion, and radiographic investigations were performed to arrive at a diagnosis. Canal preparation was performed after access cavity preparation and working length determination using either manual step-back technique with stainless steel K-files (size 06-80; Mani, Inc) or ProTaper Universal rotary files (Shaping files Sx, S1, and S2 and finishing files F1, F2, and/or F3; Dentsply Maillefer Ballaigues) by continuous rotary instrumentation in a crown-down manner using an X-Smart Plus endomotor (Dentsply Maillefer). The same amount of irrigating solution, 2.5% sodium hypochlorite (Reckitt Benckiser) at 30 mL per canal, was used in each group, and RC Prep (Stone Pharmaceuticals) was used for canal lubrication. A 30-G needle with a rubber stopper length-guide was advanced into the canal as far as 2 mm short of the working length and was moved up and down during irrigation. Approximately 3 mL of 17% EDTA (Prevest DenPro Ltd.) was used post–crown preparation to remove the smear layer. A post-obturation radiograph was taken immediately and obturation repeated in the event of apical extrusion of gutta percha (GP), when GP did not fill the entire canal length, or in cases of existing voids within the filling. All treatments were performed by a single operator to eliminate interoperator bias, and all procedures were performed in accordance with ethical standards set forth in the Declaration of Helsinki (as revised in Brazil 2013).

**Treatment outcome assessment for the present follow-up study**

Assessments were carried out by 2 independent evaluators (endodontists) who were blinded to the groupings. Precalibration of evaluators yielded good intra- and interexaminer
agreements, as shown by Cohen’s kappa values, which ranged from 0.88 to 0.94 for all measured criteria.

Treatment outcome was based on the guidelines set by ESE and tooth survival.2 Pain rating was obtained after employing the Universal Pain Assessment Tool (Wong-Baker FACES Pain Rating Scale).13 Tooth mobility was elicited and graded according to Miller’s index.20 For radiographic assessment, periapical radiograph was used as recommended for routine endodontic evaluation.24 A modified periapical index (PAI) scoring system was used to assess for periapical lesions.2 Teeth were classified as having a periapical lesion when the PAI score was 3 or greater.2 The size of any radiolucency was determined by measuring the largest horizontal and vertical width with a ruler in millimetres.22 Preoperative radiographic findings were compared with radiographic findings from the post 6-month, 1-year, 4-year, and 5-year follow-up periods to determine whether radiolucency was a new postoperative lesion or a preexisting lesion that had remained the same size, decreased, or increased. Multi-rooted teeth were assigned the highest PAI score of their roots.23 Where there was contradiction between evaluators, the radiograph was discussed until a consensus was reached or the higher score was adopted. Teeth with absence of any sign or symptoms regardless of PAI score were considered functional and thus regarded as a success.2,6

Tooth survival was referred to as evidence of a tooth being present 12 months or more after RCT. A tooth was classified a failure if extracted at any time after treatment.7 Treatment outcome was classified as “favourable,” according to the ESE, when the tooth was asymptomatic and had radiologic evidence of a normal periodontal ligament space.5 An “uncertain” outcome was defined as presence of radiographic evidence revealing a periapical lesion that had remained the same size, decreased, or increased. Multi-rooted teeth were assigned the highest PAI score of their roots.23 Where there was contradiction between evaluators, the radiograph was discussed until a consensus was reached or the higher score was adopted. Teeth with absence of any sign or symptoms regardless of PAI score were considered functional and thus regarded as a success.2,6

Statistical analyses
Statistical analyses were performed using IBM SPSS, version 23.0 (IBM Corporation). Descriptive analysis was carried out using frequency and proportion for categorical variables and mean and standard deviation for numeric variables. Data were statistically analysed using Pearson chi-square, Fisher exact test, and 2-sided linear-by-linear association, where applicable. Pearson correlation coefficient was employed to determine the level of correlation between preparation technique and postoperative clinical and radiographic findings, and treatment outcome. In terms of correlation coefficient, $r \leq 0.2$ was considered as weak, $>0.2$–$0.5$ as moderate, $>0.5$–$0.7$ as strong, and $>0.7$ as very strong. Kaplan–Meier survival analysis and log-rank test were performed to visualise and compare the tooth survival probabilities based on instrumentation technique. All statistical tests were interpreted at a 5% significance level.

Results

Characteristics of participants/treated teeth
Results presented in this study represent the analysis of 90 root-treated teeth of 77 patients who were followed up from the previously reported trial.14 Eighteen patients with 30 teeth declined to continue participation after the 6-month review. Hence, a total dropout of 30 teeth (13 in the rotary and manual groups, respectively) was recorded after the 6-month review and no other dropout occurred during the continued 5-year review. Reasons for the dropouts in both groups were related to geographic relocation of some participants, whilst others declined to continue participation. Preoperative clinical and radiographic parameters of the 2 groups were not significantly different, as reported in the primary clinical trial.14 The sample comprised 37 men with 43 treated teeth and 40 women with 47 treated teeth; ages were between 18 and 62 years, with a mean age of 30.6 ± 10.99 years. The recruitment period was from April 2014 to March 2015, and the last recruit completed the 5-year follow-up in March 2020.

The post 6-month review was done at the seventh month after treatment for all teeth included in the follow-up study. The results of clinical, radiographic, and treatment outcomes, including tooth survival, are presented.

Clinical outcome
Fifty-eight (64.4%) of 90 teeth had mild or moderate pain prior to treatment. There was no pain incidence after the 6-month review; however, pain was recorded in one tooth in each group by the 4-year review period. Eleven teeth presented with grade I mobility pretreatment, and after treatment, grade I mobility was observed in a single tooth (manual group) at all review periods except at final review. Fifty percent of 90 teeth presented with preoperative tenderness to percussion, which totally resolved by the 6-month review. There was recurrence in 2 teeth and 1 tooth at the 4-year review and the final review, respectively (Table 1). No other symptoms were recorded.

Radiographic outcome
Fourteen (32.6%) and 10 (21.3%) teeth in the manual group and the rotary group, respectively, had preoperative periapical radiolucency. A significantly greater number of teeth in the manual group compared to the rotary group still had radiolucency at the post 6-month ($P = .038$) and 1-year ($P = .033$) follow-up. Moderate and significant correlations were seen between preparation technique and radiolucency measured at post 6-month ($r = 0.219$; $P = .038$) and 1-year ($r = 0.226$; $P = .032$) reviews. Radiolucency gradually resolved over the 5-year period except for 3 teeth in total that persistently presented with same-sized radiolucency.

Treatment outcome
Complicated coronal fracture and irreversible pulpitis recorded the most favourable outcomes throughout the different review periods ($P < .05$; Table 2). Overall, a more favourable outcome
Table 1 – Relationship amongst pain, mobility, TTP, PR, and root canal preparation technique.

| Characteristic of pain | Preoperative pain (%) | Post 6-month (7-month review) postoperative pain (%) | 1-year postoperative pain (%) | 4-year postoperative pain (%) | 5-year postoperative pain (%) |
|------------------------|-----------------------|----------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                        | Rotary Manual         | Rotary Manual                                      | Rotary Manual                 | Rotary Manual                 | Rotary Manual                 |
| No pain                | 14 (29.8)             | 0 (0)                                              | 47 (100)                      | 46 (97.9)                     | 47 (100)                      |
| Mild pain              | 22 (46.8)             | 0 (0)                                              | 0 (0)                         | 1 (2.1)                       | 0 (0)                         |
| Moderate pain          | 11 (23.4)             | 0 (0)                                              | 0 (0)                         | 0 (0)                         | 0 (0)                         |
| Total                  | 47 (100)              | 47 (100)                                           | 47 (100)                      | 47 (100)                      | 47 (100)                      |
| P value                | .479                  | N/A                                                | .730                          | N/A                           | N/A                           |

| Characteristic of mobility | Preoperative mobility (%) | Post 6-month postoperative mobility (%) | 1-year postoperative mobility (%) | 4-year postoperative mobility (%) | 5-year postoperative mobility (%) |
|-----------------------------|---------------------------|----------------------------------------|----------------------------------|----------------------------------|----------------------------------|
|                            | Rotary Manual             | Rotary Manual                          | Rotary Manual                   | Rotary Manual                   | Rotary Manual                   |
| No mobility                 | 45 (95.7)                 | 0 (0)                                  | 47 (100)                        | 47 (100)                        | 47 (100)                        |
| Grade 1                     | 2 (4.3)                   | 0 (0)                                  | 1 (2.3)                         | 0 (0)                           | 0 (0)                           |
| Total                       | 47 (100)                  | 47 (100)                               | 47 (100)                        | 47 (100)                        | 47 (100)                        |
| P value                     | .005*                     | .478                                   | .478                            | .478                            | N/A                             |

| Characteristic of TTP | Preoperative TTP (%) | Post 6-month postoperative TTP (%) | 1-year postoperative TTP (%) | 4-year postoperative TTP (%) | 5-year postoperative TTP (%) |
|-----------------------|----------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                       | Rotary Manual        | Rotary Manual                      | Rotary Manual                 | Rotary Manual                 | Rotary Manual                 |
| Absent                | 24 (51.1)            | 47 (100)                           | 47 (100)                      | 46 (97.9)                     | 47 (100)                      |
| Present               | 23 (48.9)            | 0 (0)                              | 0 (0)                         | 1 (2.1)                       | 0 (0)                         |
| Total                 | 47 (100)             | 47 (100)                           | 47 (100)                      | 47 (100)                      | 47 (100)                      |
| P value               | .500                 | N/A                                | .730                          | .472                          | N/A                           |

| Characteristic of PR | Preoperative PR (%) | Post 6-month postoperative PR (%) | 1-year postoperative PR (%) | 4-year postoperative PR (%) | 5-year postoperative PR (%) |
|----------------------|---------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
|                       | Rotary Manual       | Rotary Manual                     | Rotary Manual                | Rotary Manual                | Rotary Manual                |
| Absent               | 37 (78.7)           | 46 (97.9)                         | 46 (97.9)                    | 46 (97.9)                    | 46 (97.9)                    |
| Same size            | 0 (0)               | 0 (0)                             | 1 (2.1)                      | 1 (2.1)                      | 1 (2.1)                      |
| Increased            | 10 (21.3)           | 0 (0)                             | 0 (0)                        | 0 (0)                        | 0 (0)                        |
| Decreased            | 0 (0)               | 0 (0)                             | 1 (2.1)                      | 0 (0)                        | 0 (0)                        |
| Total                | 47 (100)            | 47 (100)                          | 47 (100)                     | 47 (100)                     | 47 (100)                     |
| P value              | .149                | .038*                             | .033*                        | .216                         | .457                         |

No teeth presented with severe pain; no grade 2 or 3 mobility. One tooth in the manual group was extracted due to vertical root fracture before the final review.

* Statistical significance.
N/A represents no statistics for variables with all entries in only one group.
TTP, tooth tender to percussion; PR, periapical radiolucency.
### Table 2 – Relationship amongst gender, diagnosis, tooth location, tooth type, and treatment outcome in all treated teeth.

| Gender       | Post 6-month (7-month review) treatment outcome (%) | 1-year treatment outcome (%) | 4-year treatment outcome (%) | 5-year treatment outcome (%) |
|--------------|----------------------------------------------------|-----------------------------|------------------------------|------------------------------|
|              | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable |
| Female       | 44 (53.7)   | 3 (37.5)  | 0 (0)        | 44 (53.0)   | 3 (42.9)  | 0 (0)        | 46 (54.1)   | 1 (25.0)  | 0 (0)        | 46 (53.5)   | 1 (33.3)  |
| Male         | 38 (46.3)   | 5 (62.5)  | 0 (0)        | 39 (47.0)   | 4 (57.1)  | 0 (0)        | 39 (45.9)   | 3 (75.0)  | 1 (100)      | 40 (46.5)   | 2 (66.7)  |
| Total        | 82 (100)    | 8 (100)   | 0 (0)        | 83 (100)    | 7 (100)   | 0 (0)        | 85 (100)    | 4 (100)   | 1 (100)      | 86 (100)    | 3 (100)   |
| P value      | .308        | .450      | .301         | .790         |           |              |               |           |              |               |           |

| Diagnosis    | Post 6-month treatment outcome (%) | 1-year treatment outcome (%) | 4-year treatment outcome (%) | 5-year treatment outcome (%) |
|--------------|-----------------------------------|-----------------------------|------------------------------|------------------------------|
|              | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable |
| Apical periodontitis | 45 (54.9) | 7 (87.5)  | 0 (0)        | 46 (55.4)   | 6 (85.7)  | 0 (0)        | 48 (56.5)   | 3 (75.0)  | 1 (100)      | 49 (57.0)   | 2 (66.7)  |
| Uncomplicated coronal fracture | 6 (7.3) | 0 (0)     | 0 (0)        | 6 (7.1)     | 0 (0)     | 0 (0)        | 6 (7.0)     | 0 (0)     | 0 (0)        | 6 (7.0)     | 0 (0)     |
| Irreversible pulpitis         | 21 (25.6) | 0 (0)     | 0 (0)        | 21 (25.3)   | 0 (0)     | 0 (0)        | 21 (24.7)   | 0 (0)     | 0 (0)        | 21 (24.4)   | 0 (0)     |
| Pulp necrosis                | 10 (12.2) | 1 (12.5)  | 0 (0)        | 10 (12.0)   | 1 (14.3)  | 0 (0)        | 10 (11.8)   | 1 (25.0)  | 0 (0)        | 10 (11.6)   | 1 (33.3)  |
| Total                       | 82 (100)  | 8 (100)   | 0 (0)        | 83 (100)    | 7 (100)   | 0 (0)        | 85 (100)    | 4 (100)   | 1 (100)      | 86 (100)    | 3 (100)   |
| P value                     | .000*      | .001*     | .018*        | .718         |           |              |               |           |              |               |           |

| Tooth location   | Post 6-month treatment outcome (%) | 1-year treatment outcome (%) | 4-year treatment outcome (%) | 5-year treatment outcome (%) |
|------------------|-----------------------------------|-----------------------------|------------------------------|------------------------------|
|                  | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable |
| Maxillary        | 56 (68.3)   | 4 (50.0)  | 0 (0)        | 56 (67.5)   | 4 (57.1)  | 0 (0)        | 56 (65.9)   | 3 (75.0)  | 1 (100)      | 57 (66.3)   | 2 (66.7)  |
| Mandibular       | 26 (31.7)   | 4 (50.0)  | 0 (0)        | 27 (32.5)   | 3 (42.9)  | 0 (0)        | 29 (34.1)   | 1 (25.0)  | 0 (0)        | 29 (33.7)   | 1 (33.3)  |
| Total            | 82 (100)    | 8 (100)   | 0 (0)        | 83 (100)    | 7 (100)   | 0 (0)        | 85 (100)    | 4 (100)   | 1 (100)      | 86 (100)    | 3 (100)   |
| P value          | .251        | .429      | .723         | 1.000        |           |              |               |           |              |               |           |

| Tooth type       | Post 6-month treatment outcome (%) | 1-year treatment outcome (%) | 4-year treatment outcome (%) | 5-year treatment outcome (%) |
|------------------|-----------------------------------|-----------------------------|------------------------------|------------------------------|
|                  | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable | Favourable  | Uncertain | Unfavourable |
| Anterior         | 36 (43.9)   | 6 (75.0)  | 0 (0)        | 37 (44.6)   | 5 (71.4)  | 0 (0)        | 39 (45.9)   | 2 (50.0)  | 1 (100)      | 39 (45.3)   | 2 (66.7)  |
| Posterior        | 46 (56.1)   | 2 (25.0)  | 0 (0)        | 46 (55.4)   | 2 (28.6)  | 0 (0)        | 46 (54.1)   | 2 (50.0)  | 0 (0)        | 47 (54.7)   | 1 (33.3)  |
| Total            | 82 (100)    | 8 (100)   | 0 (0)        | 83 (100)    | 7 (100)   | 0 (0)        | 85 (100)    | 4 (100)   | 1 (100)      | 86 (100)    | 3 (100)   |
| P value          | .449        | .568      | .892         | .767         |           |              |               |           |              |               |           |

One tooth was extracted due to vertical root fracture before the final review.
* Statistical significance.
N/A represents no statistics for variables with all entries in only one group.
was noted when rotary instrumentation was used compared to manual instrumentation. This difference was statistically significant at the post 6-month and 1-year reviews ($P = .021$ and $.043$, respectively; Table 3). Moderate and significant correlations existed between preparation technique and treatment outcome at post 6-month ($r = 0.248; P = .018$) and 1-year ($r = 0.221; P = .037$) reviews. Teeth with a favourable outcome were similar in both groups by the final review (Table 3).

### Survival analysis

The survival probability of the rotary group (100%) was greater than that of the manual group (97.7%) at the 5-year review; however, this finding was not statistically significant ($P = .296$). One tooth in the manual group was extracted due to a vertical root fracture (Figure 1).

### Discussion

The ESE recommends that endodontic success or failure may be fully ascertained only after 4 years posttreatment. This supports the report of Molven et al that emphasised that even though RCT might appear successful shortly after treatment, a minimum of a 4-year review is of utmost importance to be conclusive. Therefore, this study adopted a long-term evaluation to determine endodontic success. Longevity is a key consideration in RCT, which is addressed by tooth survival. Tooth survival is a patient-centred measure of endodontic success, whereas treatment outcome—which considers periapical healing—is a clinician’s more objective view of success.

The rotary group had a significantly ($P < .05$) more favourable outcome compared to the manual group at the post 6-month and 1-year review periods. However, there was no significant difference ($P > .05$) in long-term outcomes in the 2 groups. Rotary and manual instrumentation both resulted in high and comparable favourable outcome and 5-year survival. This supports the minimum of 4-year recommendation to ascertain endodontic success. A retrospective study by Cheung and Liu reported similar findings of a significantly higher favourable outcome over a short-term review following rotary as compared to manual RCT. The higher outcome noted in the rotary group may be attributed to evidence of a lesser amount of debris extrusion periapically with subsequent faster periapical healing. Apical debris extrusion, which occurs more in hand instrumentation, may in turn lead to an inflow of blood and exudate which encourages further multiplication of intracanal bacteria, further worsening the chronic periapical lesion. The similar 5-year survival rate noted in the 2 groups in this study is consistent with that of a retrospective study by Fleming et al, who employed tooth survival as a success criterion in 2 technique groups after a long-term follow-up.

Complete pain resolution at the end of the preceding short-term clinical trial coincided with nil pain at the commencement of this study. However, 2 participants, one in each group, experienced mild pain at the 4-year review that totally resolved by the final review. The mild pain may be due to periodontal causes or occlusal trauma, which the patient could not recollect during the review and which are conditions unrelated to prior pulpal or periapical pathology.

### Table 3 – Relationship between treatment outcome and root canal preparation technique at different review periods.

| Treatment outcome | Post 6-month (7-month) treatment outcome (%) | 1-year treatment outcome (%) | 4-year treatment outcome (%) | 5-year treatment outcome (%) |
|-------------------|---------------------------------------------|-----------------------------|----------------------------|-----------------------------|
| Rotary            | 46 (97.9)                                  | 46 (97.9)                   | 46 (97.7)                  | 46 (97.9)                   |
| Manual            | 36 (83.7)                                  | 37 (86.0)                   | 27 (64.3)                  | 30 (72.7)                   |
| Favourable        | 45 (99.2)                                  | 45 (99.2)                   | 44 (96.5)                  | 45 (99.2)                   |
| Uncertain         | 0 (0)                                      | 0 (0)                       | 2 (4.3)                    | 0 (0)                       |
| Unfavourable      | 0 (0)                                      | 0 (0)                       | 1 (2.3)                    | 1 (2.3)                     |
| Total             | 46 (100)                                   | 46 (100)                    | 47 (100)                   | 46 (100)                    |
| $P$ value         | .021                                       | .043                        | .572                       | .498                        |

One tooth in the manual group was extracted due to vertical root fracture before the final review.
Tooth tenderness totally resolved in both groups by the post 6-month review. However, tenderness was noted in 2 teeth, one in each group, when assessed at the 4-year review and in 2 teeth only in the manual group at the final review. These patients were noted to exhibit some plaque retention around the restoration margins and periodontal pockets measuring 4 to 5 mm in depth. It is therefore likely that tooth tenderness experienced by these patients was due to periodontal causes.

The significantly lower number of teeth with periapical radiolucency in the rotary group compared to the manual group at 6-month and 1-year review supports the report of better periapical healing following rotary instrumentation due to reduced incidence of pulpal debris extrusion. The increased debris extrusion containing micro-organisms associated with hand instrumentation would further aggravate the inflammation and slow the periapical healing rate. Because more than 40% of patients in each group presented with apical periodontitis prior to RCT, the significant difference in periapical healing in both groups during the intermediate reviews buttressed this explanation. Cheung and Liu also reported significantly better periapical healing following rotary instrumentation after short-term monitoring. Similar healing rates were, however, observed in both groups in our study after long-term monitoring.

The high rate of tooth retention and favourable outcomes following RCT performed by a skilled operator in this study support the view that endodontic success is highly dependent on the operator’s expertise. This effect was demonstrated by Cheung and Liu, wherein RCT performed by postgraduate students had significantly higher success rates than those performed by undergraduates.

Limitations of this study are similar to most extended follow-up studies, and not all participants included in the previous clinical trial consented to participate in the follow-up study. Withdrawals from clinical trials normally occur, but the 25% dropout rate in this study (following the short-term study) may have caused the available data to be subject to potential bias and reduced the sensitivity of analysis. A larger sample size of the clinical trial, if available for this present study, would have given more representative results. However, it is worth noting that despite the dropouts, the total number of teeth reviewed in the present study was still greater than the minimum sample size, since we considered the possibility of attrition. Further extended studies are recommended for the review of the remaining patients who continued the present follow-up study.

Ideally, whenever possible, the basic unit of sample population in similar clinical studies is the patient rather than the tooth. It becomes difficult to adhere to this ideal in cases such as this study, in which some participants had a left and a right tooth that met the inclusion criteria and both teeth were included as their response to treatment in general reflected the overall experimental conditions. Although this study has endeavoured to take the patient into account, it did not accurately reflect the clinical experience of the study population since the patient selection was not exclusively on a per-tooth basis.

The high 5-year success rate in both groups differs from the significantly better outcome observed in the rotary group during the short-term (post 6-month and 1-year) assessment period. Although this can be explained by the usual continuous resolution of postoperative pain, swelling, and periapical pathology that follows a successful RCT, a paucity of comparable data makes it difficult to draw a definitive conclusion. We therefore recommend that more long-term follow-up studies be performed to determine the difference in treatment outcomes following RCT performed using either manual or rotary instrumentation technique.
Conclusions

The rotary instrumentation technique was shown to be more efficacious in promoting postendodontic healing at the short-term review periods compared to the manual instrumentation technique after single-visit RCT; however, both groups had similar favourable outcomes and survival rates after an extended 5-year monitoring period.

Author contributions

John O. Makanjuola: conceptualisation, methodology, investigation, project administration, resources, formal analysis, visualisation, writing—original draft, and writing—review and editing.

Olabisi H. Oderinu: conceptualisation, methodology, supervision, validation, and writing—review and editing.

Donna C. Umesi: conceptualisation, methodology, supervision, validation, and writing—review and editing.

Conflict of interest

None disclosed.

Acknowledgements

The authors express their sincere gratitude to Drs Idon, Sotunde, Egbunah, Aladenika, and Adeoye for their contributions during the inputting of data, statistical analysis, and preparation of the manuscript.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.identj.2022.08.008.