Post-Operative Evaluation of Endodontic Microsurgeries Done Using a Piezoelectric Ultrasonic Technique (An in vivo Study)

Thesis Submitted in partial fulfillment of the requirements for Doctor Degree in Endodontics

By

Mahmoud Yehia Mohamed Abouel Naga

B.D.S 2009, Faculty of Dental Medicine, Al Azhar University

M.S.C 2018 in Endodontics, Faculty of Dental Medicine Al Azhar University

Assistant Lecturer, Department of Endodontics,

Faculty of Dental Medicine, AL Azhar University (Boys-Cairo)

Supervisors

Prof. Dr. Ashraf Samir Refai

Professor of Endodontics, Faculty of Dental Medicine

Al Azhar University (Cairo-Boys),

Prof. Dr. Moataz Bellah Ahmed AlKhawas

Professor of Endodontics, Head of Endodontic Department,

Faculty of Dental Medicine , Al Azhar University, (Cairo-Boys)

Department of Endodontics,

Faculty of Dental Medicine , Al Azhar University, (Cairo-Boys)

1445 H – 2023 G

تقييم ما بعد الجراحات الدقيقه اللبية تمت باستخدام تقنية الموجات فوق الصوتية الكهروإجهادية (دراسة داخل الجسم الحي)

بحث مقدم كجزء من مقومات الحصول على درجة الدكتوراه فى علاج الجذور

مقدم من

الطبيب/ محمود يحيي محمد ابوالنجا

بكالوريوس طب وجراحة الفم والأسنان - 2009

كلية طب الأسنان - جامعة الأزهر – بنين - القاهرة

ماجستير علاج الجذور2018 - كلية طب الأسنان - جامعة الأزهر – بنين - القاهره

مدرس مساعد - قسم علاج الجذور- كلية طب الأسنان - جامعة الأزهر – بنين - القاهره

المشرفون

أ.د / أشرف سمير رفاعي

أستاذ علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

أ.د / معتز بالله احمد الخواص

أستاذ علاج الجذور- رئيس قسم علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

قسم علاج الجذور

- كلية طب الأسنان - جامعة الأزهر – بنين - القاهره

م 2023 – هـ 1445

لجنة الاشراف

أ.د / أشرف سمير رفاعي

أستاذ علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

أ.د / معتز بالله احمد الخواص

أستاذ علاج الجذور- رئيس قسم علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

لجنة الحكم والمناقشة

أ.د / عمرو محمد احمد عبداللة

أستاذ علاج الجذور

كلية طب الأسنان – جامعة الاسكندرية

أ.د / طاهر مدحت إسلام

أستاذ علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

أ.د / أشرف سمير رفاعي

أستاذ علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

أ.د / معتز بالله احمد الخواص

أستاذ علاج الجذور- رئيس قسم علاج الجذور

كلية طب الأسنان - جامعة الأزهر– بنين - القاهرة

Discussion Committee

Prof. Dr. Amr Mohammed Ahmed Abdallah

Professor of Endodontics, Faculty of Dental Medicine

Alexandria University.

Prof. Dr. Taher Medhat Islam

Professor of Endodontics, Faculty of Dental Medicine

Al Azhar University (Cairo-Boys),

Prof. Dr. Ashraf Samir Refai

Professor of Endodontics, Faculty of Dental Medicine

Al Azhar University (Cairo-Boys),

Prof. Dr. Moataz Bellah Ahmed AlKhawas

Professor of Endodontics, Head of Endodontic Department,

Faculty of Dental Medicine , Al Azhar University, (Cairo-Boys).

Supervisory Committee

Prof. Dr. Ashraf Samir Refai

Professor of Endodontics, Faculty of Dental Medicine

Al Azhar University (Cairo-Boys),

Prof. Dr. Moataz Bellah Ahmed AlKhawas

Professor of Endodontics, Head of Endodontic Department,

Faculty of Dental Medicine , Al Azhar University, (Cairo-Boys).

1. Introduction

Endodontic treatment aims to eliminate bacterial biofilms that colonize complex root canal anatomy. Achievement of this goal is performed by mechanically shaping, cleaning and obturation of the root canals to create an adequate environment for periradicular healing [(1)]. Even with the advancement in endodontic tools such as magnification, Cone beam computed tomography (CBCT), Ni-Ti rotary files and ultrasonics, some cases cannot be successfully managed through non-surgical treatment or retreatment which necessitate surgical intervention [(2,3)].

The outcome of endodontic surgery was reported an estimated overall success rate ranged from 82 % to 94 % [(4,5,6)]. The outcome of endodontic surgery depends on several factors such as gender, site, size and extent of the bony cavities in addition to the techniques used for the osteotomy and root end resection [(7)]. The osteotomy and root end resection are mostly accomplished by conventional tools, Piezosurgery and/or Trephine bur. The technique used for the osteotomy and root end resection influences the degree of postoperative complications such as pain and swelling [(8,9,10)].

Conventional tools such as surgical burs are characterized by availability, ease and speed. Nevertheless, there are several complications associated with conventional tools, such as excessive cutting force, high cutting temperature and surrounding tissue damage [(11)]. Research revealed that increasing the cutting temperatures above 47 °C during surgical procedures, even for intermittent periods, leads to irreversible osteonecrosis that has a negative impact on the post-operative recovery time and complications [(9,10)].

Piezosurgery is a typical ultrasonic vibration cutting device that has been gradually applied to bone surgery, such as osteotomy, implant surgery, maxillofacial surgery, spinal surgery and neurosurgery [12]. The bone grafts harvested with a piezosurgery exhibited greater short-term cell viability than chips harvested with a bur and showed greater osteocyte viability and reduced cell death. [13]. It was found that Piezosurgery had less postoperative inflammation, trismus, and pain in comparison with traditional rotary instruments in lower third molar extraction [14]. Piezosurgery is usually considered to be more expensive and slower than conventional tools. Besides, Piezosurgery is associated with an initial learning curve that takes time to learn how to use effectively during the osteotomy [15].

Trephine burs are traditionally used for the removal of failed implants and bone graft harvesting. Recently, trephine burs were used for bone osteotomy and root ends resection. Only a few studies investigated piezosurgery and trephine bur osteotomy and the underlying outcomes. The aim of the study was directed to evaluate the effect of piezosurgical technique in compared to trephine bur technique after guided endodontic periapical microsurgery on the post-surgical clinical and radiographic outcomes.

2. Review of literature

Section outline:

- **2.1 Endodontic Surgery / Microsurgery.**
- **2.2 Periradicular surgery:**
  - **2.2.1 Soft tissue management**
  - **2.2.2 Hard tissue management (Osteotomy)**
  - **2.2.3 Periradicular management.**
- **2.3 Mechanism of bone healing following osteotomy.**
- **2.4 Methods of evaluation of bone healing.**

2. Review of literature

2.1 Endodontic Surgery / Microsurgery:

Endodontic surgery is a branch of dentistry that is concerned with the diagnosis and treatment of lesions of endodontic origin that do not respond to conventional endodontic therapy or that cannot be treated by conventional endodontic therapy. The scope of endodontic surgery is to achieve the three-dimensional cleaning, shaping and obturation of the apical portion of the root canal system that is not treatable via an access cavity, but only accessible via a surgical flap [16,17]. The first recorded surgical endodontic procedure of incision and drainage of an acute abscess was performed by a Greek physician dentist named **Aetius** [18]. Since that, surgical endodontic procedures had been developed and refined as a result of the valuable contributions of many pioneers in dentistry.

During the 1800s and 1900s, Several articles were published describing the periapical abscess and the related surgical procedures. **Richard Cortland** [19] in 1801, described an abscessed tooth as “Pus being a fluid, and pent up in socket of the lower jaw, must and will make its way out. It cannot ascend to the surface or edge of the gum; it must therefore take another direction; and without early professional assistance, penetrates the alveoli, gum and integuments of the face, from whence flows a watery ichor that continues until the cause is removed”.

In 1839, **Harris** [20] proposed the use of a lancet or sharp pointed knife to evacuate pus from a tumor of gums, where the treatment of an abscessed tooth during this period was done by application of heat in the mouth to bring the abscess to a head so that the pus gets discharged, pressure is relieved, and the pain stopped.

In 1871, **Dr. Smith S.** [21] published an article, that described alveolar abscesses and their treatment options including tooth extraction or root end resection "If a necrosed root is present, it must be extracted. To save the tooth, the only alternative is to excise the necrosed portion and the remainder of the tooth may assume a healthy condition and be tolerated by the surrounding structures. This may be accomplished by cutting through the alveolus with a suitable instrument, and cutting and scraping away the necrosed portion of the root, the necrosed portion excised, the end polished".

In 1884, **Dunn et al.** [22] described the "amputation of fangs" using a tubular saw to enter the jaw efficiently, removing the entire diseased portion. Approximately one month following surgery, the root canal was obturated to ensure "as favorable a condition as possible, I take a tube about two or three lines in diameter, the extremity of which is a saw, and apply it to the engine, I cut through the gum, alveolar process, and apex of the root, and generally am successful in bringing it away with its sac inside the tubular saw". On the other hand, another technique was developed by **Farrar** [23] in 1884, to manage the alveolar abscesses by passing a drill through gums and bone and reaching the root ends, which were then resected accordingly.

In 1886, **G.V. Black** [24] recommended "the amputation of the apex of the root of any teeth in the case of long neglected abscess". The procedure was considered easily performed with the use of a fissure bur, and to be "worthy of a trial before giving up an otherwise valuable tooth."

Despite the alveolar abscesses being painful, the treatment modalities including incision and drainage, root end resection or extraction were more painful. In 1887, **Grayston** [25] used cocaine anesthesia in the surgical management of an alveolar abscess.

In 1898, **Partsch** (26,27,28) described root end resection techniques by using a semilunar incision (Partsch incision). Endodontic surgical techniques, especially molar surgeries, were developed, practiced, and published in Europe.

The development of surgical endodontic procedures before 1900 has been attributed to a few courageous clinicians and scientists who had the foresight to document and teach these principles and techniques. However, many others contributed to the evolutionary process, and although not as prominent as **Smith**, **Farrar**, **Black** or **Partsch**, their efforts lent credibility and encouragement to the continued use and development of endodontic surgery.

In 1908, **Béal** (29) published an article on the technique of "résection de l'apex" (root-end resection) and, along with case reports, highlighted the development of endodontic surgery and presented detailed surgical indications and techniques to manage "lésions radiculaires."

In 1917, **Ivy1** (30) and **Howe** (31) recommended the sealing of the apically resected tubules with silver nitrate. "By this means we believe the open tubuli of the bare root end is sealed, and any bacteria in them prevented from emerging."

The continued development of surgery on the European Continent led to the publication of significant and detailed articles, monographs, and texts devoted to extensive coverage of all surgical concepts, particularly molar surgery. The first of these was by **Dr Neumann** (32,33) discussed both the theoretical and clinical techniques of mandibular molar surgeries, he provided an extensive description of the surgical armamentarium and a description of the use of amalgam as a root-end filling material. Neumann provides the first detailed anatomical description of the relationships of the mandibular roots to both osseous and neurovascular structures and relates these to periapical surgical procedures.

In 1936, **Peter** [34] published a textbook on surgical endodontics that served as a prelude for today's surgical endodontics. This book reviewed the literature, elaborated on historical developments, outlined the indications of surgical endodontics, and described the flap design for posterior teeth. Peter discussed the position of the inferior alveolar canal in relation to the mandibular molar roots and the relationship of the maxillary sinus to the apices of the maxillary teeth. Different techniques for management of root end resection and preparation were also developed in this era.

In an article published by **Grossman** in 1974 [35], many different surgical endodontic procedures were discussed that were available at the time. For example, he discussed hemisection, root amputation, root end resection, endodontic implants, tooth replantation, transplantation, and implantation. At that time, he stated that a transplanted tooth would exfoliate within two to three years because of resorption. However, advances and understanding at that time were making it possible to maintain a transplanted tooth.

During the 1980s and 1990s, surgical endodontics has been elevated to a viable treatment option, there have been many advances in treatment planning objectives, anesthesia applications and hemostasis consideration, magnification for surgical visibility and manipulation, management of soft tissue, hard tissue and wound healing, root-end management including new apical filling materials such as mineral trioxide aggregate (MTA) that discovered and brought into use by **Dr Torabinejad** [36,37,38].

Several classifications were proposed to classify endodontic surgeries according to etiology, technique, and site. **John I. Ingle** [38] classified endodontic surgeries into:

3. **Surgical drainage**
   A. Incision & drainage. (I & D)
   B. Cortical trephination & Marsupialization
3. **Periradicular surgery:**
   A. Curettage.
   B. Biopsy
   C. Root end resection.
   D. Root end preparation and filling.
   E. Corrective surgery:
      - Perforation repair
      - Root resection.
      - Hemisection.
4. **Replacement surgery:** (Replantation)
5. **Implant surgery**
   - Endodontic implant
   - Root form osseointegrated implants.

2.2 Peri-radicular microsurgery:

The peri-radicular microsurgery procedures encompass the removal of the buccal bone to facilitate surgical debridement of pathological peri-radicular tissue followed by the removal of root-end resection. A minimum of 3 mm preparation depth is required to effectively seal the accessory canals that may be present. Finally, a root-end cavity is obturated with a retrograde filling followed by surgical site closure [(7)]. This procedure may be undertaken after unsuccessful retreatment, or when retreatment is impossible or has an unfavorable prognosis. The ultimate goal of any periradicular microsurgery is to create a perfect seal between root canal space and periodontium thereby aiding the regeneration of periapical tissues and complete repair of osseous defects. The regeneration of bone following pathologic destruction has an important bearing on tooth retention. Insufficient or inconsistent bone healing is caused by the ingrowth of connective tissue into the bone defect, preventing osteogenesis [(7)].

During the last two decades, many researchers have reported on the outcome of peri-radicular microsurgery, the overall success rate was reported and ranged from 82 % to 94 % [(4,5,6)].

In 2001, **Zuolo M et al.** [(39)], evaluated the prognosis of periradicular surgery using well-defined case selection and a rigorous surgical protocol. A total of 114 teeth were treated as follows, a reflection of a full mucoperiosteal tissue flap, residual soft tissues were curetted, root ends were resected with a fine high-speed diamond bur, root-end cavities were prepared ultrasonically with diamond tips, and IRM root-end fillings were placed. The results of this study showed **91.2%** success out of a total of 102 teeth and nine as failure (8.8%) after the observation period based on accepted parameters of evaluation.

In 2010, **Setzer et al.** [7] investigated the outcome of traditional peri-radicular surgery compared to peri-radicular microsurgery and the probability of success by means of meta-analysis. The results revealed statistically significant success rates of **59%** for traditional peri-radicular surgery and **94%** for peri-radicular microsurgery. The use of microsurgical techniques is superior in achieving predictably high success rates for root end surgery when compared with traditional techniques.

In 2013, **Kreisler et al.** [40] evaluated the effect of patient and tooth related factors on the outcome of periradicular surgery. A total of 255 patients undergoing periradicular surgery were investigated clinically and radiographically 6 to 12 months postoperatively. The overall success rate was **88.0%**. Several factors influence the success rate of periradicular surgery including **gender** (females (89.8%) - males 84.0%), **age** (the success rate was significantly higher in patients 31 to 40 years), and **tooth type** (premolar (91.9%), anterior teeth (86.1%) and molars (86.4 %).

In 2015, **Kang et al.** [5] developed a systematic review and meta-analysis to evaluate and compare the clinical and radiographic outcomes of nonsurgical endodontic retreatment and endodontic microsurgery. The overall success rate for endodontic microsurgery of **92%**.

In 2017, **Wang et al.** [41] studied 98 teeth in 81 patients who performed endodontic microsurgery using a microscope. The patients were recalled and examined clinically and radiographically at least 1 year after surgical treatment. The outcome was determined based on clinical and radiographic results. Radiographic healing was classified into 4 categories: complete, incomplete, uncertain, and unsatisfactory healing. The percentage of complete and incomplete healing 12 to 30 months after endodontic microsurgery was 90.5% (74.3%: complete healing), (16.2%: incomplete healing).

In 2020, **Pianto et al.** [42], A total of 573 articles discussed long-term outcome of endodontic microsurgery, evaluated by Meta-analysis. The results showed survival rate outcomes varied (**79 - 100 %**) with the follow-up time ranging from 2 to 13 years. They concluded that five prognostic factors influenced the outcome including smoking habits, tooth location and type, absence/presence of dentinal defects, interproximal bone level, and root-end filling material.

In 2020, **Pallarés-Serrano et al.** [43] made a systematic review of clinical studies with at least one year of follow-up was done to assess the success rate of endodontic surgery including endoscopy for magnification and illumination. Endodontic surgery with the help of an endoscope is associated with high success rates **(88.9 - 94.9%)**. He concluded that an endoscope was associated with high success rates of endodontic surgery in the included studies.

In 2021, **Azim et al.** [44] evaluated the outcome of endodontic microsurgery using a cone-beam computed tomography scan and prognostic factors affecting the outcome. The results revealed that the survival rate was 93%. The success and survival rate of endodontic microsurgery were very high, and the occurrence of a major procedural error during surgery was the only factor affecting the outcome.

2.2.1 Soft tissue management:

The primary purposes of the flap design are to provide adequate surgical access to the underlining bone and root structure and to promote scar free soft tissue healing. This procedure should prevent any damage to adjacent anatomical entities. The key considerations for positioning and planning the minimally invasive endodontic microsurgery access flap include size and location of the lesion, smile line, biotype, width of attached gingiva, depth of gingival sulcus and existing crown margins/coronal restorations [(45)].

In peri-radicular microsurgery, two major categories of flaps were proposed [(46)]. The first, an esthetic oriented flap that is performed in the anterior region of the mouth due to the position of the roots and root apices, relies on direct straightforward access to the apical lesion. Furthermore, the aesthetics of the soft tissue becomes a priority. Esthetic oriented flap consists of a horizontal submarginal incision together with one or two vertical releasing incisions. The second, a functionally oriented flap performed in the posterior region of the mouth due to esthetics of the soft tissue plays a secondary role, with the focus being on convenient and adequate surgical access to the root apices that allows for faster and complication-free endodontic microsurgery. A functionally oriented flap consists of a horizontal sulcular incision together with one or two vertical releasing incisions.

In 1984, **Kramper et al.** [(47)] evaluated the clinical and histological features of healing of surgical flap designs used in periapical surgery including the semilunar, marginal, and submarginal flaps. The flap sites were evaluated preoperatively, immediately postoperatively, and at 1, 2, 3, 4, 5, 7, 10, 15, 20, 25, 30, 40, and 60 days after surgery. The results revealed loss of alveolar bone accompanied by gingival recession occurred with the marginal flaps.

From the evidence presented, it would appear that the submarginal incision is the flap design of choice in periapical surgery. However, scar formation occurred with the submarginal and semilunar incisions, while very little occurred with the marginal flap.

In 2003, **Velvart et al.** [48] compared the loss of papilla height when using the marginal full thickness flap and papilla base incision flap. The marginal full thickness flap resulted in a loss of papilla height of 1.10 +/- 0.71 mm at 1 month and 1.25 +/- 0.81 mm at the 3-month recall. In contrast, papilla base incision flap, only minor changes could be detected: 0.07 +/- 0.09 mm at 1 month and 0.10 +/- 0.15 mm at 3 months, and there was a significant difference between the two incision techniques. The use of the papilla base incision flap was recommended, to avoid opening of the interproximal space, when periradicular surgical treatment is necessary.

In 2014, **Taschieri et al.** [49] compared the 2 flap techniques including papilla base and marginal flap used in endodontic microsurgery. Outcome variables were assessed preoperatively and 6 months after surgery. The results accept that no significant difference between the 2 flap techniques was found for gingival recession or probing depth at any follow-up time.

In 2021, **Albanyan et al.** [50] investigated the impact of the incision type including marginal, Sub-marginal and Papilla-based incisions on soft tissue healing and crestal bone remodeling following endodontic microsurgery. Papillary-based or marginal incisions both had more recession compared to the sub-marginal incision, which showed 0% recession. None of the flaps designs results in any statistically significant changes in papillary height.

2.2.2 Hard tissue management - Osteotomy:

Osteotomy is defined as a surgical removal of the cortical and cancellous bone to gain access to the apical portion of the root [7]. The first reported osteotomy was performed on the mandible in the USA in 1849 by **Hullihen S** by remove a wedge-shaped section from the anterior portion of the mandible using saw [51]. Since that, many improvements have been published in the fields of orthognathic surgery and transfer to endodontic surgery.

The osteotomy procedures can be accomplished using either using conventional tools such as manual osteotomes, rotating surgical cutting burs and oscillating bone saws, or by using relatively recent cutting devices such as piezosurgery and laser [10]. There are several problems associated with the techniques of osteotomies such as high cutting temperature, longer operation time and surrounding tissue damage which produces a significant degree of trauma to the surrounding soft and hard tissue structures, potentially resulting in a significant inflammatory reaction [52]. The risk of irreversible biologic damage to the bone matrix, which could result in thermal osteonecrosis as follow, increases in heat will cause the denaturalization of the membrane proteins, leading to decreased osteoclastic and osteoblastic activity, dehydration and desiccation of the surface, and hyperemia and, consequently, fibrosis and osteocyte degeneration, which can contribute to cell death. Finally, osteoclastic activity will increase, and the tissue will become necrotic. All these events can affect bone regeneration [7]

2.2.2.1 Surgical Burs:

Surgical burs are defined as rotating instruments, mounted on high-speed, low-speed devices manufactured from different materials and shapes and used to perform an osteotomy such as Lindeman surgical burs.

A. Cutting temperature.

Several studies have shown that an increase in bony temperature leads to thermal bony necrosis which is directly proportional to the increase in temperature and duration of exposure**.**

In 1982, **Eriksson** [53] stated that temperatures below the denaturation point of alkaline phosphatase could alter the reparative capability of bone, and that the regeneration of osteocytes can be delayed, because temperatures of over 47 ◦C cause denaturation of protein, inactivation of enzymes, dehydration of cells, rupture of membranes, disruption of the hydroxyapatite lattice and collagen matrix, and occlusion and coagulation of small vascular channels. These thermal, vascular, and mechanical changes contribute to the formation of necrotic tissue around the surgical site. They also analyzed the changes that take place in bone when it is heated to ranges of 47 ◦C to 50 ◦C, and found that a temperature rise of about 47 ◦C for one minute is the crucial temperature for the prevention of thermal injury to the bone.

In 2009, **Romeo** [54] compared the peripheral bone damage induced by different cutting systems including Er: YAG laser, Piezosurgery, high-speed and low-speed drills. The results showed that rotary cutting instruments that operated at 20,000 rpm caused significantly more osteonecrosis than those that operated at 40,000 rpm.

In 2016, **Siroraj A** [55] found the ideal speed for making a precise osteotomy with minimal damage to the surrounding bone. The results revealed that the osteotomy made with the high-speed handpiece was better than that made with the low speed one on all counts. The margins in the high speed group were more or less precisely as required, with less debris and no thermal necrosis, which illustrated the efficacy of a high speed osteotomy.

B. The cutting efficiency:

The cutting efficiency of surgical instruments directly affected the time of the entire operation. The research evaluated the cutting efficiency of the surgical cutting burs in comparison to other techniques.

In 2011, **Sivolella** (56) performed a statistical analysis of clinical orthopedic surgery for mandibular third molar germ extraction. The results were that the time needed to complete the osteotomy and extraction was significantly greater for the piezosurgery group than for surgical cutting burs. The time was (15.77±6.56 min) for piezosurgery and was (11.77±6.24 min) for surgical cutting burs.

In 2017, **Basheer** (57) assessed and compared the surgical and postsurgical outcomes of third molar removal using piezoelectric surgery and rotary bur applied in a hand piece and a rotary speed ranging around 35,000 rpm was used. The results showed that the time taken for complete osteotomy by rotary bur was less than that by piezoelectric device, which was significant statistically.

In 2019, **Mauricio** (58) evaluated twenty-one Lindeman surgical burs under scanning electron microscopy to evaluate the damage to the bur's integrity after 0 to 9 osteotomies on bovine ribs. The results showed that the burs presented with some type of deformation at both the tip and the body, even after their first use and cutting efficiency on the bone were varied.

2.2.2.2 Piezosurgery

Piezosurgery is a typical ultrasonic vibration cutting device that consisted of an intermediate frequency generator that generates high frequency electrical signals, an operating handle that includes an ultrasonic transducer, amplitude transformer, work tips and a bomb that allows for irrigation during the operation. High frequency electrical signals are translated into high frequency mechanical vibration through the piezoelectric ceramic transducer and then the ultrasonic amplitude is amplified by an amplitude transformer. Finally, high frequency reciprocating oscillating of tips is achieved tissue excision.

In 1880, **Pierre** and **Jacques Curie** (59) discovered that crystals of many substances subjected to mechanical strains, develop electrical charges on their surface. it was observed that when crystals of proper size or metals of proper configuration and content were subjected to an alternating electrical field, these crystals or metals so treated, vibrated with oscillation of specific frequency and amplitude.

In 1927, **Wood** and **Loomis** (60) published their work “Physical and Biologic Effects of High Frequency Sound Waves of Great Intensity”. Since that time, ultrasound has been used mostly for the treatment of neuromuscular and musculoskeletal ailments. Early investigations of ultrasound dealt mainly with the effects of large doses on animals and animal tissues. In light of the overenthusiastic reports with claims of success in the treatment of such diverse diseases as sciatica, malignancies, peptic ulcer, arthritis, etc.

Regarding the nature and use of this physical agent as it is particularly applied in dentistry. In **1953 Catuna** (61) and late in 1974 **Volkov** (62)**,** proposed the piezoelectric effect of ultrasonic vibration applied to the cutting hard bone tissue.

In 1981, **Aro** [63] described the experimental application of using the ultrasonic device in bone cutting. In this study, long bones and scapulas of rabbits were cut by an ultrasonic cutting device and an oscillating saw, the ultrasonic saw was smooth and easy to use, and it was easier to perform an accurate osteotomy line, but the instrument became overheated during use.

In 1998, **Torrella** [64] added an independent water supply device on the ultrasonic device for sterile saline irrigation, and this involved the lateral approach of the maxillary sinus in sinus augmentation. it reduces the risk of perforating the Schneiderian membrane, improves vision and provides a more conservative and controlled osseous incision.

A. Cutting temperature:

In 2012, **Schütz** [65] evaluated the intraosseous temperature changes during the use of piezosurgical inserts under conditions as close as possible to clinical practice. The study pointed out that the correct use of the piezosurgery device did not give rise to prolonged temperature increases over 47 °C and hence did not cause any irreversible thermal damage in the bone.

In 2014, **Alam** [66] studied temperature rise in bovine cortical bone drilled with conventional and ultrasonic assisted cutting techniques by infrared thermography and finite element simulations. Ultrasonic assisted cutting with a frequency below 20 kHz could result in a lower temperature compared to conventional cutting with the same cutting parameters. The temperatures generated in cases with vibration frequency exceeding 20 kHz were significantly higher than those in conventional for the range of drilling speeds and feed rates. The amplitude of vibration had no significant effect on bone temperature.

Higher levels of the drilling speed and feed rate were also found responsible for generating temperatures above a thermal threshold.

Also, research indicated that the thermal damage could be reduced by selecting appropriate cutting parameters, such as blade tip vibration velocity, applied load, frequency and coupling contact conditions, and cutting tips of the bone saws (67).

B. The cutting efficiency:

Piezosurgery is useful when bone must be cut close to important soft tissues, such as nerves, vessels and the Schneiderian membrane or when mechanical or thermal injury must be avoided. Only a limited number of evidence-based studies with different results have evaluated traumatic nerve injury after maxillofacial surgery using piezoelectric devices and rotary instruments.

In 2008, **Schaeren et al** (68) concluded that direct exposure of a peripheral nerve to piezosurgery, even in the worst-case scenario, does not dissect the nerve. This makes piezosurgery a promising tool for osteotomy procedures in close proximity to nerves during endodontic surgery.

This result contradicts research published in 2017 by **Köhnke** (69) evaluated piezosurgery for bilateral sagittal split osteotomy for inferior alveolar nerve perturbation by using piezoelectric devices and surgical rotary instruments. Piezoelectric osteotomy showed no advantage in preventing neurosensory perturbation.

In 2021, **Zandi** (70) evaluated the damage that may occur to the inferior alveolar nerve, histologically, after osteotomy of the buccal cortex of the mandible using piezoelectric devices and surgical rotary instruments. Statistical analyses revealed no significant difference between groups in damage to the inferior alveolar nerve. The present study showed that piezosurgery devices, similar to conventional rotary instruments, have the potential to cause severe nerve damage during surgery and should therefore be used with care.

Piezosurgery is not a method for fast surgeries, but it is suitable for sensitive and non-traumatic operation procedures. In 2011, **Sivolella** [(56)] performed a statistical analysis of clinical orthopedic surgeries for mandibular third molars extraction. The results were that the time needed to complete the osteotomy and extraction was significantly greater for the piezosurgery group than for surgical cutting burs. The time was (15.77±6.56 min) for piezosurgery and was (11.77±6.24 min) for surgical cutting burs.

In 2017, **Basheer** [(57)] assessed and compared the surgical and postsurgical outcomes of third molar removal using piezoelectric surgery and rotary bur applied in a hand piece and a rotary speed ranging around 35,000 rpm was used. The results showed that the time taken for complete osteotomy by rotary bur was less than that by piezoelectric device, which was significant statistically.

In 2018, **Otake** [(71)] tested the cutting time of the piezoelectric device in comparsion with rotary instruments. The results revealed that the time for piezosurgery to cut through the tibia was the longest and was significantly different from that for the carbide, fissure and round burs.

C. Bone Surface:

The bone material removal process could affect the surface morphology of bone after cutting, causing cracks on the bone surface, resulting in the secondary damage of bone tissue, affecting postoperative cleaning, causing wound contamination and increasing patient recovery time [(72)].

In 2008, **Peter** [73] examined the roughness differences of rabbit skull surface. The values observed for surface roughness were as follows: 3.97 μm (micro-saw), 5.7 μm (Lindemann bur), 2.48 μm (ultrasonic osteotome with the two insert rough tips) and 3 μm (ultrasonic osteotome with the two insert fine tips). They concluded that the bone surface (Piezosurgery) was mostly orderliness, smooth and more accurate.

In 2009, **Zhou** [74] evaluated the spiral chips that could cause higher specific cutting energy and rough hole surfaces in drilling. The results were that conventional drilling produced spiral cone chips while ultrasonic-assisted drilling produced needle-shaped chips. Also, in conventional cutting, the chips were seen rotating along the drill bit rubbing against the hole surface and blocking the flutes. ultrasonic-assisted drilling was observed to produce broken chips and no rubbing of the chips was seen against the hole surface.

2.2.2.3 Laser:

Laser osteotomy offers the potential advantage of high precision, reduced collateral damage to surrounding tissues, high productivity, low roughness of cut surfaces and minimum distortion. The prevailing complications of the laser osteotomy were thermal side effects, which revealed massive wound healing impairment due to negative thermal and thermomechanical side effects such as carbonization, microfractures in the bone and an extended zone of coagulation necrosis in adjacent soft tissue. The situation changed with the introduction of pulsed laser systems with additional water sprays which allowed direct photoablation of mineralized hard tissues [75].

In 2001, **Gouw-Soares** [76] reported an apical surgery protocol to be used. An Er:YAG laser was applied to perform the osteotomy and root resection, whereas Nd:YAG laser irradiation was used to seal the dentinal tubules and reduce possible bacterial contamination of the surgical cavity. The improvement in healing was achieved by incorporating the use of a low-level gallium aluminum arsenide diode laser to the treatment protocol. Three years follow up examination of the clinical case showed a radiographically significant decrease in the radiolucent periapical area and no clinical signs and symptoms.

In 2011, **Martins** (77) performed osteotomies with a surgical bur and a Er: YAG laser and found that bone repair progressed from the inner surface to the periosteum with no bone callus over the external surface when bur was used. However, when the laser was used bone repair was initiated on the periosteum and endosteum of the surface cortical margins of the lesion and progressed towards the central regions.

2.2.2.4 Surgical Trephine Bur:

Trephine burs are traditionally used for the removal of failed implants and bone graft harvesting. Recently, trephine burs were used for bone osteotomy and root ends resection. The research in this field is lacking but the few cases reports published described trephine burs.

In 2019, Tavares W (78) performed ultraconservative guided apicoectomy surgery in the premolar with intimate contact with the maxillary sinus using conventional implant drills. The osteotomy and root end resection was performed using Ø 3.5 mm diameter instrument (Straumann® guided surgery, Straumann, Basel, Switzerland) at 980 RPM under copious irrigation with saline until reached the bed of the drill handle and ensured apical resection as planned. The apical lesion was removed with a curette, and the surgery site was cleaned with saline irrigation. This technique provides a very simple, reproducible and reliable technique.

In 2019, **Antal** [79] performed a case series to justify the clinical safety and accuracy of guided root-end resection with a trephine bur. Fourteen root end resections were performed in 11 patients. Surgery was performed using a surgical guide and trephine burs for the osteotomy and root end resection as well. The results revealed that no intraoperative complications were observed in any of the cases. The root end was successfully and completely resected by the trephine bur in all cases and the patients were free of symptoms indicating recurrence or complications at the 6 month follow up. Overpenetration was a characteristic finding, which indicates the necessity of a stop trephine bur. The results supported the use of guided trephination for root end resection.

In 2019, **Popowicz** [80] performed a case study to evaluate endodontic microsurgery with the aid of implant planning software, a 3D printed surgical guide precisely positioned according to the preoperative CBCT scan measurements, and a modified soft tissue access. A hollow trephine bur was used to perform the osteotomy, resection of the root, and enucleation of the lesion. The use of the positioning guide and trephine burs, allowed the clinicians to precisely achieve targeted tissues and shorten the procedure time. A less than 12-month CBCT follow-up of both cases showed complete 3D healing of the surgical site.

In 2020, **Antal** [81] performed osteotomy and root-end resection using custom designed trephine burs manufactured specifically for use in targeted endodontic microsurgery. The results showed that a patient with persistent periapical lesions was successfully treated using custom designed trephine burs without any complications. Furthermore, the 6-month follow-up found uneventful healing.

2.2.3 Periradicular management.

2.2.3.1 Root end resection

Historically, many authors [82] have advocated periradicular curettage as the definitive treatment in endodontic surgery without root end resection. The rationale for periradicular curettage as a terminal procedure is to protect root length and maintain a cemental covering on the root surface.

In 1975, **De Deus** [83], showed that many apical ramifications and lateral canals exist at least 3 mm from the root end. Thus, root-end amputations are shorter than 3mm. may not remove all lateral canals and apical ramifications, increasing the risk of reinfection and eventual failure.

In 1984, **Vertucci** [84], made a detailed study of two thousand and four hundred permanent teeth using the clearing technique in order to determine the number of root canals and their different types, the ramifications of the main root canals, the location of apical foramina and transverse anastomoses, and the frequency of apical deltas. The results showed great variation in root canal anatomy. The rate of lateral canals and accessory canals in maxillary molars was around 50% in the mesiobuccal roots, and they were mostly found at the apex. In the mandibular molars, lateral canals were found in great numbers in the furcation region.

In 1990, **Blasković** [85] examined two hundred and thirty permanent roots using stereomicroscopically to determine the frequency of apical, lateral and furcational accessory canals. The frequency of apical accessory canals averaged 19.6% and lateral 8.3%. These findings emphasize the necessity for undertaking meticulous disinfection and qualitative apical seal.

The root end resection can be performed using different techniques including surgical burs, ultrasonic systems or/and lasers [86,87]. Several authors have shown that the type of instrument and cutting angle used are directly related to apical surface roughness and dentinal tubule exposure after root end resection.

In 1988, **Neddermann** [88] evaluated the surface properties of the cut root end and gutta-percha obturating material following apical root resection using a scanning electron microscope. Thirty roots were divided into six equal groups and apical root resections were performed using three bur configurations in both high-speed and low-speed handpieces and five roots were resected with a slow-speed diamond saw as controls. The result revealed that the smoothest surface and the least amount of guttapercha disturbance was produced by the # 57 plain fissure bur in the low-speed handpiece. The roughest and most irregular surfaces were produced by the crosscut fissure burs in both high and low speed resections.

In 1999, **Weston** [89] evaluated sixty human single-rooted teeth with fully formed apices, which were collected, instrumented and obturated. The roots were randomly divided into 12 different groups. Apical root end resections were performed using eight different instrument configurations, and two different directions in which the bur moved across the root face in relation to its direction of rotation. The root ends were examined using scanning electron microscopy. Each instrument produced a characteristic surface finish on the resected root end that mirrored its cutting profile. Smearing and shredding of the gutta-percha across the root face occurred only when the handpiece was moved across the root face in the reverse direction in relation to the direction of rotation of the bur.

In 1992, **Stabholz** [90] investigate the effects of Nd: YAG laser on the permeability of dentin following apicoectomy and retrofill. The results showed that the application of an Nd: YAG laser melted apical dentin surfaces and reduces the permeability of resected roots.

In 2007, **Duarte** [91] compared by scanning electron microscopy, the smoothness of the resected apical root surface after preparation with high-speed surgical burs and with an Er: YAG laser. Smoother surfaces were observed for the groups treated with the surgical burs while rougher surfaces were obtained with the Er: YAG laser.

In 2009, **Bernardes** [92] compared a chemical vapor deposition (CVD) coated ultrasonic tip with high and low speed carbide burs. They evaluated the root end resection time and analyzing root end surfaces using SEM. They concluded that ultrasonic root-end resection using the CVD coated tip took longer and resulted in rougher surfaces than carbide burs at both high and low speeds.

In 2010, **Camargo** [86] evaluated the apical root surface, gutta-percha interface, and preparation time of root-end resections made with burs, ultrasound, or laser. Thirty endodontically treated teeth were resected using surgical burs, chemical vapor deposition ultrasonic tip, and ErCr: YSGG (Waterlase). The preparation time was recorded and the resected root-ends were examined under a scanning electron microscope. The bur produced the smoothest surface and fastest operation, followed by chemical vapor deposition ultrasonic tip.

To our knowledge, no study has evaluated the effect of piezosurgery on root end resection. Further studies are necessary, especially in vivo investigations, to determine the influence of root end resection techniques on apical healing after endodontic surgery.

2.2.3.2 Root end preparation

The root end preparation can be performed conventionally using rotary burs in a microhandpiece or by using ultrasonic. The rotary burs pose several problems such as difficult access to the root end, the inability to establish preparations parallel to the canal, and the risk of lingual perforation of the root [93]. The ultrasonic retrotips have shown many advantages over the traditional handpiece used in surgical endodontics. The long axis of the tooth can be followed, thus preserving canal morphology, and apical cavities can be shaped more easily, safely, and with greater precision than with conventional handpieces [94,95,96].

Several studies on the use of ultrasonic retrotips also report improved cleaning of cavity walls compared with conventional instruments and reduced smear layer volume after root canal preparation.

In 2001, **Peters** [97] compared the efficacy of root end cavity preparations and the time required to prepare using ultrasonic diamond coated and stainless steel retrotips. The results reveled that the ultrasonic diamond coated retrotips removed more dentine than stainless steel retrotips and should therefore be used with care to avoid overpreparation or perforation. The preparation times ranged from 25 s to 361 s and were significantly lower for ultrasonic diamond coated tips than the stainless steel retrotips.

In 2003, **Ishikawa** [98] evaluated and compare the efficiency of root end preparations using zirconium nitride coated retrotip, stainless steel tip or diamond coated ultrasonic retrotips. The time required to prepare the root end cavity, the number of microcracks produced on the resected surface and the number of dentinal tubule openings on the root canal wall were evaluated using scanning electron microscope images.

There was no significant difference in the number of microcracks and dentinal tubule openings present in the root apices prepared by the three retrotips. The time required for root end cavity preparation using the diamond coated ultrasonic retrotip was significantly less than that using the other.

In 2010, **Del Fabbro** [(99)] investigated root end morphology after retrograde cavity preparation using a piezoelectric device at different power settings and in different modes of operation in fresh cadavers. They showed that, when the piezoelectric tip oscillated with a constant vibration, the power level did not affect the incidence or type of dentin cracks, and margin quality was fairly regular. Conversely, a significantly greater alteration of the root end and a qualitatively worse cavity margin were observed when pulsation was added.

In 2013, **Liu** [(100)] evaluated the effect of Jetip and AS3D ultrasonic tip for root-end preparation. The resultes showed that Jetip and AS3D provided rapid and regular root-end preparations. The cutting efficiencies of both retrotips decreased with the number of the uses. The Jetip showed smooth microprojections after root end preparation, whereas the AS3D tip exhibited the loss of diamond particles.

In 2020, **Palma** [(101)] compared root end preparation performed with two different ultrasonic tips CVDentus and NSK. Photomicrographs were taken following root end preparation to assess the root surface microcracking, marginal integrity and preparation time. The incidence of microcracks in both groups was 12.5%. Solely intracanal microcracking was found, consistently positioned within the widest side of the remaining dentine. No statistically significant differences were verified between both experimental groups regarding marginal integrity and preparation time.

2.3 Mechanism of bone healing following osteotomy.

A set of events occurs following a bone fracture or osteotomy and culminates in the remarkable ability of bone to regenerate and return to its original tissue structure and function [102]. Bone healing is an extremely complicated process and can be divided into primary and secondary healing based on differences in the mobility between the fracture fragments [103].

Primary healing or direct ossification [104] (without formation of a periosteal callus) happens when bone injured surfaces are juxtaposed and fixed through surgery and bone remodeling through the original fracture line leads to bone healing such as bone window technique. Primary bone healing is less frequent, since it requires a perfect reduction and the compression of the fracture with a distance between the bone segments of less than 0.1 mm.

Secondary healing or indirect ossification involves the classic stages of injury including inflammation, repair (formation of a soft cartilaginous primary callus and mineralization) and bone remodeling. The speed of consolidation is influenced by the fractured bone, the type of fracture, the treatment method and the general state of the patient. Local factors are also influential such as the separation of the bone ends, which could be related to bone loss or resorption at the fracture site, soft tissue interposition between the bone ends, and excessive traction or the use of internal fixation. Secondary bone healing involves a cartilage group that is replaced by bone which is the most common form of repair that takes place in all other circumstances and is usually divided into four stages that partially overlap each other.

A. The first stage "Inflammatory Stage":

This stage begins immediately following fracture/osteotomy and continues for approximately 2 to 3 weeks. At the osteotomy site, Platelets release platelet derived growth factors including PDGF, TGFI3, and epidermal growth factor, which are molecular mediators required for healing and lasts a few days and is characterized by pain and swelling. Hematoma formation provides the first population of cells to the osteotomy site, including granulocytes, macrophages and lymphocytes and mast cells. The hematoma becomes organized by platelet and fibrin deposition. Macrophages secrete several growth factors such as fibroblast growth factors that initiate fibroplasia. Osteoprogenitor cells migrate into the osteotomy site from the endosteum, medullary cavity, and cambium layer of the periosteum. Endothelium may also serve as a source of osteoprogenitor cells. Endothelial cells also contain endothelial cell derived growth factors, which cause bone cell proliferation. Fibroblasts, macrophages and capillaries together form the external periosteal callus. Angiogenesis is thought to be mediated by macrophages, which produce angiogenic factors within the locally hypoxic conditions of the fracture callus. New blood vessels originate from the surrounding soft tissues, representing an extraosseous blood supply. This blood supply is transient, independent of fascial attachments and distinct from normal periosteal arteries. These vessels feed the periosteal callus and any detached cortical fragments, reaching a maximum blood flow by day 10 post osteotomy. As healing progresses, the contribution of extraosseous blood to further bone healing also diminishes.

B. The second stage “soft callus stage”:

The undifferentiated periosteal callus begins to undergo rapid chondrogenic transformation and proliferation. These precursor cells probably originate from the periosteum or the organizing hematoma and differentiate into chondroblasts, fibroblasts, and osteoblasts. Variations in oxygen tension determine the differentiation of pluripotential cells to cartilage producing chrondroblasts, or bone producing osteoblasts. Initially, type I, II, and III collagen are deposited, but as the process continues, type I collagen predominates. Calcium hydroxyapatite is deposited in the matrix. The cartilaginous callus mineralizes and envelops the bone ends, leading to an increase in stability between the fracture fragments. As stability increases, the reestablished medullary blood supply assumes the primary role of supplying the fibrocartilaginous callus. Cartilage is then gradually replaced by bone through a process identical to endochondral ossification. Osteoblasts produce woven bone that is random in orientation and interwoven with the capillary channels which are modified into lamellar bone with haversian system organization. At this stage, the bone union is achieved, but the fracture site is structurally different from that of the original bone

C. The third stage “hard callus stage”:

The progression and regression of this stage strictly depends on the presence of blood supply.

In case of a good blood supply: new osteoblasts differentiate and start to lay down the bone matrix during intramembranous ossification. During intramembranous ossification, two different processes of bone formation exist, occurring in sequence, named static osteogenesis and dynamic osteogenesis. Static osteogenesis is characterized by pluristratified cords of stationary osteoblasts which differentiate by inductive stimuli at roughly constant distance from the capillaries without moving during their transformation into osteocytes from the differentiation site. The dynamic osteogenesis is performed by the typical monostratified laminae of movable osteoblasts. The following events occur in sequence: firstly, variously polarized stationary osteoblasts irregularly arranged inside cords give rise, in the same place where they differentiate, to osteocytes clustered within confluent lacunae, thus allowing the formation of preliminary thin trabeculae made up of woven bone that, due to their too high cellularity, are not effectual from a mechanical viewpoint. Afterwards, along the surfaces of the static osteogenesis trabecular preliminary framework, dynamic osteogenesis occurs, which is mostly involved in filling primary haversian spaces, thus giving rise to primary osteons. Dynamic osteogenesis bone consists in lamellar bone which is mechanically more resistant compared to static osteogenesis trabecular bone, since it is less cellularized and arranged in a more orderly pattern; moreover, it occurs in relation to mechanical stimuli, instead of inductive vascular-derived factors as occurs for static osteogenesis.

On the contrary, in case of a blood supply deficiency, thus leading to low local oxygen rate, cartilage may form within the fibrous tissue; eventually, the cartilage, after hypertrophy and calcification, will be replaced by bone, as in endochondral ossification. In the case of bone repair by endochondral ossification, static osteogenesis never seems to take place. In fact, the osteoblasts in contact with the remnants of the calcified cartilage are directly arranged in movable laminae and all appear to be functionally polarized in the same direction, i.e., toward the calcified cartilage. Thus, in endochondral ossification, dynamic osteogenesis is not preceded by static osteogenesis.

At the end of the third stage, independently of the type of ossification intramembranous or endochondral, the new bone that bridges the bone fragments is usually wider than the original bone profile. Once mechanical integrity has been re-established.

D. The fourth stage “remodeling stage”:

This represents the last stage of bone healing, which may lead to the recovery of the original anatomical shape. The balanced action of osteoclastic resorption and osteoblastic deposition is governed by Wolff’s law and modulated by piezoelectricity, a phenomenon in which electrical polarity is created by pressure exerted in a crystalline environment [105].

2.4 Methods of evaluation of bone healing:

2.4.1 2D Radiographic Healing Assessments.

In 1972, **JORGEN RUD** [106] proposed radiographic healing criteria based on the correlation between radiographic and histologic findings and classified the radiographic healing with a minimum observation period of one year to four groups as follow.

Group 1 - Complete healing: Reformation of a periodontal space, which means that a lamina dura is to be followed around the apex. The width of the periodontal space in the apical region may he widened to as much as twice the normal width around non-involved parts of the root. A tiny defect in the lamina dura (maximum 1 mm^2) adjacent to the root filling is tolerated. The bone cavity should be filled-in with bone, although this may not have the same radiopacity and structure as the non-involved bone.

Group 2 - Incomplete healing (scar tissue): Bone structure may or may not be recognized within the rarefaction. The periphery of the rarefaction is irregular and may be demarcated by a compact bone border. The rarefaction often is located asymmetrically around the apex. The connection of the rarefaction with the periodontal space is angular. Bone surrounding the rarefaction may show a fine meshed structure or be interspersed with coarse bone trabeculae having radiolucent areas. When the bone regeneration proceeds, a lamina dura around the apex may be formed, isolating a rarefaction in the bone.

Group 3 - Uncertain healing: Some degree of bone regeneration, so that the original rarefaction has decreased compared with a post-operative. The size of the rarefaction shotfld be more than twice the width of the normal periodontal space. The periphery of the rarefaction is nearly always circular or semicircular. The rarefaction is usually located symmetrically around the apex as a funnel-shaped extension of the periodontal space.

Group 4 - Unsatisfactory healing (failures): The radiographic signs of this group are the same as for uncertain healing, except that in the unsatisfactory group the rarefaction is either enlarged or unchanged in comparison with a post-operative or previously taken follow-up radiograph.

In 1987, **OLAV MOLVEN** **[107]** evaluated a large series of endodontic surgery cases radiographically one year after the operation. The cases were grouped in to the following four healing groups; Complete healing, incomplete healing (scar tissue), uncertain healing and unsatisfactory healing (failures)

Complete healing after endodonfic surgery: Complete bone repair; no apical periodontal space can be discerned

A. Re-formation of periodontal space of normal width and lamina dura to be followed around the apex.
B. Slight increase in width of apical periodontal space, but less than twice the width of non-involvedparts of the root.
C. Tiny defect in the lamina dura (maximum 1 mm^2) adjacent to the root filling.
D. Complete bone repair; bone bordering the apical area does not have the same density as surrounding non-involved bone.

Incomplete healing (scar tissue) after endodontic surgery

The rarefaction has decreased in size or remained stationary, and is characterized by one or more of the following findings.

A. Bone structures are recognized within the rarefaction; the periphery of the rarefaction is irregular and may be demarcated by a compact bone border, the rarefaction is located asymmetrically around the apex and the connection of the rarefaction with the periodontal space is angular.
B. Isolated scar tissue in the bone with findings. This is a later stage of the same case. Isolated scar tissue was not observed in the present 1-year series

Uncertain healing after endodontic surgery: The rarefaction has decreased in size, and with one or more of the following characteristics;

A. the radiolucency is larger than twice the width of the periodontal space;
B. bordered by lamina-dura like bone structures;
C. has a circular or semicircular periphery;
D. located symmetrically around the apex as a funnel-shaped extension of the periodontal space;
E. the bony structures are discernible within the bony cavity.

A collar-shaped increase in width of lamina dura coronal to the radiolucency may also be found.

Unsatisfactory healing after endodontic surgery; The rarefaction has enlarged or is unchanged.

2.4.2 3D Radiographic Healing Assessments:

The 3 dimensional (3D) reconstruction of an anatomic area at a relatively low radiation dose has become possible by the use of cone beam computed tomography (CBCT). That is why CBCT imaging has been welcomed in the field of dentistry and particularly in endodontics in recent years. On CBCT images it is possible to distinguish which root or roots are involved in the lesion, as well as its exact location and volume [(108)]. A recent [(109)] study used CBCT scans and digital periapical radiographs to determine the radiologic changes in the periapical tissues 1 year after primary endodontic treatment. The results showed that the sensitivity of 2D radiographs is quite insufficient, especially in making such a comparison, because of the superimposition of adjacent tissues, the thickness of the overlying cortical bone, the complex anatomy of multirooted teeth, or, more importantly, the lack of capacity of this 2D method to assess the’’depth’’ (buccolingual size) of a lesion.

2.4.2.1 Quantitative CBCT Evaluation:

CBCT evaluation using PENN [(110-111)] for evaluation the bone healing after one year follow up including,

Complete Healing:

A. Reformation of periodontal space of normal width and lamina dura over the entire resected and unresected root surfaces

B. Slight increase in width of apical periodontal space over the resected root surface, but less than twice the width of non-involved parts of the root

C. Small defect in the lamina dura surrounding the root-end filling.

D. Complete bone repair with discernible lamina dura; bone bordering the apical area does not have the same density as surrounding non-involved bone.

E. Complete bone repair: Hard tissue covering the resected root-end surface completely. No apical periodontal space can be discerned.

Limited Healing:

A. The continuity of the cortical plate is interrupted by an area of lower density.

B. A low density area remains asymmetrically located around the apex or has an angular connection with the periodontal space.

C. Bone has not fully formed in the area of the former access osteotomy.

D. The cortical plate is healed but bone has not fully formed in the site.

Unsatisfactory Healing:

The volume of the low density area appears enlarged or unchanged.

3. Aim of the study

The aim of the study was directed to evaluate the effect of Piezosurgical technique in compared to trephine bur technique after guided endodontic periapical microsurgery on the post-surgical clinical and radiographic outcomes. The null hypothesis stated that there no significant difference between both techniques.

4. Patients and Methods

4.1 **Study design and population.**

4.2 **Selection of the Patients.**

4.3 **Pre-operative Assessment**

- **4.3.1 Clinical Examination.**
- **4.3.2 Radiographic Evaluation**

4.4 **Patients Consents.**

4.5 **Non-Surgical / Pre-Surgical Management**

4.6 **Grouping and Randomization of the patients**

- **4.6.1 Piezosurgery Assisted Group**
- **4.6.2 Trephine Burs Assisted Group**

4.7 **Surgical Guide designing & Fabrication.**

4.8 **Pre-operative Pain assessment**

4.9 **Surgical Intervention.**

- **4.9.1 Patients' preparation and anaesthetization**
- **4.9.2 Flap Elevation.**
- **4.9.3 Osteotomy and root-end resection**
- **4.9.4 Flap repositioning and Suture.**
- **4.9.5 Immediate Post-surgical CBCT.**
- **4.9.6 Emergency Protocol.**
- **4.9.7 Post-surgical Care.**

4.10 **Post-surgical Evaluation.**

4.11 **Data management and analysis.**

4. Patients and Methods

4.1 Study design and population.

This is a randomized clinical trial was designed according to the guidelines stated by the Royal College of Surgeons of England (RCS) [112]. The study was approved by the Ethics Committee of Faculty of Dental Medicine, Al Azhar University for Research on Human Subjects Number **722/1224**. The protocol of this study was registered for documentation at **www.clinicaltrials.gov.** **(ID: NCT05863728).**

According to the data of a published clinical trial concerning endodontic microsurgery and bone healing [113,114], the minimum sample size was 9 patients in each of 2 groups which has an 80 % power to detect a difference between means of 0.099 with a significance level (alpha) of 0.05 (two-tailed).

4.2 Selection of the Patients:

The necessary measures have been taken to protect patients' own lives, their physical and psychological health and to protect their dignity, in addition to reducing the side effects of the medical research. Out of fifty-two patients, twenty healthy male patients aged between 18 and 45 years old were selected from the outpatient clinic of the Endodontic Department, Faculty of Dental Medicine, Al Azhar University to be included in the study. The selected patients have no general medical contraindications for oral surgical procedures (Scores 1–2) according to the classification of the American Society of Anesthesiologists (ASA) [115]. Mandibular first molar teeth were selected according to specific inclusion criteria including,

A. Teeth presented with failed non-surgical treatment or re-treatment. Failure is due to iatrogenic errors at the apical 3mm of the mesial root canal including canal ledging, zipping and transportation, root perforation, separated instrument and canal calcification.

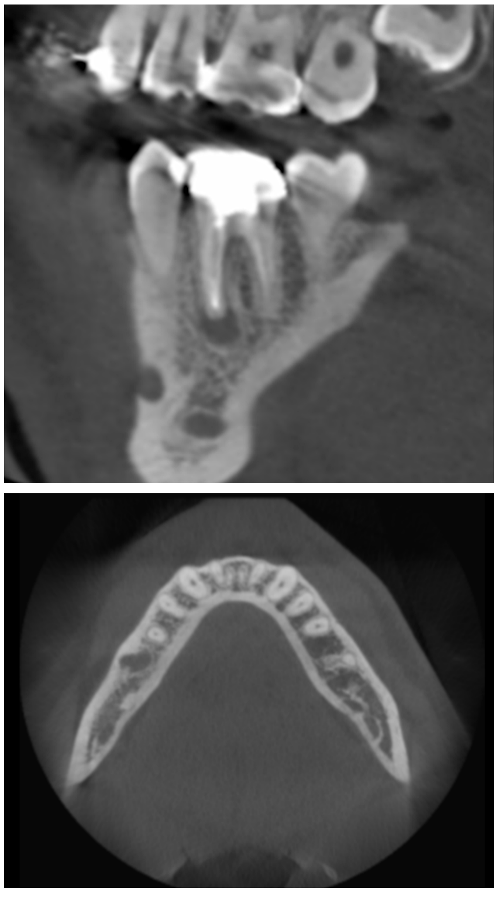
B. Teeth presented with normal pocket depth ranges from 1 to 3mm, up to grade II tooth mobility.

C. Teeth presented without periapical radiolucency (Class A) or with periapical radiolucency not more than 1 mm in diameter both mesiodistally and buccolingually (Class B) according to preoperative endodontic microsurgical classification of teeth **[93]**.

D. Teeth presented with non-fused mesial and distal roots; the mesial roots are range from 10 to 15 mm. in length, measured from the Cementoenamel junction (CEJ) to the radiographic root apex. Type III root canal configuration (Two canals run separately from orifice to apex) **[116]**. The root canal curvature angle was measured using Weine technique **[117]** to be not less than 160° in both directions buccolingually and mesiodistally. The mesial root apex is away from the distal root apex of the same tooth and from the mandibular 2^{nd} premolar root apex by 4 $\pm$1 mm. The mesial root apex is away from the roof of the inferior alveolar nerve canal by 5 $\pm$1 mm. if there is no periapical radiolucency. In case of the presence of a periapical radiolucency not more than 1 mm in diameter, the mesial border of the periapical radiolucency was away from the distal root surface of the mandibular 2^{nd} premolar root apex by 4 $\pm$1 mm. the distal border of the periapical radiolucency was away from the mesial root surface of the distal root apex of the same tooth by 4 $\pm$1 mm. The inferior border of the periapical radiolucency was away from the roof of the inferior alveolar nerve canal by 5 ±1 mm. The superior border of the periapical radiolucency was limited to the level of the radiographic apex. In case of presence of overextended separated instrument, the tip of the extended instrument was away from the roof of the inferior alveolar nerve canal by 5 ±1 mm.

E. At the apical 3 mm of the mesial radiographic root apex, the distance from the outer surface of the buccal cortical plate of bone to the buccal side of the mesial root is 1.5 ± 0.5 mm (**Depth I**). The buccolingual dimension of the mesial root is 7 mm ± 2mm **(Depth II)**. The distance from the lingual surface of the mesial root to the outer surface of the lingual cortical plate of bone is 3.5 ± 0.5 mm. **(Depth III) (Figures 1-4).**

Figure (1): 2D radiograph showing endodontically treated mandibular 1st molar with iatrogenic errors.



Figures (2, 3): CBCT scans (coronal & axial views) showing endodontically treated mandibular 1st molar with iatrogenic errors.

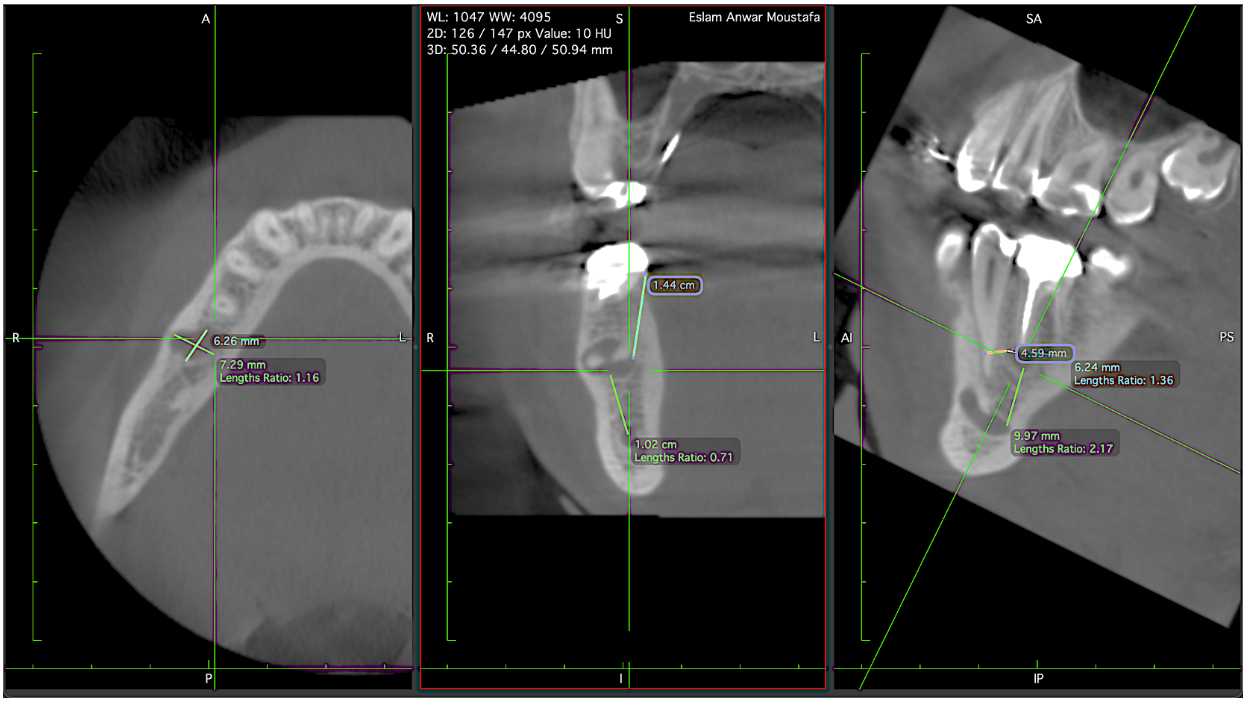


Figure (4): CBCT scans (Axial, Sagittal & Coronal views) showing the selection criteria of endodontically treated mandibular 1st molar with iatrogenic errors.

4.3 Pre-operative Assessment:

4.3.1 Clinical Examination:

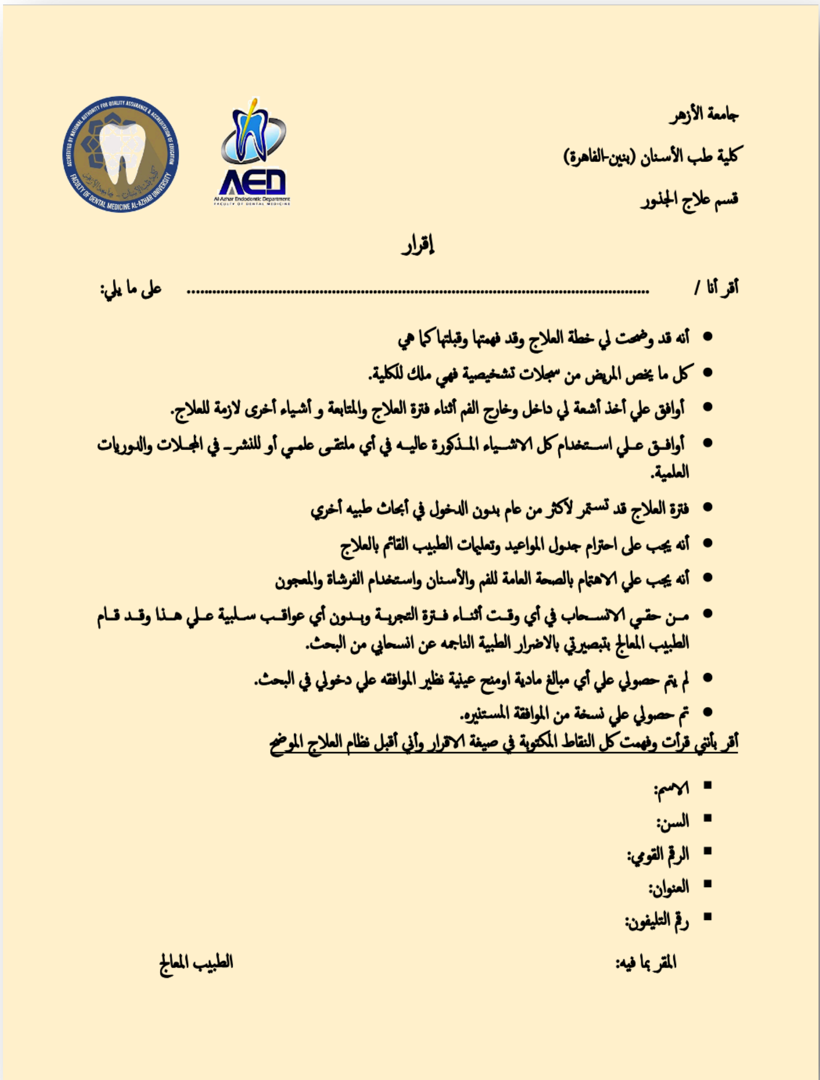
Extraoral examination was performed including assessment of a facial asymmetry and palpation of the lymph nodes. Intraoral examination was performed including soft and hard tissue visualization, palpation of the periapical area, vertical and horizontal percussion, mobility test, probing test, and vitality test of the selected tooth, evaluation of presence of swelling or sinus tracts.

4.3.2 Radiographic Evaluation:

A preoperative digital periapical radiograph (FONA CDRelite. Slovakia) was taken as a tentative measure followed by preoperative cone beam computed tomography (CBCT) scanning. A CBCT scanning was performed under standard specifications (3D PLANMECA Cone Beam) (Voxel size 250µm, FOV: 110 mm, 120 kV, 5 mA, 9 s) (PLANMECA ROMEXIS ® 3d Viewer). Tooth morphology was evaluated including root length, width, curvature and relationship to other teeth, vital structure. Evaluation of the iatrogenic errors at the apical 3mm of the mesial root canal and periapical radiolucency and its relationship to the radiographic root apex. Evaluation of the supporting bone and the restorability of the teeth. Teeth that did not fulfill the previously mention inclusion criteria were excluded from the study.

4.4 Patient consent:

The selected patients that were included in the study, have signed a written informed consent after exploring all steps of the study. The patients were informed about the protocol of emergency in case of serious complications during the surgical intervention. **(Figure 5).**



جامعة الأزهر

كلية طب الأسنان (بنين-القاهرة)

قسم علاج الجذور

إقرار

أقر أنا / .... على ما يلي:

- أنه قد وضحت لي خطة العلاج وقد فهمتها وقبلتها كما هي
- كل ما يخص المريض من سجلات تشخيصية فهي ملك للكلية.
- أوافق علي أخذ أشعة لي داخل وخارج الفم أثناء فترة العلاج والمتابعة و أشياء أخرى لازمة للعلاج.
- أوافق علي استخدام كل الاشياء المذكورة عاليه في أي ملتقى علمي أو للنشر في المجلات والدوريات العلمية.
- فترة العلاج قد تستمر لأكثر من عام بدون الدخول في أبحاث طبيه أخري
- أنه يجب على احترام جدول المواعيد وتعليمات الطبيب القائم بالعلاج
- أنه يجب علي الاهتمام بالصحة العامة للفم والأسنان واستخدام الفرشاة والمعجون
- من حقي الانسحاب في أي وقت أثناء فترة التجربة وبدون أي عواقب سلبية علي هذا وقد قام الطبيب المعالج بتبصيرتي بالاضرار الطبية الناجمه عن انسحابي من البحث.
- لم يتم حصولي علي أي مبالغ مادية اومنح عينية نظير الموافقه علي دخولي في البحث.
- تم حصولي علي نسخة من الموافقة المستنيره.

<u>أقر بأنني قرأت وفهمت كل النقاط المكتوبة في صيغة الاقرار وأني أقبل نظام العلاج الموضح</u>

- الاسم:
- السن:
- الرقم القومي:
- العنوان:
- رقم التليفون:

المقر بما فيه: الطبيب المعالج

Figure (5): A photograph showing the patient consent templet.

4.5 Non-Surgical / Pre-Surgical Management:

4.5.1 Non–Surgical management:

All steps of the non-surgical endodontic management were carried out under varying degrees of magnification (8X–16X) using a dental operating microscope (S2350, Zumax Medical Co. China). Scaling and root planning were done for all patients using an ultrasonic scaler (Woodpecker UDS-A, Guilin, China) and oral hygiene care methods including daily teeth brushing and mouth wash were instructed. The supra structure restorations including core, posts and/or crowns were removed if present in addition to caries removal. The rest of the tooth structure was evaluated for restorability.

The teeth were isolated using a rubber dam kit (Sanctuary Health, Perak, Malaysia). In case of root canal treated teeth, the gutta perchea was removed first using the ProTaper retreatment system (Dentsply Maillefer, Switzerland) accompanied with gutta perchea solvent (Carvene, Prevest DenPro, India). The canals were instrumented using ProTaper D1 in a crown-down sequence followed by placement of 0.5 ml of GP solvent into the canals. Then D2 and D3 files were used sequentially to remove the softened GP [118].

After removal of gutta perchea remnants, the iatrogenic errors at the apical 3mm of the mesial root canals were categorized and managed as follows:

A. Separated Instruments:

In case of a separated instruments located below the curvature of the root (could not be visualized), the management was directed toward bypassing of the separated instruments as follows; Straight-line access and coronal flaring using SX (Dentsply Maillefer, Switzerland) were established, the canals were filled with 17% EDTA gel as a chelating agent (Meta Biomed Co. Ltd, Korea). The bypassing protocol was started by introducing pre-curved size 06, 08, # 10 K manual files (Dentsply Maillefer, Ballaigues, Switzerland) into the canals alongside of the separated instruments [119]. After several fail attempts to bypass the separated instruments, the management was directed toward the surgical intervention [120].

In case of a separated instruments located below the curvature of the root and projected beyond the root apex, bypassing the separated instruments were neglected due to the greater possibility of complete extrusion of the fragment into the periapical area. The management was directed toward the surgical intervention [121].

B. Canal Ledging:

In case of canal ledging (deviation of the root canal wall) in the apical 1/3, the management was directed to bypassing of the ledges. Straight-line access and coronal flaring using SX were established, the canals were filled with 17% EDTA gel. The bypassing protocol was started by introducing pre-curved size 06, 08, # 10 K manual files into the canals. A slight rotation of the file combined with a pecking motion was done till advancement the instrument to the full working length of the canal [122]. After several fail attempts to bypass the ledges, the management was directed toward the surgical intervention.

C. Zipping:

In case of canal zipping (Apical transportation of a curved canal), it is not possible to achieve proper cleaning, disinfection and proper filling. Thus, the management was directed toward repair of the perforation using MTA prior to the surgical intervention [123].

D. Canal Calcification:

In case of canal calcification in the apical 1/3, the operator was tried to manage the canal calcification as follow. Straight-line access and coronal flaring using SX were established, the canals were filled with 17% EDTA gel. A slight rotation of the file combined with a pecking motion was done using size 06, 08, # 10 C+Files (Denstply, Tulsa, OK, USA) till advancement the instrument to the full working length of the canal [124]. If not, the management was directed toward the surgical intervention.

Finally, all cases that could not be managed non-surgically, were included in the study.

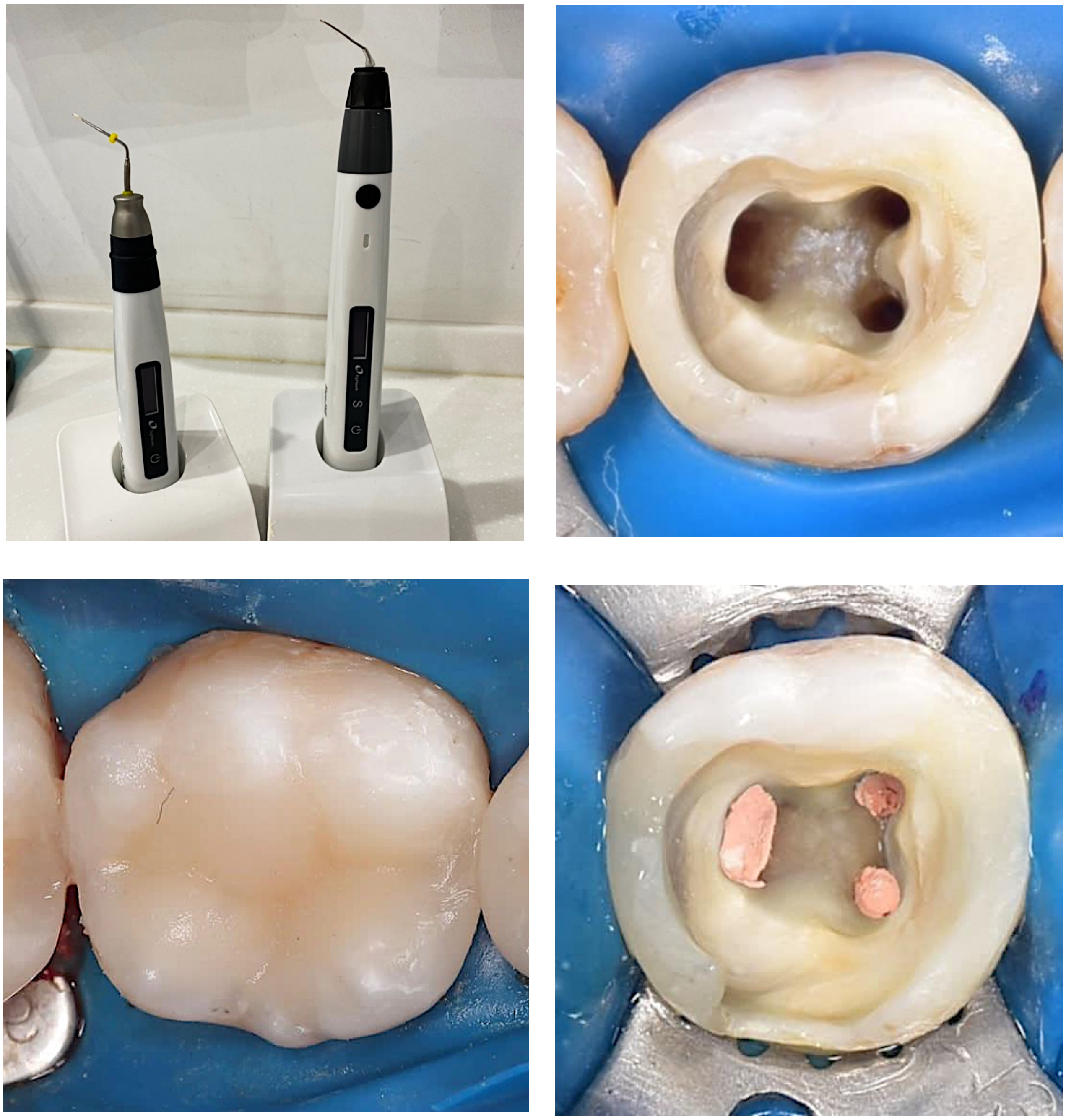
4.5.2 Pre-Surgical Management:

The **1st visit** (In the mesial root canals): The working length and working width were measured at the level of the coronal extent of the iatrogenic errors by placing a suitable size K file and the length was confirmed by taking digital periapical radiographs. The canals were instrumented using rotary files system protaper next (Dentsply Maillefer, Switzerland) to a file size # X5 using a brushing motion filling technique accompanied with irrigation between each file with 5% sodium hypochlorite (NaOCl) (Clorox, Clorox Inc.) using side-vented irrigation tips (Ultradent Products Inc., USA). In case of the canal apical diameter was wider than # X5, no further instrumentation of the root canal was done. Passively activated irrigation was performed for 3 min using ultrasonic activator (Ultra X, Eighteeth, Changzhou, China). The mesial canals were dried using absorbent paper points (Meta, Biomed, South Korea) and an orthograde MTA (TehnoDent., Russia) was mixed with normal saline under manufacture instructions [125]. The mix was applied using MTA applicator (MAP One, Switzerland) into the canals and compacted using different size pluggers to a level 6 mm. from the radiographic apex and confirmed using digital radiographs. The rest of the canals were cleaned from the excesses MTA and a wet cotton pellet and temporary filling was applied.

The **2nd visit** (In the distal root canals): The working length and working width were measured at 0.5 mm from the radiographic apex by placing a size #15 K file and the length was confirmed by taking digital radiographs. The canals were instrumented using rotary files system protaper next to a file size # X4 accompanied with 5% sodium hypochlorite irrigation and the canals were passively activated for 3 min.

After that, All the mesial and distal canals were dried and obturated using vertical compaction technique as follows **[126]**, the root canal resin sealer (Adseal Meta, Biomed, Cheongju, South Korea) was applied into the canals using a manual spreader # 30 (Mani Inc., Tochigi, Japan). Starting with the distal root canals, the master apical gutta perchea points corresponded to X4 (Meta, Biomed, South Korea) were snugly fit into the canals. The pin was inserted into level of 5 mm from the radiographic apex then heated for 2 seconds at 200°C (Fast Pack, Eighteeth, Changzhou, China) to soften the gutta perchea points. The soften gutta perchea were compacted using different size pluggers. The rest of the mesial and distal canals were obturated by soften injecting gutta percha (Fast Fill, Eighteeth, Changzhou, China) and the gutta perchea were compacted using different size pluggers. The excess sealer and gutta perchea were removed and cleaned.

The tooth surfaces were etched with 37% phosphoric acid (Meta Biomed Co.Ltd. Meta Etchant, Korea), bonded (Solobond M. Voco. Germany) and restored using bonded composite restoration (Polofil Nht. Voco. Germany) to the level of the occlusal surface with the aid of Celluloid molar crowns (Tor VM, Moscow, Russia) (**Figures 6-9).**



Figures (6-9): Photographs showing steps of non-surgical management of mandibular 1st molars.

4.6 Grouping and Randomization of the patients:

The selected patients were randomly divided into **Two groups** (n = 10) according to the type of the cutting tools during bony cavity preparation and root end resections **(Table 1).**

Group I:	**Piezosurgery** assisted cavity preparation.
Group II:	**Trephine Bur** assisted cavity preparation.

Table (1): A table Showing grouping of the patients.

Randomization of the selected patients was done by giving each patient a number from 1 to 20. The patient's numbers were submitted in a Research Randomizer software (www.randomizer.org) for blind distribution of the selected patients in each group **(Table 2).**

Research Randomizer Results	
Range: From 1 to 20	
Group I	**Group II**
9	**15**
5	**3**
13	**17**
20	**8**
1	**14**
16	**19**
7	**2**
12	**11**
18	**6**
4	**10**

Table (2): A table Showing research randomization.

4.7 Surgical Guide Template designing & Fabrication:

A Surgical guide was virtually designed to locate the appropriate osteotomy site, the mesial root apex of the mandibular first molars precisely and the 3 mm apical resection level of the root ends and the lesion area (In case of 1 mm. periapical lesion) as follows.

4.7.1 Scanning of the patients:

A CBCT scan was taken using both of lip retraction and open vertical bite techniques [127,128]. A lip retraction technique was performed using a medium size cheek lip retractor (JIAXING, mainland, China) for lip and cheek retraction. An open vertical bite technique was performed using a small size bite block (Anhui, Shanghai, China) to open the mouth vertical with 45° degree. After scanning, the digital imaging, and communications in medicine (DICOM) file was exported.

A digital optical impression was acquired using an intra-oral scanner (Omnicam, Sirona Dental System, GmbH, Germany). Both maxillary and mandibular arches were captured including teeth, ridges, and alveolus during the impression. After scanning, stereolithography (STL) file was exported. The STL file was merged and superimposed with the DICOM file acquired from the CBCT in an implant planning software (Blue Sky Plan 3, Blue Sky Bio) for surgical guide designing.

4.7.2 Designing of the surgical guide template:

Using a virtual measure/tracing tool provided by the implant planning software, an Inferior alveolar nerve was marked and traced slice by slice started from the mandibular canal within the ramus to the mental foramen. The dimension of the mandibular 1st molar was measured mesiodistally, buccolingually, and occlusoapically. The iatrogenic errors located within the apical 3 mm. of the mesial root in addition to the peri-apical radiolucent area were marked and traced using a virtual measure/tracing tool. The cortical bone surrounding to the mandibular 1st molar were gauged and measured at a point 3 mm above radiographic root apex as follows,

Depth I: The distance from the outer surface of the buccal cortical plate to the buccal surface of the mesial root of the mandibular 1st molar = 1.5 mm ± 0.5 mm.

Depth II: The distance from the buccal to the lingual surface of the mesial root of the mandibular 1st molar requiring resection = 7 mm ± 2 mm.

Depth III: The distance from the lingual surface of the mesial root of the mandibular 1st molar to the outer surface of the lingual cortical plate of bone = 3.7 mm ± 0.5 mm.

The parameters of the cutting tools for both Piezosurgery tip and trephine bur used in the study were dimensionally measured using a digital caliper (JIGONG 0-150, China).

A Piezosurgery tip (IM4A, Mectron, Carasco, Italy) is a stainless-steel with titanium nitride coating tip. The length of the tip is 30 mm measured from the handpiece tip opening to the top of the cutting flutes with laser marks on the shaft up to 15 mm. The cutting tip design is rounded in cross section and the cutting flutes is 4 mm in the outer diameter and 2 mm in length. The angle between the cutting flutes and long access of the tip is 15°. **(Figure 10)**

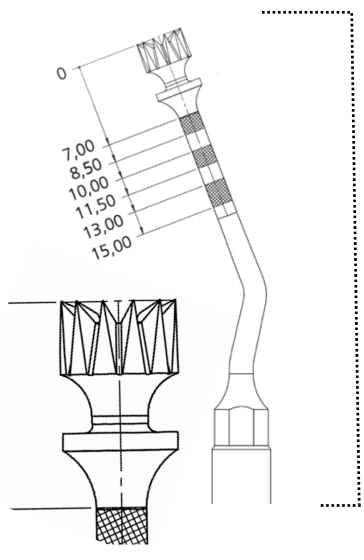


Figure (10): Draw showing Piezosurgery tip design.

A Trephine bur (TPB-4, MCT BIO, Gyeonggi-do, Korea) is a stainless-steel surgical cutting bur. The length of the bur is 28 mm. measured from the contra angle bur opening to the top cutting flutes. The barrel length is 12.8 mm with laser marks on the shaft up to 10 mm. The cutting part design is rounded in cross section, 4 mm in the outer diameter, 3 mm in the inner diameter and the depth of the cutting edges is 1.0 mm. The angle between the cutting flutes and long access of the bur is 0° **(Figure 11)**

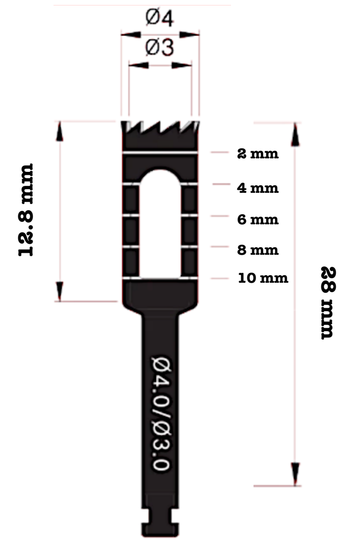


Figure (11): Draw showing Trephine bur design.

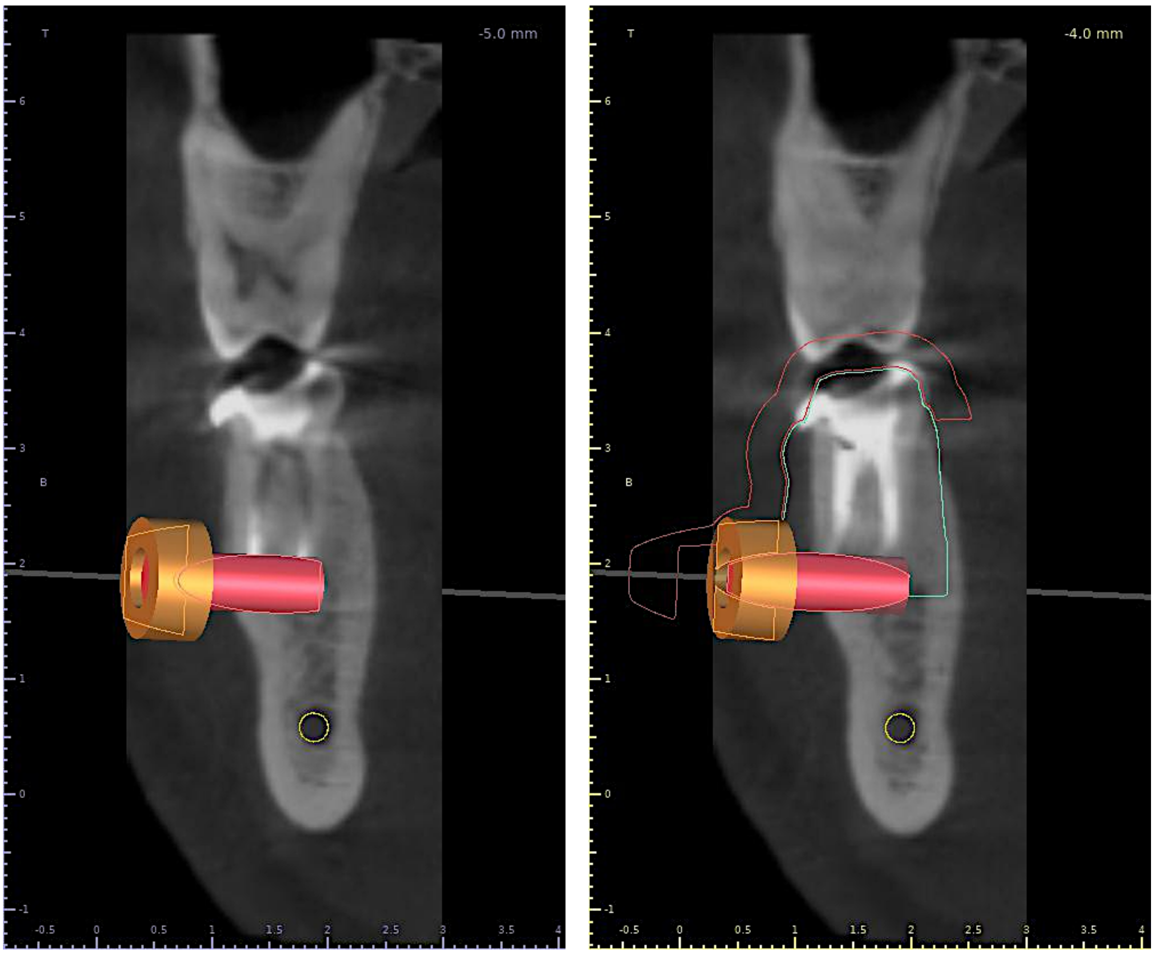
The osteotomy parameters were planned as follows,

- The upper margin of the osteotomy was planned to be at a point located 3 mm above the radiographic root apex bisecting the root.
- The lower margin of the osteotomy was planned to be at a point located 1 mm below the radiographic root apex bisecting the root.
- The diameter of the osteotomy was planned to be 4 mm related to the outer diameter of tips of the Piezosurgery tip and the trephine bur.
- The shape of the osteotomy was planned to be rounded cross-section related to the shape of tips of Piezosurgery and trephine bur.
- The Depth of the osteotomy **Depth S** was planned to be the sum of **Depth I** + **Depth II** + 1 mm. **(Figures 12 -13)**

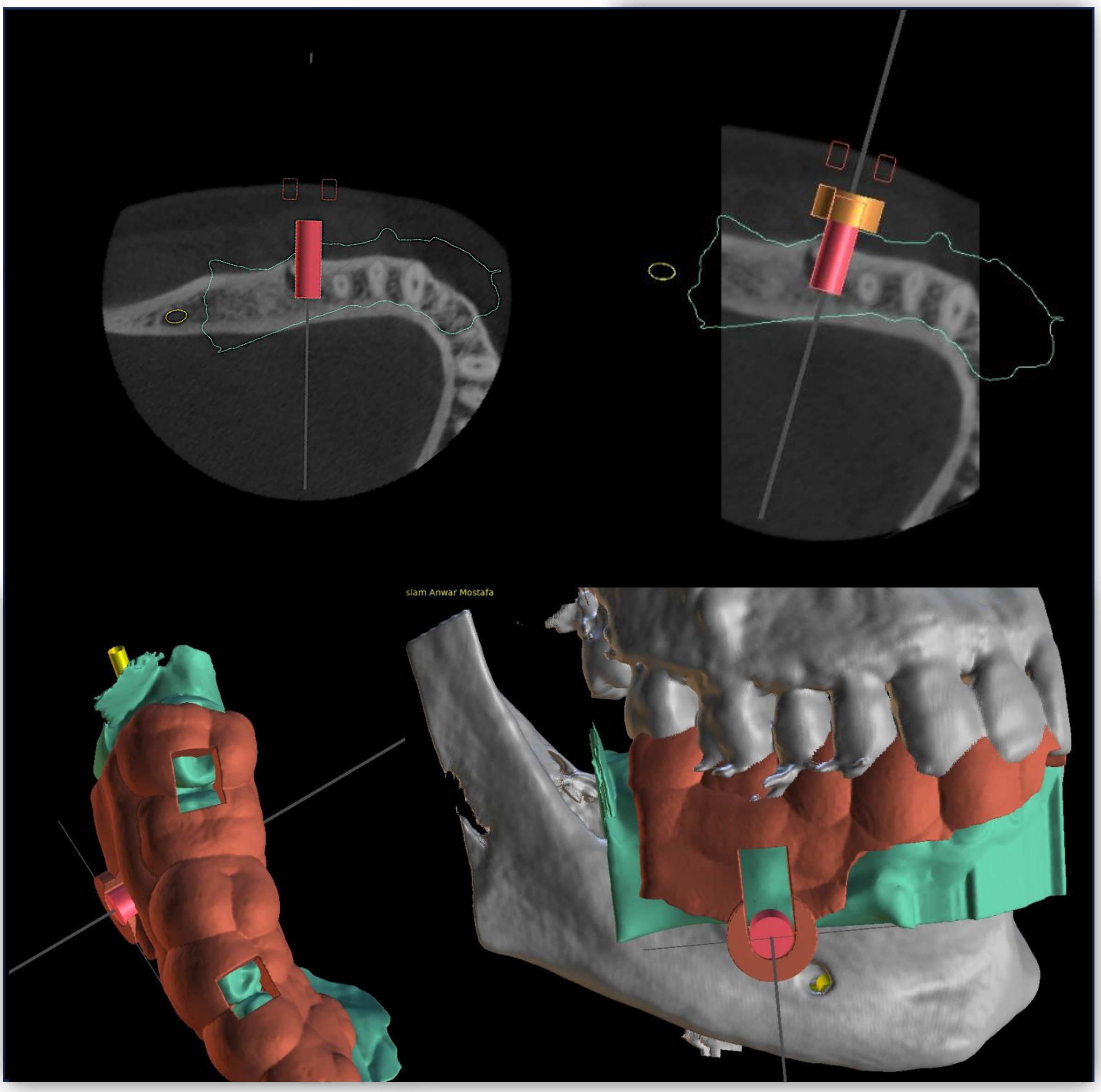
The outline borders of the surgical guide were design to cross the canine area anteriorly and to cross the mandibular 2nd molar area posteriorly. Some features were added to the design including a space reserved for soft tissue were 0.5 mm in thickness, a space for cutting tools movement within the buccal directed tunnel were 0.2 mm in thickness, a buccal tunnel directed to the osteotomy access hole for accessibility, an instrument stopper located at the buccal border of the guide to control the depth of instruments penetration, in addition to a couple of rectangular holes through the occlusal surface of the guide serves as a view box to check for complete seating of the guide.

4.7.3 Fabrication of the Surgical guide:

The virtually designed surgical guide were exported as STL file and transferred to a 3D printer (Phrozen Sonic Mighty 4K, ChiTuBox 1.6.5, Taiwan) for surgical guide fabrication using a transparent resin (Savoy Surgical Guide Clear 3D Printer 405nm Resin, China). Following, the surgical guide was checked and evaluated of any excess or sharp edges before use. **(Figure 14-18)**



Figures (12,13): CBCT sections showing digital planning for osteotomy parameters.



Figures 14-17 : Virtual digital designs for the surgical guide during the planning.

Figure 18: A photograph showing surgical guide try in.

4.8 Clinical assessment before Surgical intervention:

4.8.1 Pre-operative Pain assessment:

The preoperative pain assessment of selected patients that need surgical root canal treatment was done by the operator according to a scale modified from the Verbal Descriptor Scale (VDS) [129]. The VDS consist of a scoring system translated into an Arabic, describes a list of adjectives describing the different level of pain including, no pain (score 0), mild pain (score 2), moderate pain (score 4), strong pain (score 6), severe pain (score 8), worst pain (score 10). The operator marked the adjective which fits the pain intensity according to the patient's own words **(figure 19).** The odd numbers represent the intermediate pain intensity among the main pain levels. Patients with a score level (0 - 5) were included in the study. **(Table 3)**

Score	Pain Intensity	**Description**
(0 – 1)	**No Pain**	Tooth felt Normal
(2 – 3)	**Mild Pain**	Low Pain intensity + No Need for analgesics
(4 – 5)	**Moderate Pain**	Higher Pain intensity than mild pain level (Tolerable) + may need Non-Steroidal Anti-Inflammatory Drugs (NSAID) analgesics.
(6 – 7)	**Strong Pain**	Strong pain intensity that disrupts sleep + Need (NSAID) analgesics
(8 – 9)	**Severe Pain**	Severe pain intensity that disrupts normal activity (Eating, Walking, Sport activity, etc.) and/or Sleep + No effect of (NSAID) administration
(10)	**Worst Pain**	Severe pain that disrupts normal activity and/ or Sleep + General symptom manifestation including fever and weakness + Need Antibiotics and Narcotic analgesics.

Table (3): A table showing types of pain assessment levels

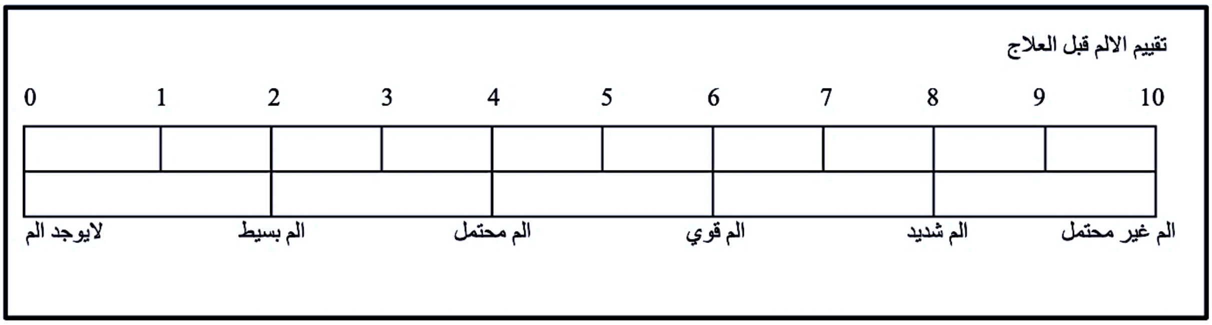


Figure (19): Template showing preoperative Pain Assessment (Translated into Arabic)

4.8.2 Pre-operative Swelling assessment:

The preoperative swelling assessment of selected patients was done by the operator according to a swelling assessment scale. The swelling assessment scale consist of a scoring system describes a list of adjectives describing the different level of swelling from (none) to (severe) [130,131]. The patients with a score level (0) were only included in the study. **(Table 4)**

Score	Status	Criteria
Score 0	**None**	No swilling.
Score 1	**Mild**	Intraoral swelling confined to the surgical field.
Score 2	**Moderate**	Extraoral swelling confined to the surgical field.
Score 3	**Severe**	Extraoral swelling spreading beyond the surgical field.

Table (4): A table showing swelling assessment levels.

4.8.3 Pre-operative Periodontal assessment:

A. Tenderness to apical palpation: The alveolar ridge on both sides of the alveolar process at the apices of the teeth was palpated with the thumb and the index finger.

B. Tenderness to percussion: The cusps of each tooth were percussioned three times with the shaft of a straight probe.

The periodontal status assessment tests (132) were performed by the operator on four teeth in each side including the test tooth and the control tooth respectively. The test tooth and its adjacent teeth were first examined followed by the control tooth and its adjacent teeth. The teeth were tested in a non-controlled randomized order. The patient's responses to apical palpation and percussion of the tested teeth were registered according to the following criteria and the patients with a score levels 0 and 1 were included in the study **(Table 5).**

Score	Status	Criteria
Score 0	**None**	A non-affirmative answer to the question whether pain was felt, (No reaction)
Score 1	**Mild**	An affirmative answer to the question whether pain was felt. (Discomfort)
Score 2	**Severe**	An affirmative answer to the question whether pain was felt. (The patient flinched when examined)

Table (5): A table showing periodontal status assessment

C. The grade of tooth mobility (133,134) were examined by the operator as following; The tooth is firmly held between metallic handles of two instruments and moved in the buccolingual direction, and the moved distance is visually estimated. The grade of tooth mobility was scored on a scale of 0 to 3 and the patients with a score level (0) were only included in the study. **(Table 6).**

Score	Status	Criteria
Score 0	**None**	no detectable movement apart from physiologic tooth movement
Score 1	**Mild**	The movements were greater than physiologic tooth mobility
Score 2	**Moderate**	The tooth mobility was up to 1 mm in bucco-lingual direction,
Score 3	**Severe**	The tooth mobility >1 mm in bucco-lingual in combination with vertical depressability.

Table (6): A table showing grade of tooth mobility assessment

D. The clinical attachment level (CAL) [135] were examined by the operator as following; the periodontal probe was inserted into the sulcus parallel to the long axis of the tooth and applying the force to move it apically into the tissue along the tooth surface. The probe was circumferentially moved around each surface of tooth to detect the areas of deepest penetration at each of six tooth surfaces: distobuccal, buccal, mesiobuccal, distolingual, lingual and mesiolingual. The clinical attachment level was recorded from the CEJ to the base of the pocket and scored on a scale of 0 to 3. The patients with a score level (0) were only included in the study. **(Table 7).**

Score	Status	Criteria
Score 0	**None**	The clinical attachment level of < 1 mm
Score 1	**Mild**	The clinical attachment of 1 - 3 mm
Score 2	**Moderate**	The clinical attachment of 3 - 5 mm
Score 3	**Severe**	The clinical attachment of ≥5 mm

Table (7): A table showing clinical attachment level assessment

4.9 Surgical Intervention.

All steps of the endodontic microsurgery were carried out under varying degrees of magnification (8X–16X) using a dental operating microscope, including flap incision, osteotomy, root-end resection, apical curettage, filling of the bone cavity, flap reposition and suturing. **(Figure 20).**

4.9.1 Patients preparation and anaesthetization:

Prior to anesthesia, disinfection of the operative field including the cheeks, tongue, gum, and lips was performed by swapping with a betadine antiseptic solution (Betadine 10% antiseptic, Nile company for pharmaceuticals and chemical industries, Egypt). Standard inferior alveolar nerve anesthesia technique (Halsted block) [136] accompanied by long buccal nerve block anesthesia was performed. Two carpules of local anesthesia solutions lidocaine 2% adrenaline 1:80.000 (Septodent, Lignospan, France) were used through a 27-gauge long needle mounted in a dental syringe.

4.9.2 Flap Elevation

A submarginal flap with one vertical releasing incision was performed using a carbon steel surgical scalpel blade no. 15c (Swann Morton, Sheffield S6 2BJ, England). The submarginal flap with one vertical releasing incision was performed as follows, a scalloping incision was performed following the free gingival margin pattern started at a point 3 mm from the attached gingiva coronally and extended mesially to a point mesial to the mandibular first premolar and extended distally to a point between the distal root of the mandibular first molar and the mesial root of the mandibular second molar. A one vertical releasing incision parallel to the long axis of the mandibular first premolar was performed mesially on a solid bone and extended to the level of muco-buccal fold. A full-thickness flap was reflected using a microsurgery muco-periosteal elevator (Molt, Sedra Dent, Pakistan) and the bleeding was controlled by local compression with a sterile gauze against the buccal cortical plate of bone **(Figures 21-23).**

4.9.3 Osteotomy and Root-End resection:

Group (I): A Piezosurgery assisted cavity preparation was performed using a **IM4A** Piezosurgery tip mounted in the handpiece of a Piezosurgery device (PIEZOSURGERY® touch, Mectron, Carasco, Italy) at an operating frequency in the range of 24 to 36 kHz with power ratings 55 W for osteotomy and root-end resection [(71)].

Rubber stoppers were applied to the shaft of each Piezosurgery tip to demarcate the depth of the osteotomy **Depth S** of each patient. The cutting mode of the piezosurgery device was adjusted on a compact bone mode and the power of irrigation with saline was adjusted to 75 ml/min. The surgical guide was fitted in its position, retracting the soft tissue flap and check. The osteotomy and root end resection were performed in an intermittent liner motion till reach the **Depth S**. The resected root end and bone fragments were removed using a small size rounded curette (Sedra Dent 2R, Universal Curette, Pakistan). The surgical guide was removed, and digital periapical radiographs were performed to confirm the osteotomy and the root end resection. Following, an apical curettage was performed using a small size rounded curette and the over-extended objects such as separated instruments or gutta percha were reached and removed. The osteotomy site was copiously irrigated using normal saline **(Figures 24-27).**

Group II: A Trephine bur assisted cavity preparation was performed using a **TPB-4** trephine bur mounted in 20:1 contra angled handpiece of an implant motor (ImplaNX, Micro-NX, Republic of Korea) at an operating speed in the range of 800 to 1200 / Torque 30 N for osteotomy and root-end resection [(137)].

Rubber stoppers were applied to the shaft of each Trephine bur to demarcate the depth of the osteotomy **Depth S** of each patient. The cutting mode of the implant motor was adjusted on a drilling mode and the power of irrigation with saline was adjusted to 75 ml/min (according to manufacture instructions). The surgical guide was fitted in its position, retracting the soft tissue flap and check. The osteotomy and root end resection were performed in an intermittent liner motion till reach the **Depth S**. The resected root end and bone fragments were removed using a small size rounded curette (Sedra Dent 2R, Universal Curette, Pakistan). The surgical guide was removed, and digital periapical radiographs were performed to confirm the osteotomy and the root end resection. Following, an apical curettage was performed using a small size rounded curette and the over-extended objects such as separated instruments or gutta percha were reached and removed. The osteotomy site was copiously irrigated using a normal saline **(Figures 28-33).**

4.9.4 Flap repositioning and Suture:

The flap edges were approximated and repositioned using a tissue forceps and compressed. An interrupted suturing technique [138] was performed using a 4-0 poly-tetra-fluoroethylene coated monofilament suture (PTFE) and 3/8 circle reverse cutting needle (Maxima, Henry Schein, NY, USA). **(Figure 34,35).**

4.9.5 Immediate Post-surgical CBCT scanning;

An immediate post-surgical CBCT scans were taken under standard specifications following flap suturing **(Figure 36).**

4.9.6 Post-surgical Care:

Post-surgical instructions were given as follows; Compression with ice was performed by patients in the surgical zone for the first (4 – 6 hours) post-surgically. The patients were instructed to rinse the mouth twice daily with chlorhexidine 0.2% mouth rinse for 1 week and a soft diet was advised during the postoperative period. The patients returned after 96 hours post-surgically for suture removal.

The patients have prescribed an oral analgesic (ibuprofen 600 mg) as needed and instructed to not take the analgesic before ask/send to the operator and no postoperative antibiotic therapy was prescribed.

4.9.7 Emergency Protocols:

An emergency protocol has been established in case of the presence of any complications associated with the endodontic microsurgery (side-chair) or occurred post operatively.

I. Coordination was made with Al-Hussein University Hospital in case of an emergency.

II. An emergency contact number was given to the patient and patient's family to call in case of an emergency or unbearable pain.

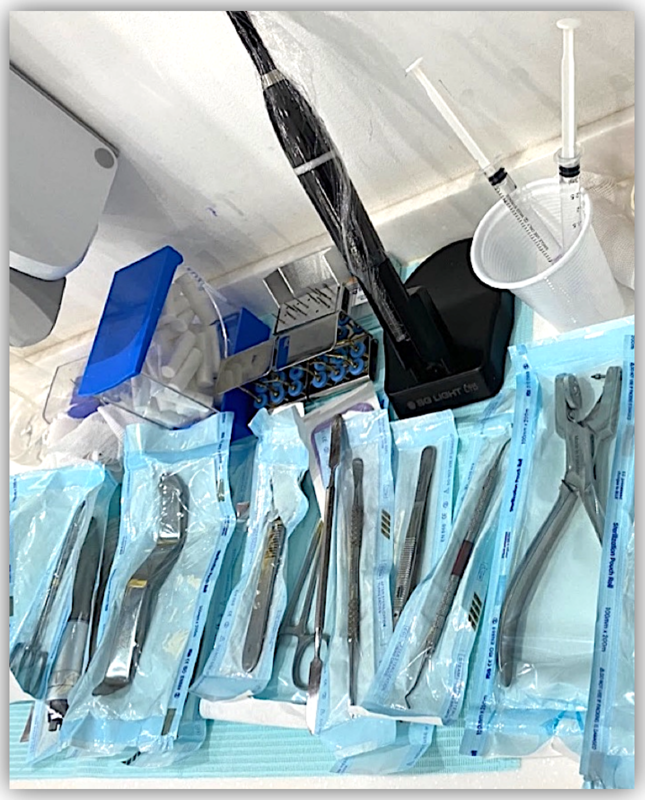


Figure (21): A photograph showing instrument used in the surgery.

Figure (20): A photograph showing Dental operating microscope (S2350, Zumax)

Figure (22): A photograph showing Submarginal flap design.

Figure (23): A photograph showing Submarginal flap with one vertical releasing incision.

Figure (24): A photograph showing surgical guide application following flap incision retracting the flap.

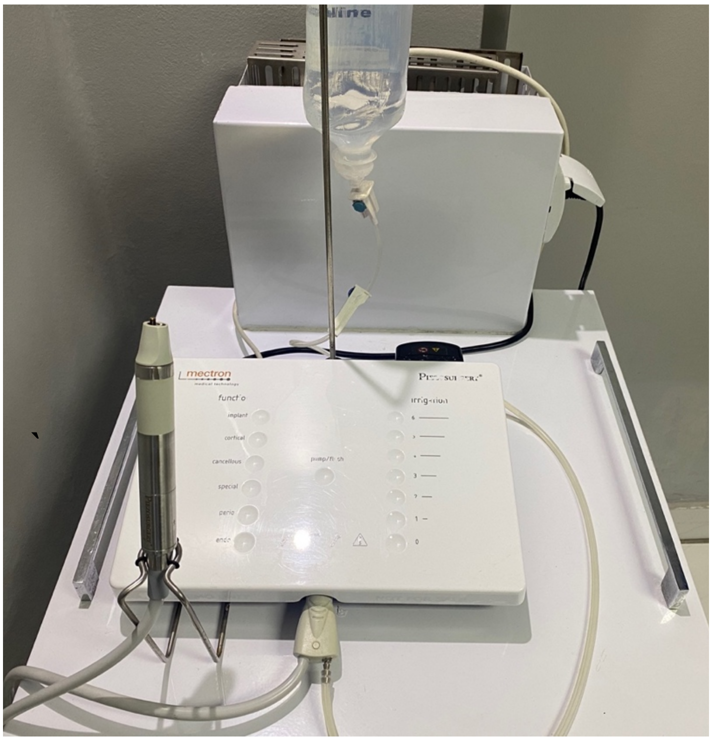


Figure (25): A photograph showing piezosurgery device.

Figure (26): A photograph showing piezosurgery ultrasonic cutting tip.

Figure (27): A photograph showing the osteotomy procedures in the piezosurgery group.

Figure (29): A photograph showing trephine bur cutting tip.

Figure (28): A photograph showing the Osteotomy procedures in the Trephine group.

Figure (31): A photograph under magnification showing bone block.

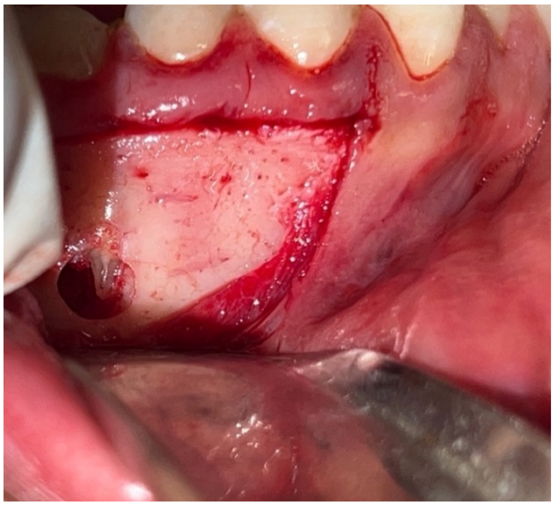


Figure (30): A photograph following the osteotomy and before root end resection.

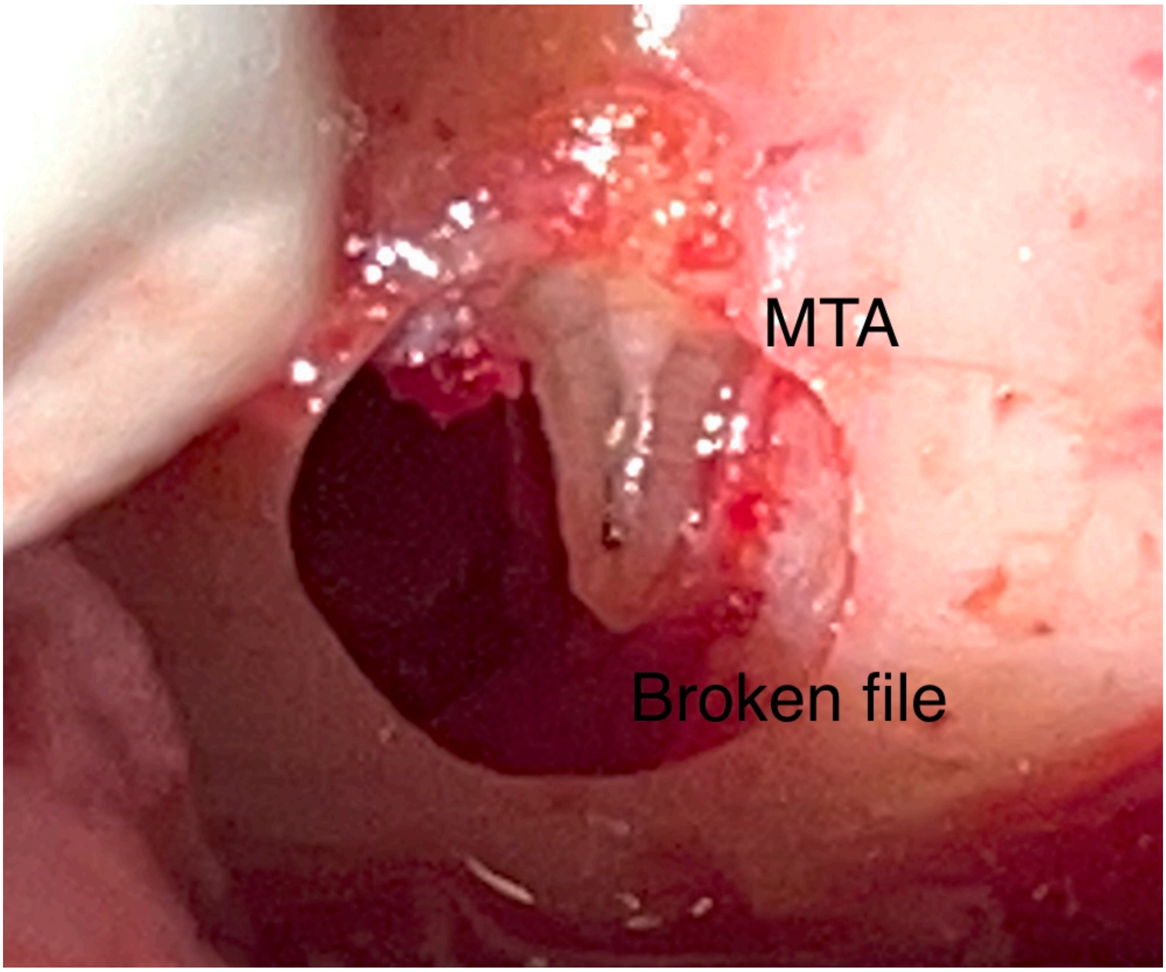


Figure (32): A photograph under magnification showing the root before resection and periapical curettage.

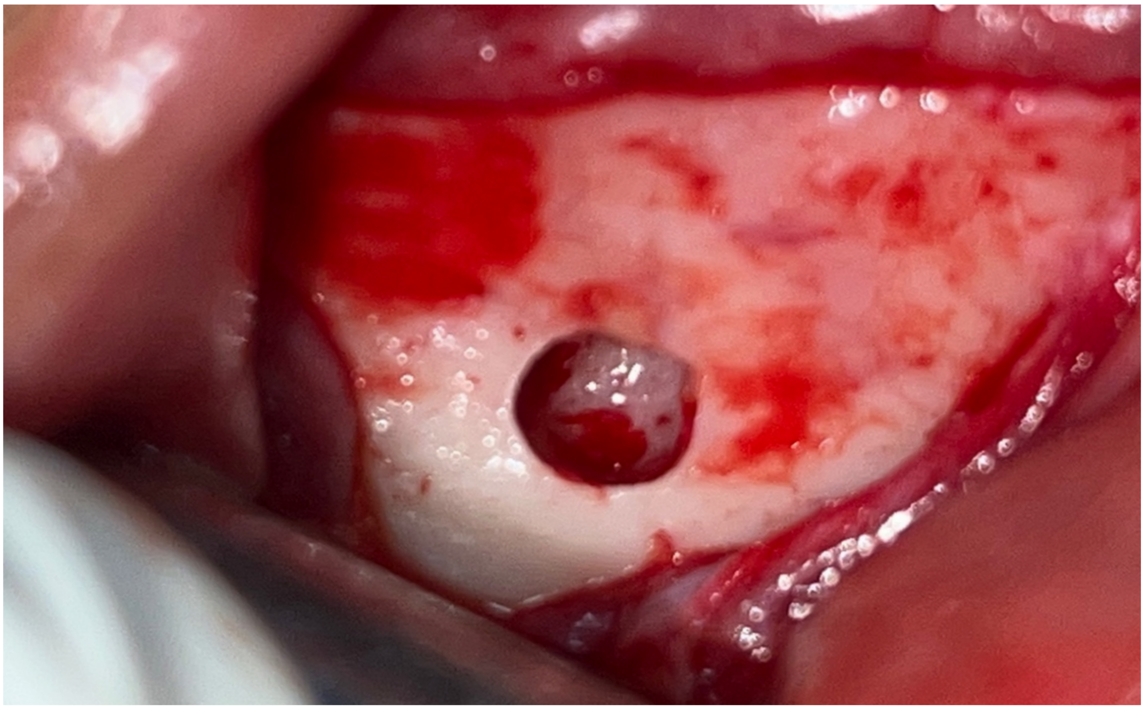


Figure (33): A photograph under magnification showing the root after resection.

Figure (35): A photograph showing suture removal at 4 days post-surgical.

Figure (34): A photograph showing flap reposition following suturing.

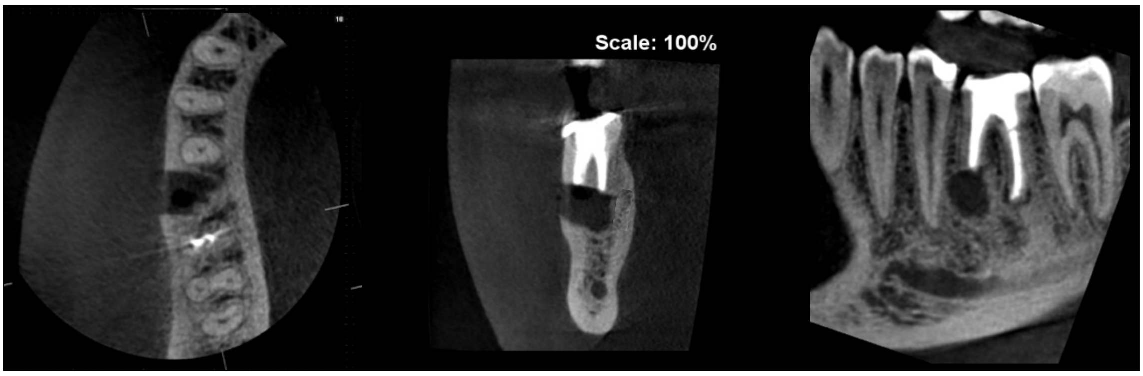


Figure (36): immediate post-surgical CBCT scan (Axial, Sagittal, Coronal views) showing the osteotomy parameters.

4.10 Post-surgical Evaluation.

4.10.1 Post-surgical Pain assessment:

The Post-surgical pain assessment was done using the modified verbal descriptor scale (VDS) for five days for each patient every 24, 48, 72, 96, and 120 hours post-surgically. Patients were initially instructed to use the VDS and the description of each level of pain intensity was explained in detail **(Score 0-10)**. Patients were given five copies of the Arabic VDS and asked to mark the level of pain intensity felt during each pain assessment. The patients were reminded by the operator one hour before each recording time mentioned in each VDS copy sheet.

4.10.2 Post-surgical swelling assessment:

The degree of swelling was recorded by the patient for five days every 24, 48, 72, 96 and 120 hours post-surgically using the swelling assessment scale. Patients were instructed to the description of each level of swelling as follows; None **(Score 0)**, Mild **(Score 1)**, Moderate **(Score 2)**, and Severe **(Score 3)**. Patients were given five copies of the Arabic swelling assessment scale and asked to mark each level of swellings. The patients were reminded by the operator one hour before each recording time mentioned in each VDS copy sheet.

4.10.3 Post-surgical palpation test:

The patients were examined by the operator 3, 6, 12 months post-surgically according to the previously mentioned criteria. The alveolar ridge on both sides of the alveolar process at the apices of the teeth was palpated with the thumb and the index finger and the patient’s responses to apical palpation of the tested teeth were registered.

4.10.4 Post-surgical Percussion test:

The patients were examined by the operator 3, 6, 12 months post-surgically according to the previously mentioned criteria. The cusps of each tooth were percussioned three times with the shaft of a straight probe and the patient's responses to apical percussion of the tested teeth were registered.

4.10.5 Tooth mobility test:

The patients were examined by the operator 3, 6, 12 months post-surgically according to the previously mentioned criteria. The tooth is firmly held between metallic handles of two instruments and moved in the buccolingual direction. The moved distance of the tested teeth was visually estimated and registered**.**

4.10.6 The clinical attachment level:

The patients were examined by the operator 3, 6, 12 months post-surgically according to the previously mentioned criteria. The clinical attachment level was recorded of the tested teeth.

4.10.7 Post-surgical CBCT Assessment:

4.10.7.1 CBCT Healing outcomes evaluation (Semi-quantitative).

Post-surgical CBCT scans were performed 6 and 12 months following the endodontic microsurgery. These scans were compared with the immediate post-surgical scans for evaluation of surgical endodontic healing according to Modified PENN 3D criteria [111].

The outcomes of the healing were classified into complete healing **(Score 0)**, limited healing **(Score 1)**, uncertain healing **(Score 2)**, and unsatisfactory healing **(Score 3) (table 8).**

Score	Status		Criteria
Score 0	**Clinical Successful Cases**	**Complete Healing**	A. Reformation of periodontal space of normal width and lamina dura over the entire resected and unresected root surfaces. B. Slight increase in width of apical periodontal space over the resected root surface but less than twice the width of non-involved parts of the root. C. Small defect in lamina dura surrounding the root end filling. D. Complete bone repair with discernible lamina dura; bone bordering the apical area doesn't have the same density as surrounding non-involved bone. E. Complete bone repair (Hard tissue covering the resected root end surface completely)
Score 1	**Clinical limited Successful Cases**	**Limited Healing**	Complete healing was observed in the immediate vicinity of the resected root surface, but the site demonstrates one of the following conditions: A. The continuity of the cortical plate is interrupted by an area of lower density. B. A low-density area remains asymmetrically located around the apex or has an angular connection with periodontal space. C. Bone has not fully formed in the area of the access osteotomy.
Score 2	**Clinical Failed Cases**	**Uncertain Healing**	The volume of the low-density area appears decreased and demonstrated one of the following conditions: A. The thickness is larger than twice the width of the periodontal space. B. The location is symmetrically around the apex as a funnel-shaped extension of the periodontal space.
Score 3		**Unsatisfactory Healing**	The volume of the periapical radiolucency appears enlarged or unchanged.

Table (8); A table showing healing outcomes levels.

4.10.7.2 Volumetric measurements (Quantitative)

The 6 and 12 months Post-surgical CBCT scans following the endodontic microsurgery were evaluated and compared with the immediate post-surgical scans for evaluation of surgical endodontic healing. The volumetric measurements and segmentation procedure of the periapical radiolucency were manipulated [139,140] using (Planmeca Romexis Viewer volume 6.0.1.812; Planmeca OY, Helsinki, Finland) and the volume of periapical radiolucency was measured in cm^3 (Semi-Automated) as followed:

1. The periapical radiolucency was located in each of the 3 planes axial, coronal and sagittal,
2. 2D segmentation in all 3 planes was assisted to select region of interest (ROI) (the radiolucent area) in these 3 slices using a automatic grayscale value range selection tool.
3. Create a 3D reconstruction of the radiolucency by expanding the selected areas in all slices in the 3 planes (wrap tool).
4. Inspect the borders of the selected volume in all slices and correct them when necessary.
5. Use the material statistics option of the software for semiautomatic defect volume recognition and calculation for the selected volumes in mm^3 for each case. **(Figure 37-38)**

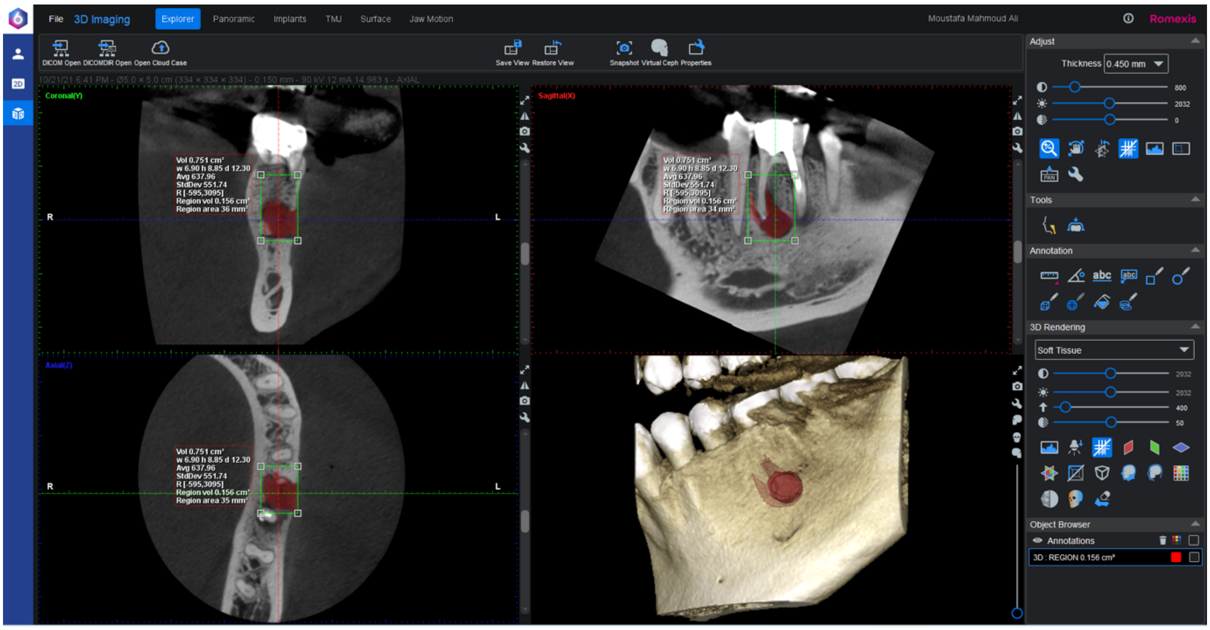


Figure (37): An immediate post-surgical CBCT scan showing semi - Automated volumetric measurement in cm^3 for periapical radiolucency (Planmeca Romexis Viewer)

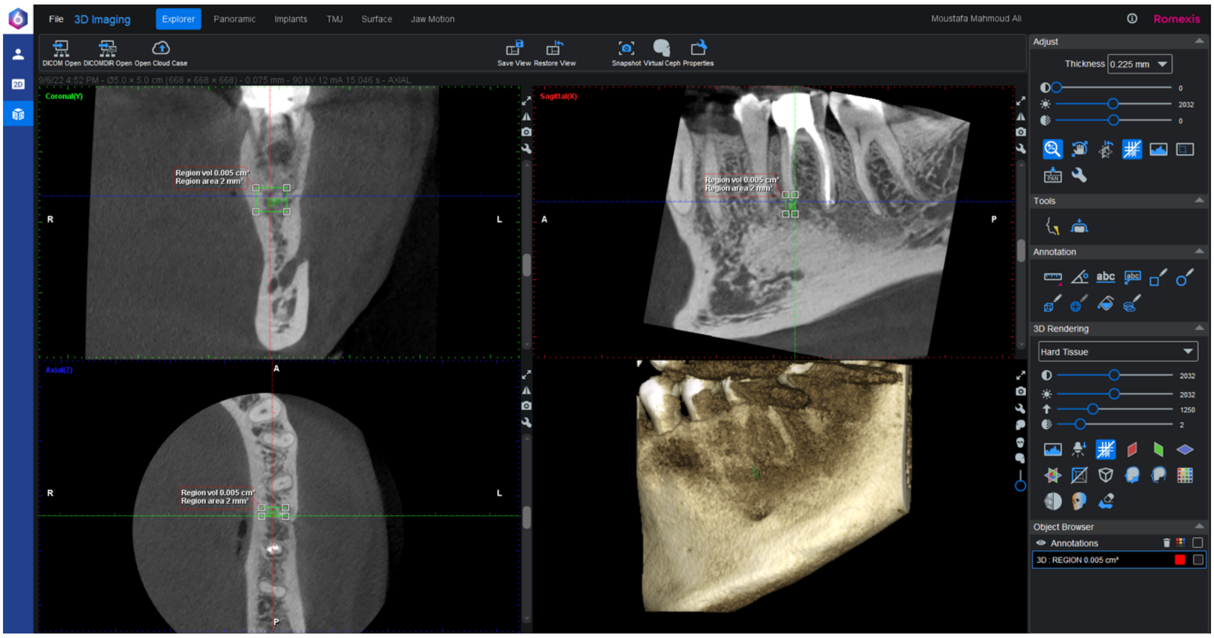


Figure (38): A post-surgical CBCT scan showing semi - Automated volumetric measurement in cm^3 for periapical radiolucency after 12 months follow up (Planmeca Romexis Viewer)

4.10.7.3 Bone density measurements (Quantitative):

The 6 and 12 months Post-surgical CBCT scans following the endodontic microsurgery were evaluated and compared with the immediate post-surgical scans for quantitatively bone density values measurements of the periapical bone defect healing using Osirix Imaging software (Pixmeo, Geneva, Switzerland) [141, 142]. The entire defect zone was outlined semiautomatic and the defect bone density values were recognition and calculation for each case using the material statistics option of the software **(Figure 39 - 40).**

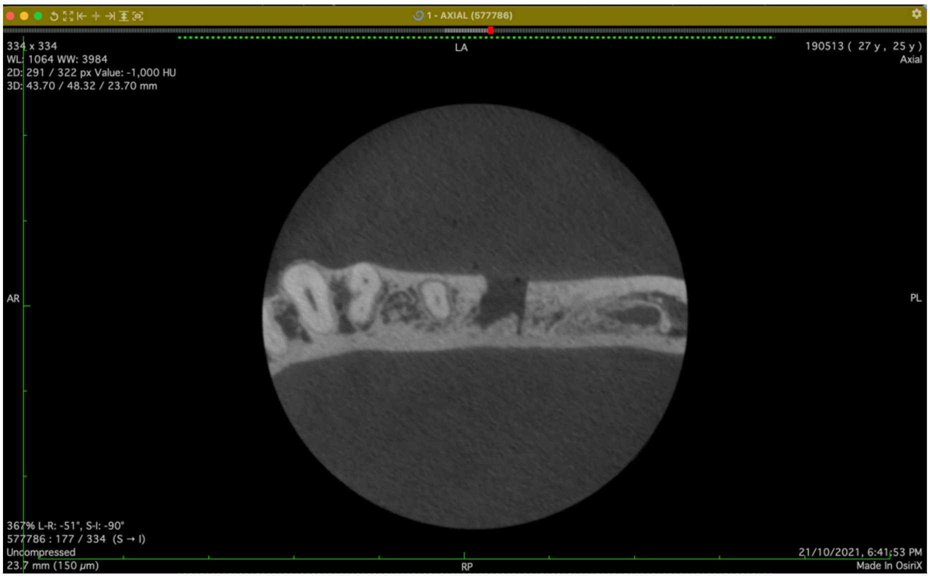


Figure (39): An immediate post-surgical CBCT scan showing Bone Density measurement for periapical radiolucency (Osirix Imaging software).

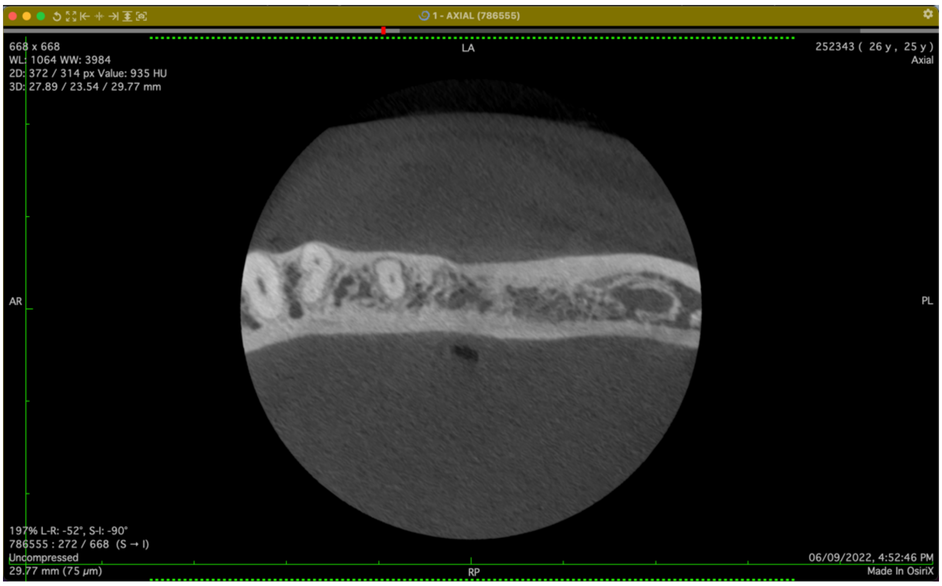
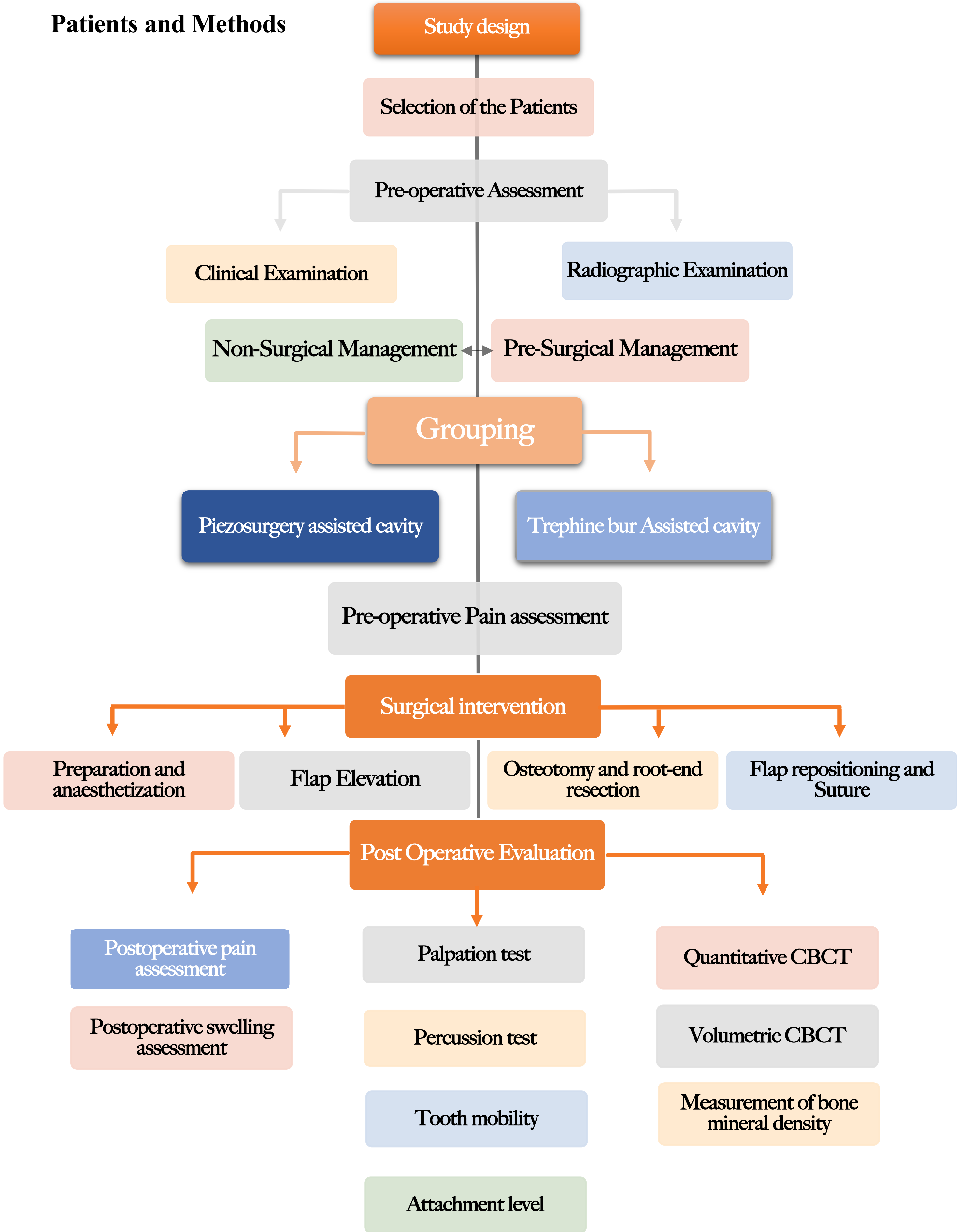


Figure (40): A post-surgical CBCT scan showing Bone Density measurement for periapical radiolucency after 12 months follow up (Osirix Imaging software).

4.11 Data management and analysis

Data was collected, tabulated, and statistically analyzed. Numerical data were summarized using means and standard deviations. Independent sample T test was used to test a difference between two groups and Friedman test was done to assess difference among repeated measures. Statistical analysis was conducted using Statistical Package for Social Sciences SPSS for Windows 25 statistical software (SPSS, Chicago).

Patients and Methods



5. Results.

Section outline:

- **5.1 Post-surgical pain assessment of the different treatment modalities.**
- **5.2 Post-surgical swelling assessment of the different treatment modalities.**
- **5.3 Post-surgical palpation assessment of the different treatment modalities.**
- **5.4 Post-surgical percussion assessment of the different treatment modalities.**
- **5.5 Post-surgical tooth mobility assessment of the different treatment modalities.**
- **5.6 Post-surgical clinical attachment level assessment of the different treatment modalities.**
- **5.7 Post-surgical CBCT Assessment:**
  - **5.7.1 Comparison between the Healing outcomes of the different treatment modalities (Semi-quantitative).**
  - **5.7.2 Comparison between the volumetric measurements of the different treatment modalities (Quantitative)**
  - **5.7.3 Comparison between the bone density measurements of the different treatment modalities (Quantitative)**

5. Results

5.1 Post-surgical pain assessment of the different treatment modalities:

Data in this section was statistically analyzed using Independent sample T test. All the pain scores mean were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at different time points.

At 24 hours: Group I recorded a pain score mean value of 0.60 ± 0.96 (mean ± SD). **Group II** recorded a higher pain score mean value of 1.40 ± 1.64. There was statistically no significant difference between groups (p=**0.206** > 0.05).

At 48 hours: Group I recorded a pain score mean value of 2.20 ± 1.47. **Group II** recorded a slightly higher pain score mean value of 2.80 ± 2.34. There was statistically no significant difference between groups (p= **0.503** >0.05).

At 72 hours: Group I recorded a pain score mean value of 2.60 ± 1.64. **Group II** recorded a slightly higher pain score mean value of 3.00 ± 2.16. There was statistically no significant difference between groups (p= **0.647** >0.05).

At 96 hours: Group I recorded a pain score mean value of 1.60 ± 1.57. **Group II** recorded a slightly higher pain score mean value of 1.80 ± 1.47. There was statistically no significant difference between groups (p= **0.733** >0.05).

At 120 hours: Group I recorded a pain score mean value of 0.60 ± 0.96. **Group II** recorded a pain score mean value of 0.60 ± 0.96. There was statistically no significant difference between groups (p= **1** >0.05). **(Table 9)(Figure 41)**.

Table (9): Comparison between pain levels of the Piezosurgery and Trephine Techniques at different time points:

Pain	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
24 h	**0.60**	0.96	**1.40**	1.64	**-1.35**	**0.206**
48 h	**2.20**	1.47	**2.80**	2.34	**-0.648**	**0.503**
72 h	**2.60**	1.64	**3.00**	2.16	**-0.466**	**0.647**
96 h	**1.60**	1.57	**1.80**	1.47	**-0.293**	**0.733**
120h	**0.60**	0.96	**0.60**	0.96	**0.00**	**1.00**

(*) A symbol mean presence of significant between groups (p<0.05)

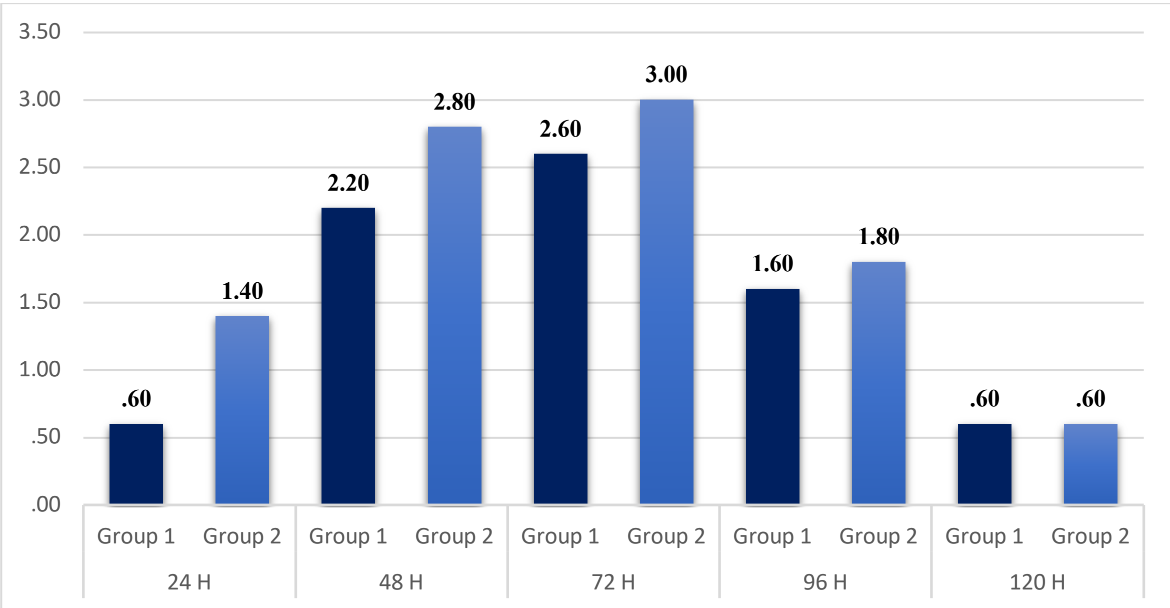


Figure (41): A chart of pain scores comparison between the groups at different time points

5.2 Post-surgical swelling assessment of the different treatment modalities.

Data in this section was statistically analyzed using Independent sample T test. All the swelling scores mean values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** in different time points.

At 24 hours: Group I recorded a swelling score mean value of 0.60 ± 0.69. **Group II** recorded a slightly higher swelling score mean value of 0.90 ± 0.31. There was statistically no significant difference between groups (p= **0.239** > 0.05).

At 48 hours: : Group I recorded a swelling score mean value of 0.90 ± 0.73. **Group II** recorded a slightly higher swelling score mean value of 1.30 ± 0.67. There was statistically no significant difference between groups (p= **0.222** >0.05).

At 72 hours: : Group I recorded a swelling score mean value of 1.10 ± 0.87. **Group II** recorded a higher swelling score mean value of 1.70 ± 0.94. There was statistically no significant difference between groups (p= **0.159**>0.05).

At 96 hours: Group I recorded a swelling score mean value of 0.40 ± 0.51. **Group II** recorded a slightly higher swelling score mean value of 0.80 ± 0.78. There was statistically no significant difference between groups (p= **0.196** >0.05)

At 120 hours: Group I recorded a swelling score mean value of 0.40 ± 0.51. **Group II** recorded a pain score mean value of 0.40 ± 0.51. There was statistically no significant difference between groups (p= **1** >0.05). **(Table 10)(Figure 42)**.

Table (10): Comparison of Swelling levels between Piezosurgery and Trephine Techniques at Different Time Points.

Swelling	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
24 h	**0.60**	0.96	**0.90**	0.31	**-1.24**	**0.239**
48 h	**0.90**	0.73	**1.30**	0.67	**-1.27**	**0.222**
72 h	**1.10**	0.87	**1.70**	0.94	**-1.47**	**0.159**
96 h	**0.40**	0.51	**0.80**	0.78	**1.34**	**0.196**
120h	**0.40**	0.51	**0.40**	0.51	**0.00**	**1.00**

(*) A symbol mean presence of significant between groups (p<0.05)

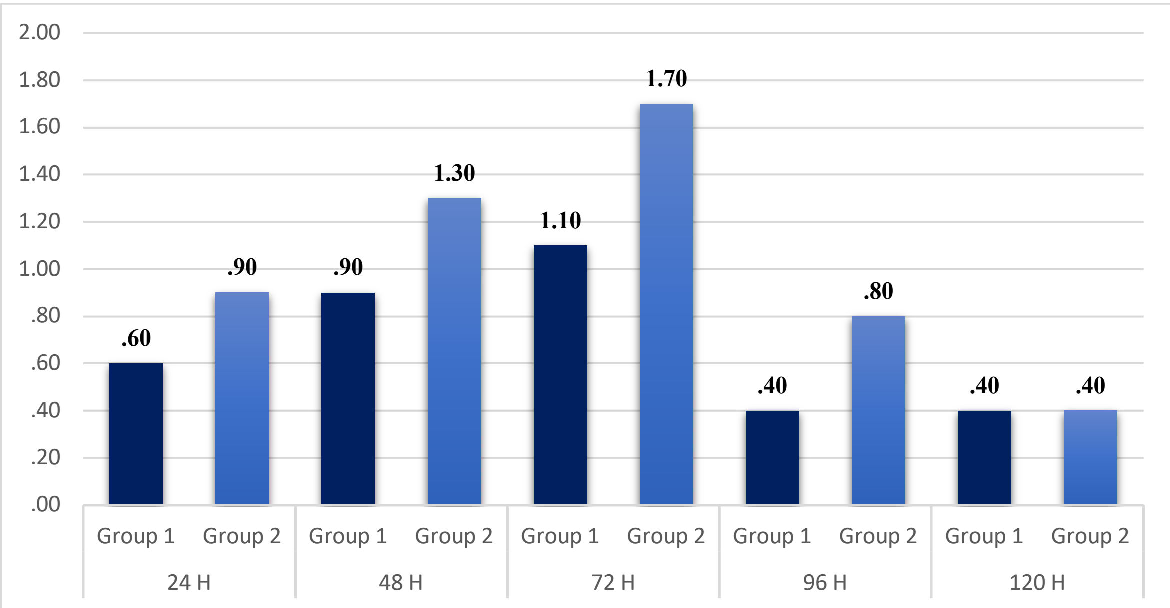


Figure (42): A chart of Swelling scores comparison between the groups at different time points

5.3 Post-surgical palpation assessment of the different treatment modalities.

Data in this section was statistically analyzed using Independent sample T test. All the postoperative palpation score values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at 3, 6 and 12 months.

- **At 3 months: Group I** recorded a palpation score mean value of 0.10 ± 0.31. **Group II** recorded a palpation score mean value 0.20 ± 0.42. There was statistically no significant difference between groups (p= **0.556** >0.05).
- **At 6 months: Group I** recorded a palpation score mean value 0.00 ± 0.00. **Group II** recorded a palpation score mean value of 0.10 ± 0.31. There was statistically no significant difference between groups (p= **0.556** >0.05).
- **At 12 months: Group I** recorded a palpation score mean value of 0.00± 0.00. **Group II** recorded a palpation score mean value of 0.00± 0.00. There was statistically no significant difference between groups (p= **1** > 0.05). **(Table 11)(Figure 43)**.

Table (11): Comparison of palpation score between Piezosurgery and Trephine Techniques at Different Time Points.

Palpation Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
3 Months	**0.10**	0.31	**0.20**	0.42	**- 0.60**	**0.556**
6 Months	**0.00**	0.00	**0.10**	0.31	**- 1.00**	**0.556**
12 Months	**0.00**	0.00	**0.00**	0.00	**ND**	**0.00**

(*) A symbol mean presence of significant between groups (p<0.05)

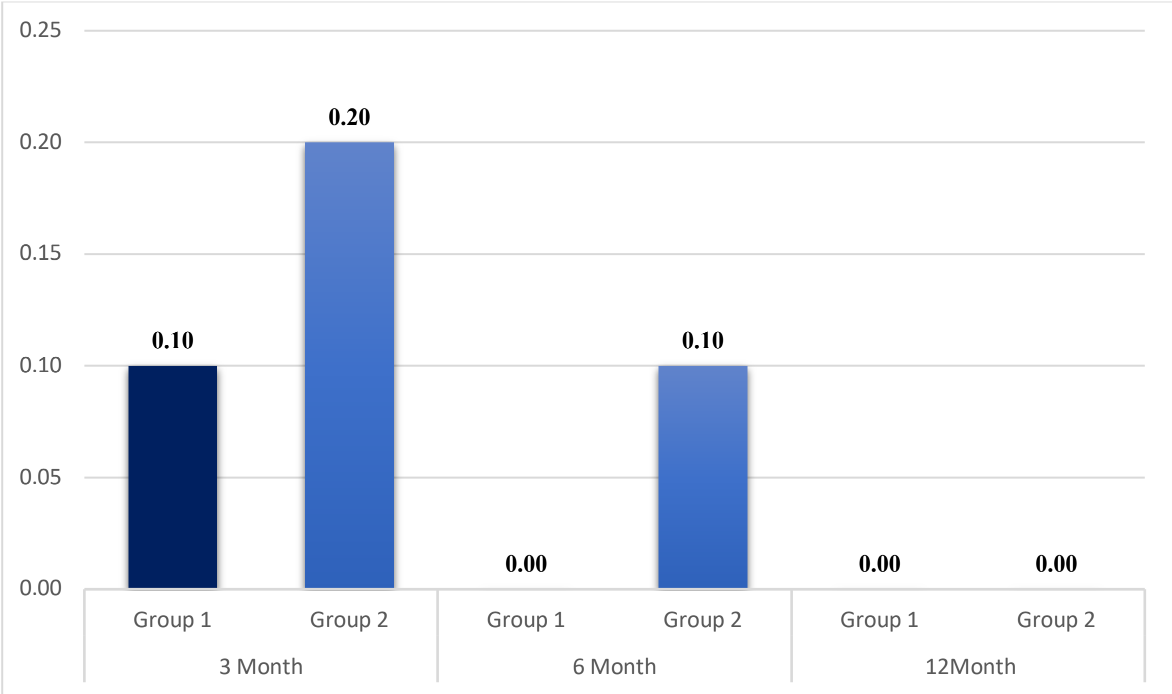


Figure (43): A chart of Palpation score comparison between the groups at different time points

5.4 Post-surgical Percussion assessment of the different treatment modalities.

Data in this section was statistically analyzed using Independent sample T test. All the postoperative percussion score values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at 3, 6 and 12 months.

- **At 3 months: Group I** recorded a Percussion score mean value of 0.10 ± 0.31. **Group II** recorded a Percussion score mean value of 0.20 ± 0.42. There was statistically no significant difference between groups (p= **0.542** >0.05).
- **At 6 months, Group I** recorded a Percussion score mean value of 0.00± 0.00 equal to **Group II**. There was statistically no significant difference between groups (p= **1** > 0.05).
- **At 12 months, Group I** recorded a median Percussion score mean value of 0.00± 0.00 equal to **Group II**. There was statistically no significant difference between groups (p= **1** > 0.05). **(Table 12)(Figure 44)**.

Table (12): Comparison of Percussion between Piezosurgery and Trephine Techniques at different time points

Percussion Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
3 Months	**0.10**	0.31	**0.20**	0.42	**- 0.60**	**0.556**
6 Months	**0.00**	0.00	**0.00**	0.00	**ND**	**0.00**
12 Months	**0.00**	0.00	**0.00**	0.00	**ND**	**0.00**

(*) A symbol mean presence of significant between groups (p<0.05)

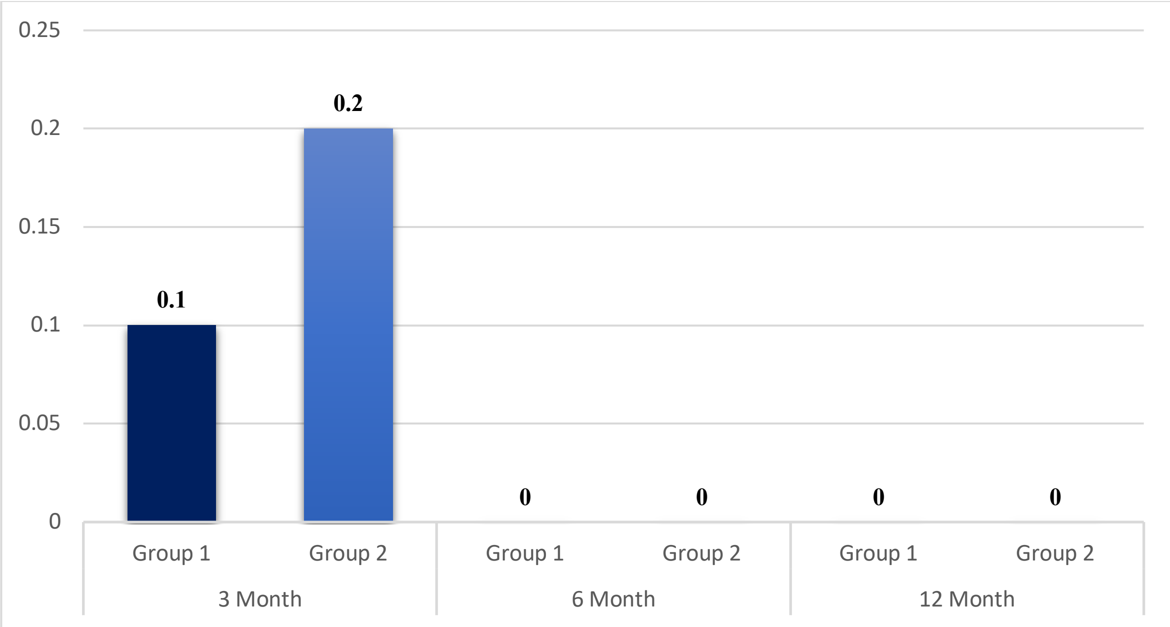


Figure (44): A chart of Percussion score comparison between the groups at different time points

5.5 Post-surgical tooth mobility assessment of the different treatment modalities.

Data in this section was statistically analyzed using Independent sample T test. All the postoperative tooth mobility scores mean values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at 3, 6 and 12 months.

- **At 3 months: Group I** recorded a tooth mobility score mean value of 0.30 ± 0.48. **Group II** recorded a tooth mobility score mean value of 0.40 ± 0.69. There was statistically no significant difference between groups (p= **0.714** >0.05).
- **At 6 months: Group I** recorded a tooth mobility score mean value of 0.00 ± 0.00. **Group II** recorded a tooth mobility score mean value of 0.20 ± 0.42. There was statistically no significant difference between groups (p= **0.168** >0.05).
- **At 12 months: Group I** recorded a tooth mobility score mean value of 0.00 ± 0.00. **Group II** recorded a tooth mobility score mean value of 0.10 ± 0.31. There was statistically no significant difference between groups (p= **0.343** >0.05). **(Table 13)(Figure 45)**.

Table (13): Comparison of tooth mobility between Piezosurgery and Trephine Techniques at Different Time Points:

Tooth mobility Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
3 Months	**0.30**	0.48	**0.40**	0.69	**- 0.372**	**0.714**
6 Months	**0.00**	0.00	**0.20**	0.42	**- 1.50**	**0.168**
12 Months	**0.00**	0.00	**0.10**	0.31	**- 1.00**	**0.343**

(*) A symbol mean presence of significant between groups (p<0.05)

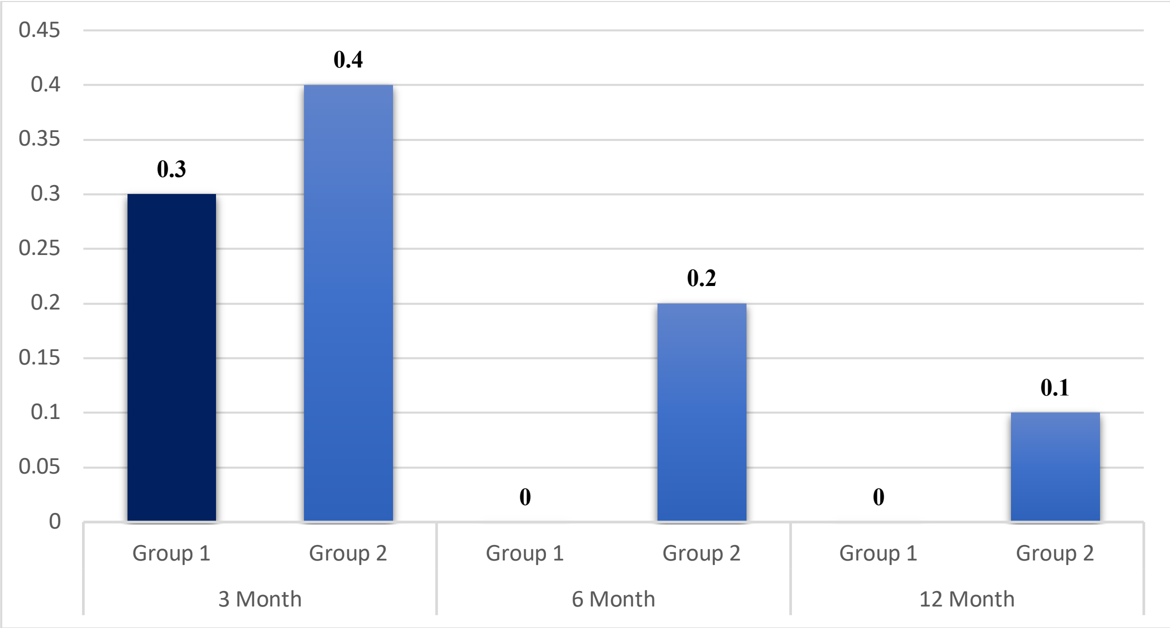


Figure (45): A chart of tooth mobility score comparison between the groups at different time points

5.6 Post-surgical clinical attachment level assessment of the different treatment modalities.

Data in this section was statistically analyzed using Independent sample T test. All the postoperative clinical attachment level scores mean values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at 3, 6 and 12 months.

- **At 3 months:** Both **Group I** and **Group II** had clinical attachment level scores mean value of **0.10** ± 0.31. There was statistically no significant difference between groups (p= **1** > 0.05).
- **At 6 months: Group I** recorded a clinical attachment level score mean value of **0.00** ± 0.00. **Group II** recorded a clinical attachment level scores mean value of **0.10** ± 0.31. There was statistically no significant difference between groups (p= **0.343** >0.05).
- **At 12 months:** Both **Group I** and **Group II** had clinical attachment level scores mean value of **0.00± 0.00.** There was statistically no significant difference between groups (p= **1** > 0.05). **(Table 4)(Figure 45)**.

Table (14): Comparison of clinical attachment level between Piezosurgery and Trephine Techniques at Different Time Points

clinical attachment level Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
3 Months	**0.10**	0.31	**0.10**	0.31	**0.00**	**1.00**
6 Months	**0.00**	0.00	**0.10**	0.31	**- 1.00**	**0.343**
12 Months	**0.00**	0.00	**0.00**	0.00	**0.00**	**1.00**

(*) A symbol mean presence of significant between groups (p<0.05)

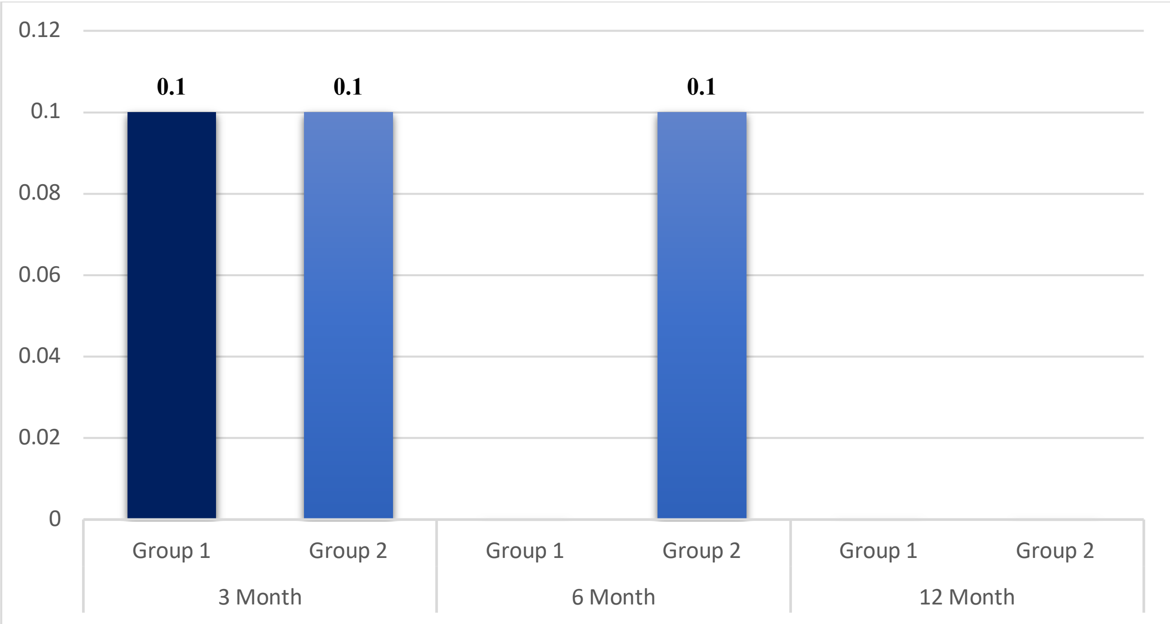


Figure (46): A chart of clinical attachment level score comparison between the groups at different time points

5.7 Post-surgical CBCT Assessment:

5.7.1 Comparison between the Healing outcomes of the different treatment modalities (Semi-quantitative).

Data in this section was statistically analyzed using fisher exact test. All the healing outcome scores mean values were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at 12 months.

- **At 12 months:** There was no statistically significant differences in the healing outcomes between **Group I** (**6** Clinical Successful Cases (60.0%), **4** Clinical Limited Successful Cases (40.0%)) and **Group II** (**3** Clinical Successful Cases (30.0%), **7** Clinical Limited Successful Cases (70.0%). (p =**0.370** > 0.05). **(Table 15)(Figure 47)**.

Table (15): Comparison of CBCT healing outcomes between Piezosurgery and Trephine Techniques at Different Time Points

CBCT Healing	Group I (Piezosurgery)	Group II (Trephine)	p value
	N (%)	N (%)	
Clinical Successful Cases	**6 (60.0)**	**3 (30.0)**	**0.370**
Clinical limited Successful Cases	**4 (40.0)**	**7 (70.0)**	

(*) A symbol mean presence of significant between groups (p<0.05)

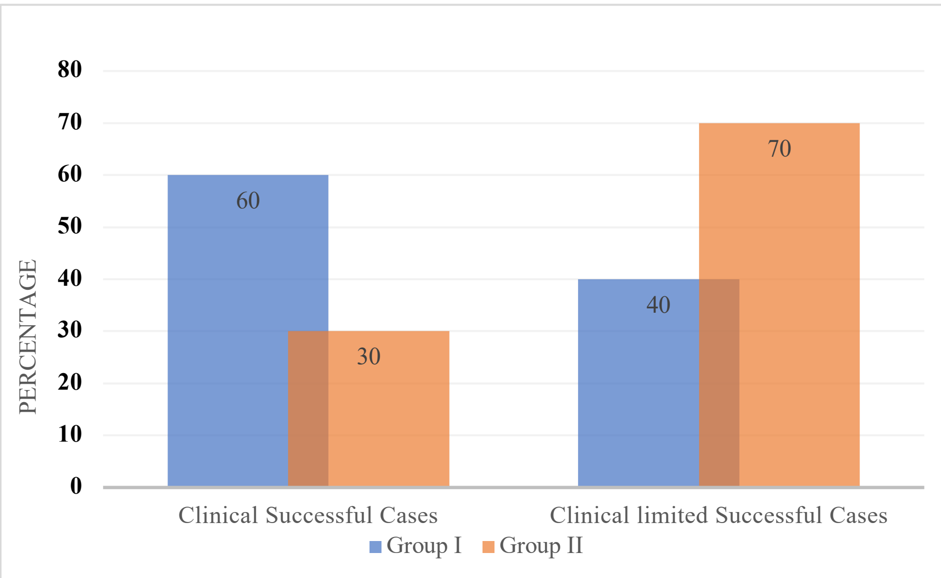


Figure (47): A chart representing healing outcomes between groups

5.7.2 Comparison between the volumetric measurements of the different treatment modalities (Quantitative):

Data in this section was statistically analyzed using independent sample T test. All the mean volumetric measurements were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at immediate post operative, 6 and 12 months.

- **Immediate post-operative:** There was no statistically significant differences in volumetric measurements mean values between **Group I** (Piezosurgery) 1.45 ± 0.2. and **Group II** (Trephine) 1.6 ± 0.2 (p = 0.165 > 0.05).
- **At 6 months:** There was a statistically significant differences in volumetric measurements mean value between **Group I** (Piezosurgery) 0.64 ± 0.2. and **Group II** (Trephine) 0.89 ± 0.2. (p = **0.025** > 0.05).
- **At 12 months:** There was a statistically significant differences in volumetric measurements mean value between **Group I** (Piezosurgery) 0.3 ± 0.2. and **Group II** (Trephine) 0.47 ± 0.1. (p = **0.004** > 0.05). **(Table 16)(Figures 48-50)**.

Table (16): Comparison of Volumetric measurements between Piezosurgery and Trephine Techniques at Different Time Points

volumetric measurements Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
0 Months	**1.45**	0.2	**1.6**	0.2	**-1.50**	**0.165**
6 Months	**0.64***	0.2	**0.89**	0.2	**-2.45**	**0.025**
12 Months	**0.3***	0.2	**0.47**	0.1	**-3.25**	**0.004**

(*) A symbol mean presence of significant between groups (p<0.05)

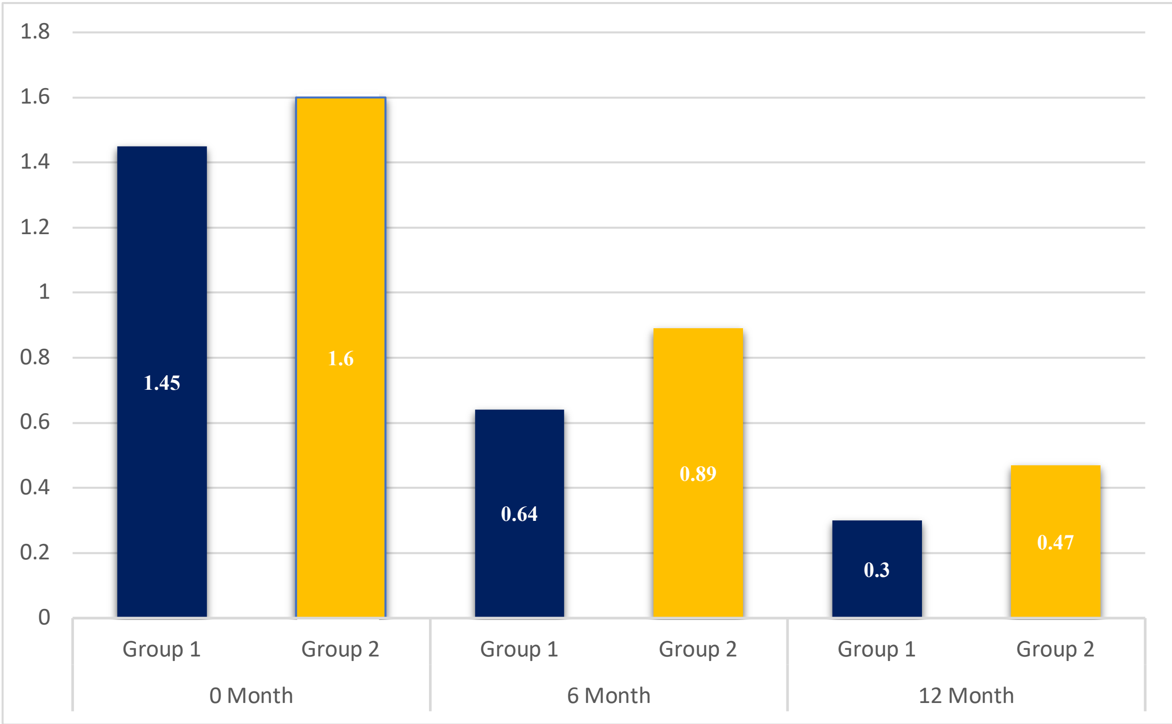


Figure (48) Comparison of Volumetric measurements between Piezosurgery and Trephine Techniques at 0, 6, 12 months

- **Volumetric measurement results for Piezosurgery and Trephine Bur groups:**

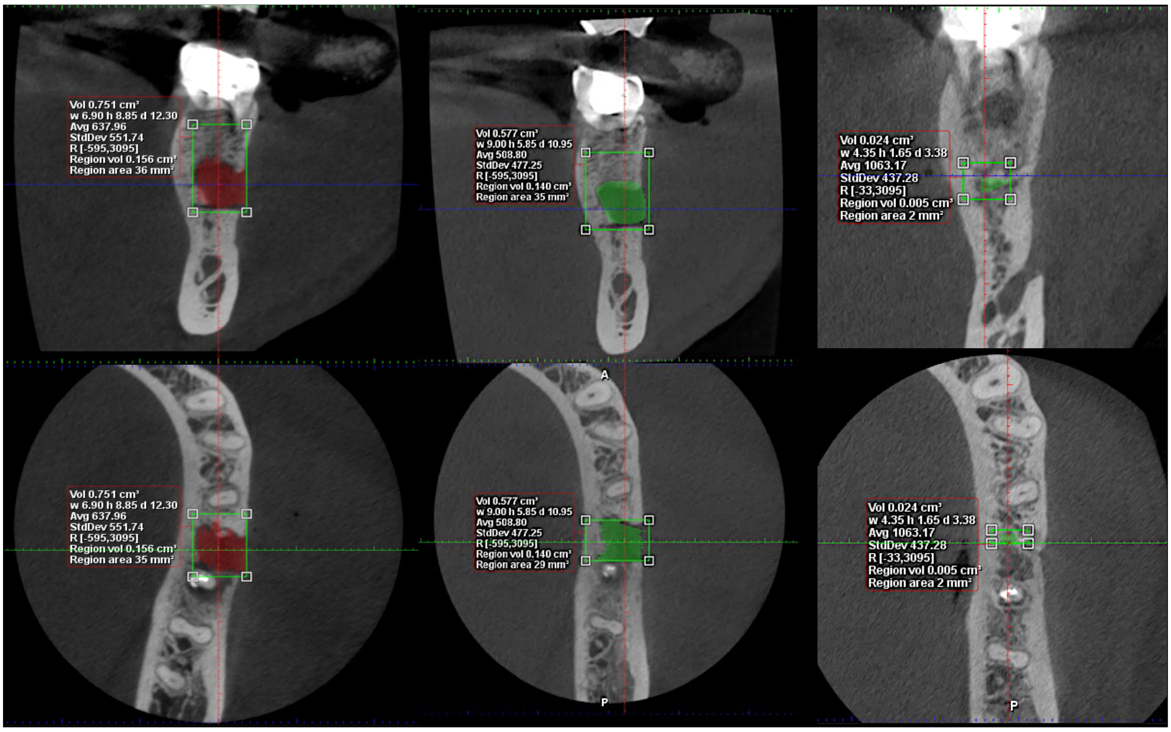


Figure (49); CBCT Scans for Piezosurgery group showing the Volumetric measurements for immediate post-surgical, 6, 12

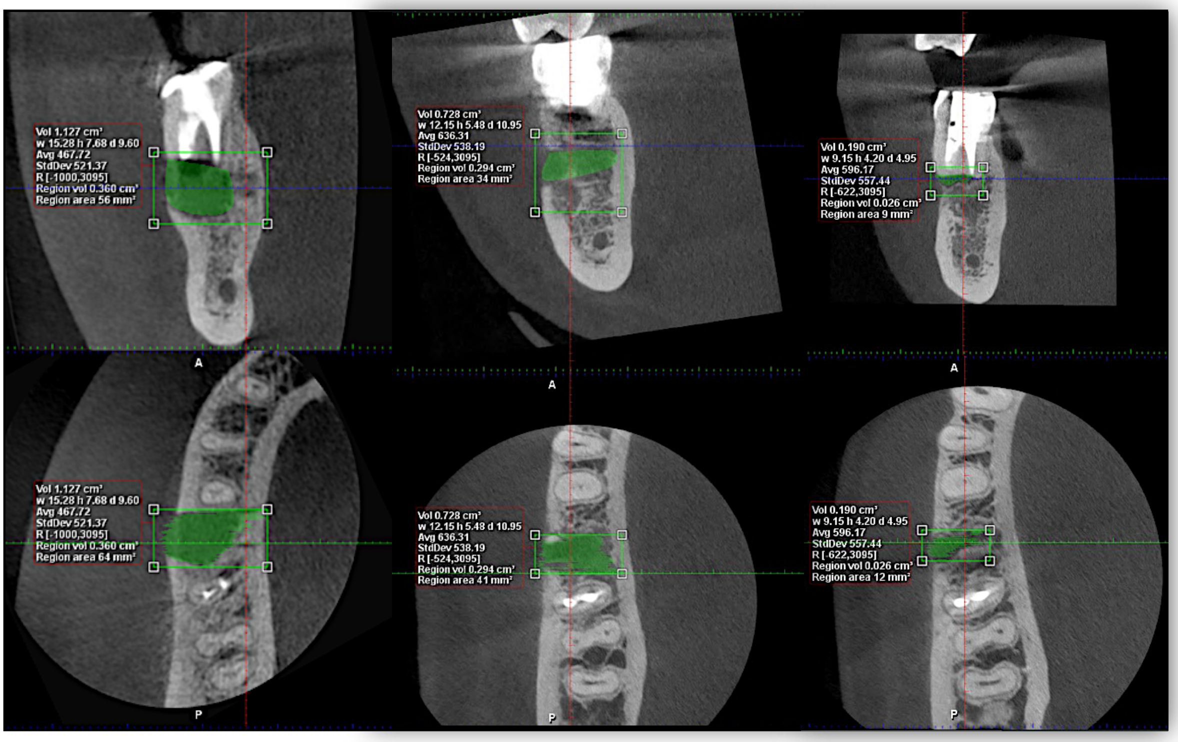


Figure (50); CBCT Scans for Trephine Bur group showing the Volumetric measurements for immediate post-surgical, 6, 12

5.7.3 Comparison between the Bone density measurements of the different treatment modalities (Quantitative):

Data in this section was statistically analyzed independent sample T test. All the mean bone density measurements were compared between groups **I (Piezosurgery)** and **II (Trephine Bur)** at immediate post operative, 6 and 12 months.

- **At Immediate post-operative:** There was no statistically significant differences in bone density measurements mean value between **Group I** (Piezosurgery) 105.2 ± 157.7. and **Group II** (Trephine) 119.1 ± 108.4. (p = 0.821 > 0.05).
- **At 6 months:** There was a statistically no significant differences in bone density measurements mean value between **Group I** (Piezosurgery) 414.7 ± 163.8 and **Group II** (Trephine) 335.3 ± 116.5. (p = 0.228 > 0.05).
- **At 12 months:** There was a statistically significant differences in bone density measurements mean value between **Group I** (Piezosurgery) 614.2 ± 149.2. and **Group II** (Trephine) 462.1± 123.5 (p = 0.023 > 0.05). **(Table 16)(Figures 51-53)**.

Table (17): Comparison of Bone density measurements between Piezosurgery and Trephine Techniques at Different Time Points

Bone density Test	Group I (Piezosurgery)		Group II (Trephine)		T Test	
	Mean	SD	Mean	SD	Test statistic	P Value
0 Months	105.2	157.7	119.1	108.4	**-0.230**	0.821
6 Months	414.7	163.8	335.3	116.5	**1.249**	0.228
12 Months	614.2 *	149.2	462.1	123.5	**2.483**	**0.023**

(*) A symbol mean presence of significant between groups (p<0.05)

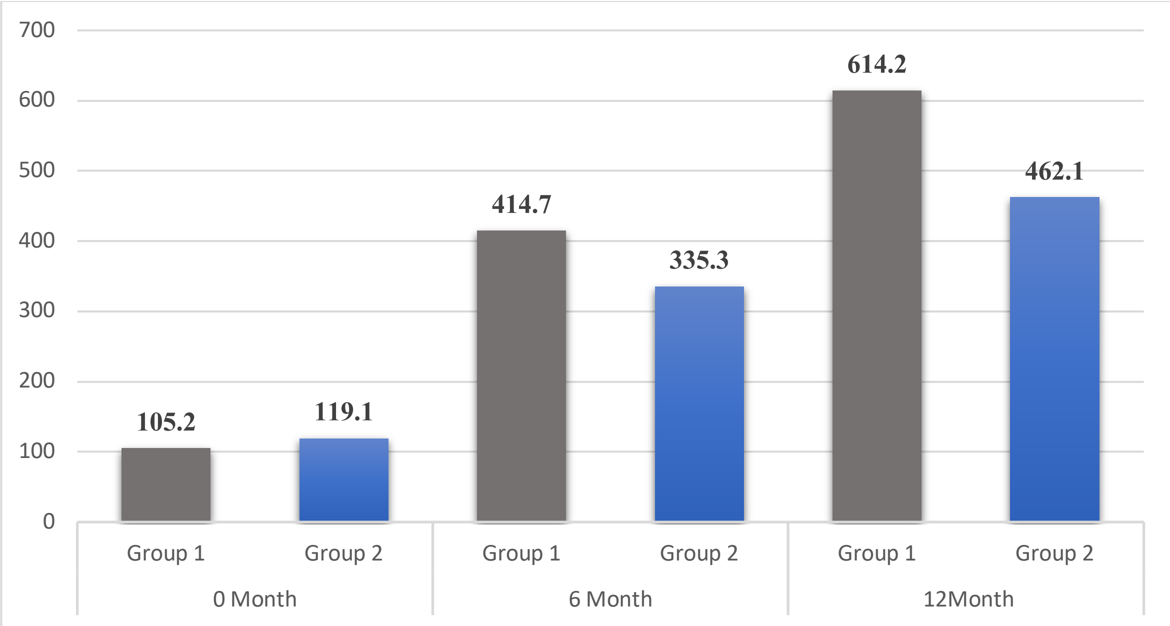


Figure (51) Comparison of bone density measurements between Piezosurgery and Trephine Techniques at 0, 6, 12 months

- **Bone density measurements results for Piezosurgery and Trephine Bur groups:**

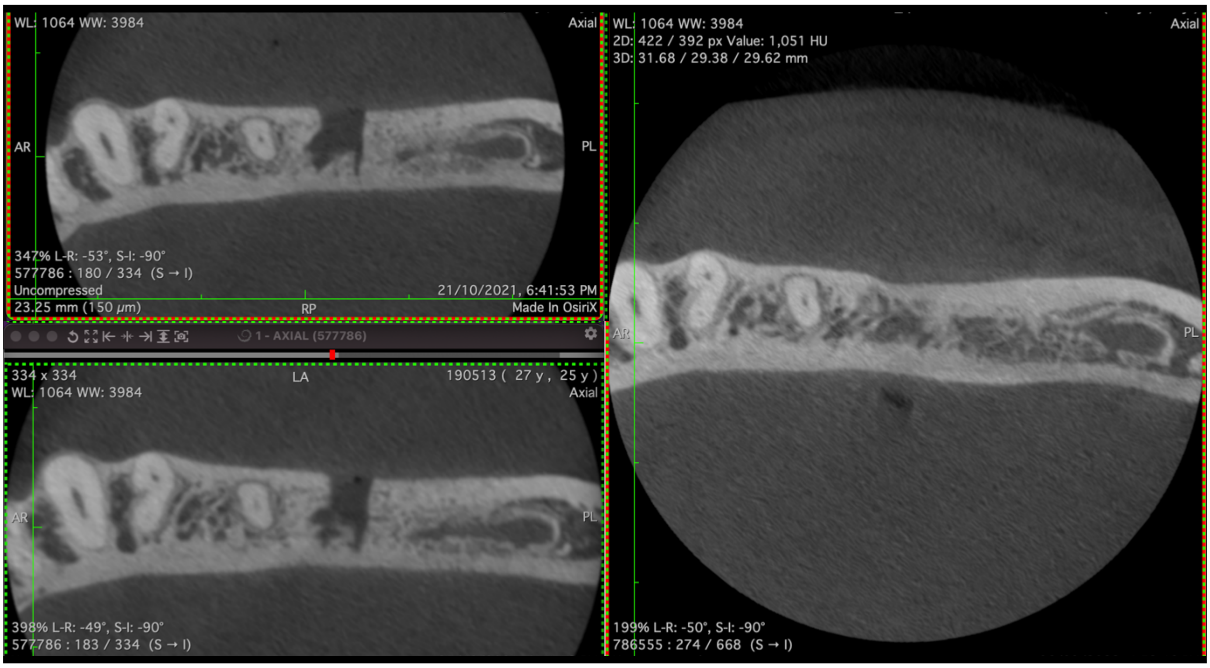


Figure (52) CBCT Scans for Trephine Bur group showing Bone Density measurements for immediate post-surgical, 6, 12

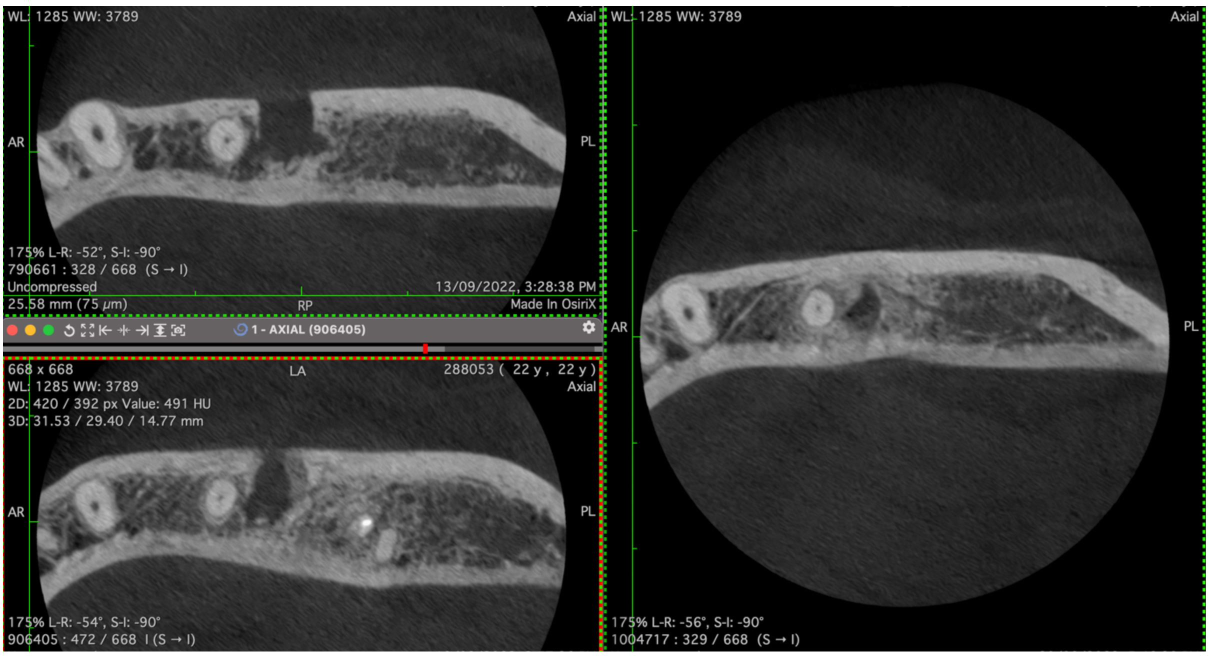


Figure (53) CBCT Scans for Trephine Bur group showing Bone Density measurements for immediate post-surgical, 6, 12

6. Discussion

Endodontic microsurgery on mandibular molars remains a great challenge for clinicians. This can be attributed to the difficult accessibility and the thickness of the buccal bone, in addition to the close relation to anatomical neurovascular structures including the mental foramen, and inferior alveolar nerve, which may pose potential risks of complications [(143,144)]. The concept of guided endodontic microsurgery has been extensively investigated in recent years for minimally invasive, precise, and efficient osteotomy and root end resection [(2,3)]. This concept utilizes either conventional tools such as surgical cutting burs or/and relatively recently cutting devices such as piezosurgery, trephine bur, and laser [(145)].

This is a randomized clinical trial was selected as it ranked at the highest level of the hierarchies rank studies according to the probability of bias with less risk of systematic errors [(146,147)]. This study evaluated the effect of piezosurgery and trephine bur as cutting tools on the post operative clinical outcomes including pain, swelling, tenderness to percussion and palpation, tooth mobility, and clinical attachment level following endodontic microsurgery in addition to bone healing evaluated using CBCT scanning.

The selected patients have no general medical contraindications for oral surgical procedures (Scores 1–2). Research contraindicated patients with various systemic complications (score > 2) to be involved in such studies as effects on the post operative clinical outcomes and healing [(148)]. The age factor was selected between 18 and 45 years old for standardization purposes to minimize the variation in response that affect the clinical outcome scores and healing. Several studies advocated that the postoperative pain after endodontic surgeries decreases with increasing age, in addition to the healing process and remodeling occuring to a lesser degree because the collagen formed is qualitatively different [149,150,151]. Only males were included in the study for standardization purposes as female patients in the menstruation period have functional impairment of the coagulation system (increased bleeding tendency) and periodic changing levels of serotonin and noradrenaline leading to increased pain prevalence that increased post-operative pain and swelling [152,153,154].

The mandibular first molar teeth were selected for many reasons as they are the most commonly endodontically treated posterior teeth and are more susceptible to iatrogenic errors including fracture instruments, ledging, and apical transportation even in the straight canals [155]. The post operative pain and swelling related to mandibular molars following endodontic surgeries were significantly higher than maxillary molars and anterior teeth [156]. The thickness of the buccal plate of bone covering the mandibular molars is significantly higher than the maxillary molars and anterior teeth. The amount of bone removed during the endodontic microsurgery is a significant predictor of developing severe pain after surgery [16,157].

The root length, curvature, and root canal configuration of the mandibular first molars were standardized to limit the variation of the study parameters keeping similar patient responses. Teeth with class A and B periapical radiolucency were selected because they are ideal candidates for endodontic microsurgery according to Rubinstein & Kim S [158] results with 96.8% healing success after one year follow up.

Preoperative CBCT scan was selected as it provides more accurate and imparts more diagnostic information than intra oral periapical radiographs [159,160]. The selected patients have signed written informed consent with a detailed explanation of the study and its potential risks for an ethical and legal obligation to inform patients well enough to allow them to make a balanced decision without malpractice [161,162,163]. Non-surgical and surgical endodontic management were carried out under magnification (8X-16X) for better visibility and accessibility [3]. All indirect/direct restorations, posts and old gutta perchea were removed to eliminate variables resulting from the difference of these materials on the quality and sealing in both coronal and radicular parts [164].

All cases that could not be managed non-surgically, were included in the study as endodontic microsurgery is an alternative approach to treat such teeth with procedure errors that can't be managed non surgically [2]. MTA was used as orthograde root end filling for its regenerative behavior on periradicular tissues, biocompatibility, and excellent sealing ability as well as its superior mechanical properties [165,166,167]. Besides its simplicity and ease, the orthograde technique used for MTA application has no significant difference regarding the sealing ability and biocompatibility in comparison to the retrograde technique [168]. The orthograde technique outperforms the retrograde technique because it avoids the adverse effect of the ultrasonic preparation including cracks and fractures on the root dentin [169, 170].

The surgical guide was fabricated to improve the accuracy of the endodontic microsurgery by precisely locating the appropriate osteotomy site (minimally invasive) and performing less sensitive techniques to anatomically vital structures such as inferior dental nerve and mental nerve [171]. The surgical guide acts as a soft tissue retractor and helps to avoid iatrogenic soft tissue damage. **Pinsky et al.** [172] confirmed that greater accuracy and consistency were achieved during endodontic surgery with surgical guidance without damaging vital structures.

CBCT scan was taken using both lip retraction and open vertical bite techniques to increase the registration accuracy during virtual surgical guide planning which is significantly influenced by the preprocessing of imported data by the user (173,174,175). The lip retraction technique was selected to overcome the CBCT limitations regarding the assessment of soft tissues and bone density due to the proximity of the gingival tissues with other soft tissues such as the lips and cheek, which would all be visualized with the same radiographic density, it is difficult to discriminate between these structures (127). The open vertical bite technique was selected to overcome the CBCT limitations regarding the assessment of the occlusal surface of the mandibular teeth during occlusion and increase the accuracy of the registration procedure of the corresponding surfaces on the model reconstructed from CBCT and the surface scan model reconstructed from a digital impression (176,177). The digital optical impression technique was selected to avoid errors during impression recording that may happen with the conventional techniques (178,179).

Lidocaine 2% adrenaline 1:80.000 local anesthesia solution was selected due to its superior safety profile as compared to other local anesthesia solutions (180) and due to its medium acting effect, that does not affect the results of postoperative pain (181). A submarginal flap with one vertical releasing incision was selected to minimize gingival recession as the soft tissue attachment level and crestal bone is not exposed. It minimizes edema which is proportional to time and amount of tissue reflected (182,143 ,183).

Piezosurgery was selected as it has minimal trauma to soft tissue and important structures such as nerves, vessels, and mucosa in contrast to conventional surgical burs or saws. It reduces damage to osteocytes and permits the survival of bony cells during the harvesting of bone (reduces the risk of postoperative necrosis) [184]. The trephine bur technique was selected as it has an easy, fast, and safe cutting instrument available in different diameters and lengths, that creates an accurate regular preparation in comparison with the other techniques [185,186]. A 4-0 polytetrafluoroethylene coated monofilament sutures were used for soft tissue flaps closure, which has a relatively high tensile strength, good handling qualities and low bacteria accumulation behavior [187].

The pain assessment using the modified verbal descriptive scale was selected because this scale is easily understood by patients and is a simple and reliable way that has been used worldwide in several studies [188,189]. The assessment of pain intensity was carried out postsurgically after 24, 48, 72, 96 and 120 hours based on research compared the post-surgical pain following endodontic surgeries. As 24 hours was chosen to allow the anesthetic solution effect to completely disappear, 48 and 72 hours intervals were chosen because it usually represents the period of the maximum peak of pain, and 96 and 120 hours intervals were chosen because it usually represents the period of the minimum rate of pain [190,191,192]. The post-surgical swelling assessment scale was selected because this scale is easily understood by patients and is simple. Several studies [130,193] have used the swelling scale for evaluation following periapical endodontic surgery. The post-surgical periodontal assessment was performed at 3, 6, and 12 months following the endodontic microsurgery using palpation, percussion, and tooth mobility tests in addition to the clinical attachment level examination test as these examination tests are recommended for evaluation of healing following the endodontic microsurgery [194].

The post-surgical CBCT was selected because it has a higher level of sensitivity in identifying the rate of periodic follow up healing following the endodontic microsurgery in comparison to 2D imaging [111,195,196]. There is no specific recommendation about the exact number of permissible x-ray doses per year in the literature [197].

The modified PENN 3D criteria were employed for evaluating radiographic healing because this method is a valuable tool for the evaluation of healing outcomes of endodontic surgeries [110]. In addition, Quantitative CBCT analysis for measurement of the volumetric and bone density changes of a periapical area over the follow up period was selected as it is a reliable, noninvasive method to monitor bone healing quantitively [142, 198].

Post-surgical pain and swelling are the most common complications after endodontic surgery [156,199]. In the present study, both of piezosurgery and Trephine bur groups showed comparable post-surgical pain levels (statistically non-significant differences at different time points). This can be explained by the fact that the magnitude of pain secondary to any surgical procedure is directly related to the amount of tissue damage [200]. Both of piezosurgery and Trephine bur techniques are minimally invasive endodontic microsurgery. The constant irrigation system that used with both techniques decreases heat generation, hence reducing tissue thermal damage, and decreasing post-surgical pain [201]. These factors led to a similar behavior for the piezosurgery and the Trephine bur regarding the post-surgical pain.

In the present study, both of piezosurgery and Trephine bur groups showed comparable postoperative swelling levels (statistically non-significant differences at different time points). This can be explained by the fact that swelling is a predictable physiological reaction following endodontic surgery. The magnitude of swelling and edema secondary to surgical procedure is directly related to the duration of the surgery, soft tissue flap design and handling, and amount of tissue damage during osteotomy. Other predisposing factors such as age, gender, and tooth position may contributed. In this study, based on the selection inclusion criteria, the soft tissue flap was minimally invasive using submarginal flap design, and the amount of tissue removed during the osteotomy procedures and duration were relatively the same in both groups. Variables such as age, gender, and tooth position were excluded from the study. These results were agreed with other studies comparing the post-surgical pain and swelling following the piezosurgery and Trephine bur [202,203].

Both of piezosurgery and Trephine bur groups showed comparable post-surgical tenderness to palpation, percussion, clinical attachment, and tooth mobility levels (statistically non-significant differences at different time points). As a result of all cases were considered healed and/ or limited healing according to healing outcome criteria, the gingival tissue and periodontal ligaments status were free of infection or inflammation at the different evaluation times. These results agree with research comparing the post-surgical periodontal status after endodontic microsurgery [204].

In the present study, both of piezosurgery and Trephine bur groups showed comparable postoperative CBCT healing outcomes (statistically non-significant differences after one year follow up) even though the percentage of clinical successful cases was higher in the piezosurgery (6 Cases) than the Trephine bur (3 Cases) groups. That may be attributed to the presence of periapical scar tissue healing that had probably interfered with the regeneration of periapical bone, these cases had been radiographically interpreted in this study as limited clinical successful cases in both groups, which needed extended follow up periods of more than one year to explore the significant between the groups.

Regarding to the volumetric measurements of periapical radiolucency after 6 and 12 months follow up. The periapical radiolucency in the piezosurgery group was smaller in size than the Trephine bur group. This may be attributed to the osteotomy technique in different terms. Piezosurgery is an ultrasonic cutting device generates micro-vibrations providing less traumatic, more precise, and smooth bone cutting that has a direct influence on the bone recovery time [(72)]. **Mouraret et al.** [(205)] revealed that the bone grafts harvested with a Piezosurgery exhibited greater short-term cell viability than chips harvested with bur and performed more new bone deposition and bone remodeling. Regarding to trephine bur osteotomy, curved root-ends created by trephine bur had labial cervical stresses, these stresses concentrated on its circumference make the root more susceptible to concurrent loss of tooth structure in the labial cervical area and apical cementum layer (cemental tears) that affect the periodontal ligaments attachment [(206, 207)]. Also, the trephine bur technique resulted in rough, with a large amount of bone debris in comparison with the piezosurgery, leading to an osteoclastic absorption of the bone irregularities and fragments to create the optimum environment for bone deposition, then the osteoblastic bone regeneration is initiated [(208,209)]. Even though the Trephine bur osteotomy was done at 1200-1500 RPM / Torque 20 N which is considered a low rotational speed range [(210,211)] and provided with internal irrigation, the osteotomy is associated with increased heat generation which led to signs of peripheral bone surface necrosis [(212,213)]. These conclusions are explaining the early initiation of bone healing in cases of piezosurgery.

The literature in this field showed contradicting results that could be caused by multiple reasons including the number of patients, the inclusion criteria and the difference of the testing parameters. The present results contrast with the research done by **Esteves et al.** [(214)], they found no significant difference in bone healing in both piezosurgery and conventional drilling groups. The disagreement is attributed to the difference in methodology as it is an animal study (Histologically and histomorphometrically study) which is completely different in the healing pattern [(215)].

Regarding to the bone density measurements after 6 months post-surgically, the piezosurgery and Trephine bur groups showed comparable results. At this stage the bone regeneration (remodelling) is not prominent enough to make a difference in bone density readings [(216)]. While after 12 months follow up, the bone density in the piezosurgery group were significant than the Trephine bur group. This may be attributed to the osteotomy technique as speed of bone regeneration and remodeling is a commitment to the cellular viability (osteoblast activity) which is more prominent in the piezosurgery technique [(217,218)]. The present study results are in accordance with **Vercelotti et al**. [(219)] where compared piezosurgery with a surgical bur in osteotomy and proved that there is better bone healing in terms of quantity and quality when using piezosurgery in osseous surgeries. Similarly, **Tsai et al.** [(220)] stated that piezosurgery might promote faster bone healing compared to rotary instruments over a short-term observation period.

Based on the results of this study, the null hypothesis is accepted in terms of the post-surgical clinical outcomes. While it is rejected in terms of volumetric measurements and bone density outcomes.

7. Summary

Some cases cannot be successfully managed through non-surgical treatment or retreatment even with the advancement in endodontic tools such as magnification, Cone beam computed tomography (CBCT), Ni-Ti rotary files and ultrasonics, which necessitate surgical intervention.

Twenty male patients between 18 and 45 years old have mandibular first molar teeth need endodontic microsurgery due to failed non-surgical treatment or re-treatment were included in the study. The selected patients were randomly divided into two groups (n = 14) according to the type of cutting tools during bony cavity preparation and root end resections. Group I: Piezosurgery assisted cavity preparation. Group II: Trephine Bur assisted cavity preparation. An apical curettage was performed and the over-extended objects such as separated instruments or gutta percha were removed. The post-surgical pain and swelling assessment were recorded for five days every 24, 48, 72, 96, and 120 hours postoperatively. The tenderness to palpation and percussion, tooth mobility and CAL tests were examined by the operator 3, 6 and 12 months. Finally, Quantitative radiographic analysis for volumetric and bone density measurement were performed.

There was no statistically significant difference between groups in the term of post-surgical pain, swelling, tenderness to percussion and palpation, tooth mobility and CAL. However, there was a statistically significant difference between groups in the term of volumetric and bone density measurements. **Conclusion:** Piezosurgery-assisted cavity preparation technique improved the healing of the osteotomy site but did not affect the post-surgical pain, swelling and tenderness to palpation and percussion.

8. Conclusion

Whin the parameter of this study:

1. Both of Piezosurgery and Trephine bur are valuable techniques for reducing post-surgical pain, swelling and tenderness to palpation and percussion.
2. Both of Piezosurgery and Trephine bur techniques are considering a minimally invasive approach for pre-radicular microsurgery.
3. Piezosurgery techniques achieve better healing outcomes than the trephine bur technique regarding bone volume and density.
4. CBCT is a valuable tool for accurate measurement of bone volumetric changes and relative bone density in patients.

Recommendation.

1. Histological studies are recommended to evaluate bone healing between Piezosurgery and Trephine bur techniques.
2. Further research is recommended with an extended follow up period of more than one year.
3. Further research is recommended to explore other evaluation methods to evaluate bone healing in patients.

9. Reference.

1 Chevigny C, Dao T, Basrani B, Marquis V, Farzaneh M, Abitbol S, Friedman S. Treatment outcome in endodontics: the Toronto study phase 4: initial treatment. J Endod. 2008;34(3):258-63

2 Sousa B, Gomes F, Ferreira C, Rocha M, Barros E, Albuquerque D. Persistent extra-radicular bacterial biofilm in endodontically treated human teeth: scanning electron microscopy analysis after apical surgery. Microsc Res Tech. 2017; 80(6):662-7.

3 Setzer F, Kohli M, Shah S, Karabucak B, Kim S. Outcome of endodontic surgery: a meta-analysis of the literature–part 2: comparison of endodontic microsurgical techniques with and without the use of higher magnification. J Endod 2012; 38(9):1–10.

4 Tsesis I, Faivishevsky V, Kfir A, Rosen E. Outcome of surgical endodontic treatment performed by a modern technique: a meta-analysis of literature. J Endod 2009;35(11):1505–11.

5 Kang M, In Jung H, Song M, Kim S, Kim H, Kim E. Outcome of nonsurgical retreatment and endodontic microsurgery: a meta-analysis. Clin Oral Investig 2015;19(3): 569–82.

6 Kohli M, Berenji H, Setzer F, Lee S, Karabucak B. Outcome of Endodontic Surgery: A Meta-analysis of the Literature-Part 3: Comparison of Endodontic Microsurgical Techniques with 2 Different Root-end Filling Materials. J Endod. 2018;44(6):923-31

7 Setzer F, Shah S, Kohli M, Karabucak B, Kim S. Outcome of endodontic surgery: a meta-analysis of the literature, part 1: Comparison of traditional root-end surgery and endodontic microsurgery. J Endod. 2010;36 (11):1757-65.

8 Ahn S, Kim N, Kim S, Karabucak B, Kim E. Computer-aided Design/Computer-aided Manufacturing-guided Endodontic Surgery:

Guided Osteotomy and Apex Localization in a Mandibular Molar with a Thick Buccal Bone Plate. J Endod. 2018; 44(4):665-70

9 Cardoni A, MacBeath A, Lucas M. Methods for reducing cutting temperature in ultrasonic cutting of bone. Ultrasonics. 2006; 22(12);44: 37-42.

10 Rashad A, Kaiser A, Prochnow N, Schmitz I, Hoffmann E, Maurer P. Heat production during different ultrasonic and conventional osteotomy preparations for dental implants. Clin Oral Implants Res. 2011;22(12):1361-5.

11 Altiparmak N, Soydan S, Uckan S. The effect of conventional surgery and piezoelectric surgery bone harvesting techniques on the donor site morbidity of the mandibular ramus and symphysis. Int J Oral Max Surg. 2015;44(9):1131-7

12 Landes C, Stübinger S, Rieger J, Williger B, Ha T, Sader R. Critical evaluation of piezoelectric osteotomy in orthognathic surgery: operative technique, blood loss, time requirement, nerve and vessel integrity. J Oral Maxillofac Surg. 2008;66(4):657-74

13 Mouraret S, Houschyar K, Hunter D, Smith A, Jew O, Girod S, Helms J. Cell viability after osteotomy and bone harvesting: comparison of piezoelectric surgery and conventional bur. Int J Oral Maxillofac Surg. 2014;43(8):966-71

14 Barone A, Marconcini S, Giacomelli L, Rispoli L, Calvo J, Covani U. Randomized clinical evaluation of ultrasound bone surgery versus traditional rotary instruments in lower third molar extraction. J Oral Maxillofac Surg. 2010;68(2):330-6.

15 Hennet P. Piezoelectric Bone Surgery: A Review of the Literature and Potential Applications in Veterinary Oromaxillofacial Surgery. Front Vet Sci. 2015 5; 2:8.

16 Friedman S, Stabholz A. Endodontic retreatment--case selection and technique. Part 1: Criteria for case selection. J Endod. 1986;12(1):28-33.

17 Bieszczad D, Wichlinski J, Kaczmarzyk T. Factors Affecting the Success of Endodontic Microsurgery: A Cone-Beam Computed Tomography Study. J Clin Med. 2022 Jul 10;11(14):3991.

18 Guerini V. “History of dentists”. Odontostomatologike Proodos.1981;35(6):198-204

19 Cortland R. Treatise on the Human Teeth: Concisely Explaining Their Structure, and Cause of Decay: to which is Added, the Most Beneficial and Effectual Method of Treating All Disorders Incidental to the Teeth and Gums; with Directions for Their Judicious Extraction. 1801

20 Harris CA. The Dental Art, Practical Treatise of Dental Surgery. Baltimore, Armstrong & Berry, 1839; 268.

21 Smith CS. “Alveolar abscess.” Am J Dent Sci. 1871; 5 (3rd series): 289-300.

22 Gutmann JL, Gutmann MS. Historical perspectives on the evolution of surgical procedures in endodontics. J Hist Dent. 2010;58(1):1-42.

23 Farrar JN. “Radical and heroic treatment of alveolar abscess by amputation of roots of teeth.” Dent Cosmos. 1884; 26:79-81.

24 Black GV. “Amputation of the roots of teeth.” In: Litch WF, ed. The American system of dentistry. Philadelphia: Lea Brothers, 1886; 990-92.

25 Grayston LDSI. “On the treatment of alveolar abscess.” Br Dent J. 1887; 8:10-4.

26 Partsch C. “Drifter Bericht der Poliklinik fur Zahn- und Mundkrankheiten des zahnärztlichen Instituts der Königl.” Universität Breslau. Dtsch Monatsschr Zahnheilkd. 1896; 14:486-99.
27 Partsch C. “Ueber Wurzelresection.” Dtsch Monatsschr Zahnheilkd. 1898; 16:80-6.
28 Partsch C. “Ueber Wurzelresection.” Dtsch Monatsschr Zahnheilkd. 1899; 17:348-67.

29 Béal M. “De la résection de l’apex.” Rev Stomatol. 1908; 15:439-46.

30 Ivy RH. “The aseptic transalveolar root resection operation.” J Nat Dent Assoc. 1917; 4:553- 64.
31 Howe PR. “A method of sterilizing, and at the same time impregnating with a metal, affected dentinal tissue.” Dent Cosmos. 1917; 59:891-904
32 Faulhaber B, Neumann R. Die chirurgische Behandlung der Wurzelhauterkrankungen. Berlin, Hermann Meusser, 1912.
33 Neumann R. Die Wurzelspitzenreseklion an den unteren Molaren. Berlin, Hermann Meusser, 1915.
34 Berman LH. Endodontic prognosis assessment. Alpha Omegan. 2011;104(1-2):12-7.
35 Rotstein, I., & In Ingle, J. I. (2019). Ingle's endodontics 7
36 Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod. 1995;21(7):349-53.
37 Torabinejad M, Rastegar AF, Kettering JD, Pitt Ford TR. Bacterial leakage of mineral trioxide aggregate as a root-end filling material. J Endod 1995;21:109 –12.
38 Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25:197–205.

39 Zuolo, M., Ferreira, M. and Gutmann, J. Prognosis in periradicular surgery: a clinical prospective study. International Endodontic Journal, 2000, 33: 91-8

40 Kreisler M, Gockel R, Aubell-Falkenberg S, Kreisler T, Weihe C, Filippi A, Kühl S, Schütz S. Clinical outcome in periradicular surgery: Effect of patient-and tooth-related factors--A multicenter study. Quintessence International. 2013;1;44(1).

41 Wang ZH, Zhang MM, Wang J, Jiang L, Liang YH. Outcomes of Endodontic Microsurgery Using a Microscope and Mineral Trioxide Aggregate: A Prospective Cohort Study. J Endod. 2017;43(5):694-8.

42 Pinto D, Marques A, Pereira JF, Palma PJ, Santos JM. Long-Term Prognosis of Endodontic Microsurgery-A Systematic Review and Meta-Analysis. Medicina (Kaunas). 2020; 3;56(9):447.

43 Pallarés-Serrano A, Glera-Suarez P, Soto-Peñaloza D, Peñarrocha-Oltra D, von Arx T, Peñarrocha-Diago M. The use of the endoscope in endodontic surgery: A systematic review. J Clin Exp Dent. 2020;12(10):972-8.

44 Azim A, Albanyan H, Azim K, Piasecki L. The Buffalo study: Outcome and associated predictors in endodontic microsurgery- a cohort study. Int Endod J. 2021;54(3):301-18.

45 Kolte R, Kolte A, Mahajan A. Assessment of gingival thickness with regards to age, gender and arch location. J Indian Soc Periodontol. 2014; 18(4):478-81.

46 Cecchetti F, Ricci S, DI Giorgio G, Pisacane C, Ottria L. Microsurgery flap in endodontic surgery: case report. Oral Implantol (Rome). 2009;2(1):19-26.

47 Kramper BJ, Kaminski EJ, Osetek EM, Heuer MA. A comparative study of the wound healing of three types of flap design used in periapical surgery. J Endod. 1984;10(1):17-25.

48 Velvart P, Ebner-Zimmermann U, Ebner JP. Comparison of papilla healing following sulcular full-thickness flap and papilla base flap in endodontic surgery. Int Endod J. 2003;36(10):653-9.
49 Taschieri S, Corbella S, Del Fabbro M. Do gingival soft tissues benefit from the application of a papilla preservation flap technique in endodontic surgery? J Oral Maxillofac Surg. 2014;72(10):1898-908.
50 Albanyan H, Aksel H, Azim AA. Soft and Hard Tissue Remodeling after Endodontic Microsurgery: A Cohort Study. J Endod. 2020 ;46(12):1824-1831.
51 Hullihen SP. Case of Elongation of the under Jaw and Distortion of the Face and Neck, Caused by a Burn, Successfully Treated. Am J Dent Sci. 1849;9(2):157-65.
52 Leach EH, Peters RA, Rossiter RJ. Experiment thermal burns, especially the moderate temperature burn. Quart J Exp Physiol Cog Med Sci.1943;32(1): 67–86.
53 Eriksson A, Albrektsson T, Grane B, McQueen D. Thermal injury to bone. A vital-microscopic description of heat effects. Int J Oral Surg. 1982 Apr;11(2):115-21.
54 Romeo U, Del Vecchio A, Palaia G, Tenore G, Visca P, Maggiore C. Bone damage induced by different cutting instruments - an in vitro study. Braz Dent J 2009;20:162–8.
55 Siroraj A, Giri G , Ramkumar S, Narasimhan M. Extraction of impacted mandibular third molars - the effect of osteotomy at two speeds on peripheral bone: a histopathological analysis. Br J Oral Maxillofac Surg. 2016;54(4):449-53.
56 Sivolella S, Berengo M, Bressan E, et al. Osteotomy for lower third molar germectomy: randomized prospective crossover clinical study comparing piezosurgery and conventional rotatory osteotomy. J Oral Max Surg Off J Am Assoc Oral Max Surg. 2011;69(6):15-23.

57 Basheer SA, Govind RJ, Daniel A, Sam G, Adarsh VJ, Rao A. Comparative Study of Piezoelectric and Rotary Osteotomy Technique for Third Molar Impaction. J Contemp Dent Pract. 2017; 1;18(1):60-4.
58 Montero-Aguilar M, Sibaja-Ruiz L, Avendaño E, Pereira-Reyes R, Pozos-Guillén A, Chavarria-Bolaños D. Evaluation of Surgical Bur Deformation and Bone Surface Roughness After Multiple Uses. J Oral Maxillofac Surg. 2019;77(9):1894-903.
59 Ewen SJ. Ultrasound and Periodontics. J Periodontol. 1960;31:101–6
60 Wood RW, Loomis AL. Physical and biologic effects of high frequency sound waves of great intensity. Phil Mag. 1927;4:417
61 Catuna MC. Sonic energy: A possible dental application, Preliminary report of an ultrasonic cutting method. Ann Dent. 1953;12:100–1.
62 Volkov MV, Shepeleva IS. The use of ultrasonic instrumentation for the transection and uniting of bone tissue in orthopaedic surgery. Reconstr Surg Traumatol. 1974;14:147-52.
63 Aro H, Kallioniemi H, Aho AJ, et al. Ultrasonic device in bone cutting. A histological and scanning electron microscopical study. Acta Orthop Scand. 1981;52(1):5-10.
64 Torrella F, Pitarch J, Cabanes G, et al. Ultrasonic ostectomy for the surgical approach of the maxillary sinus: a technical note. J Mech W Tech. 1998;13(5):697-700
65 Schütz S, Egger J, Kühl S, Filippi A, Lambrecht JT. Intraosseous temperature changes during the use of piezosurgical inserts in vitro. Int J Oral Maxillofac Surg. 2012;41(11):1338-43.

66 Alam K, Silberschmidt VV. Analysis of temperature in conventional and ultrasonically-assisted drilling of cortical bone with infrared thermography. Technol Health Care. 2014;22:243–52.

67 Lee J, Chavez CL, Park J. Parameters affecting mechanical and thermal responses in bone drilling: A review. J Biomech. 2018 11;71:4-21.

68 Schaeren S, Jaquiery C, Heberer M, et al. Assessment of nerve damage using a novel ultrasonic device for bone cutting. J Oral Maxillofac Surg 2008;66:593–6.

69 Köhnke R, Kolk A, Kluwe L, Ploder O. Piezosurgery for Sagittal Split Osteotomy: Procedure Duration and Postoperative Sensory Perturbation. J Oral Maxillofac Surg. 2017;75(9):1941-7.

70 Zandi M, Heidari A, Jamshidi S, Aminzadeh A, Rajaei S, Mousavi M, Mohammad Gholi Mezerji N. Histological evaluation of inferior alveolar nerve injury after osteotomy of mandibular buccal cortex using piezoelectric versus conventional rotary devices: a split-mouth randomised study in rabbits. Br J Oral Maxillofac Surg. 2021;59(5):561-6.

71 Otake Y, Nakamura M, Henmi A, Takahashi T, Sasano Y. Experimental Comparison of the Performance of Cutting Bone and Soft Tissue between Piezosurgery and Conventional Rotary Instruments. Sci Rep. 2018 21;8(1):17154.

72 Jung KJ, Sarkar SK, Kim WJ, Kim BR, Park JS, Lee BT. Bone Regeneration by Multichannel Cylindrical Granular Bone Substitute for Regeneration of Bone in Cases of Tumor, Fracture, and Arthroplasty. Int J Environ Res Public Health. 2022 Jul 6;19(14):8228.

73 Peter M, Kriwalsky MS, Rafael BV, et al. Micromorphometrical analysis of conventional osteotomy techniques and ultrasonic osteotomy at the rabbit skull. Clin Oral Implan Res. 2008;19(6):570-5.

74 Zhou L, Wang C, Qin Z. Investigation of Chip Formation Characteristics in Orthogonal Cutting of Graphite. Mater Manuf Process. 2009;24(12): 1365-72.

75 Moslemi N, Shahnaz A, Masoumi S, Torabi S, Akbari S. Laser-Assisted Osteotomy for Implant Site Preparation: A Literature Review. Implant Dent. 2017;26(1):129-136.

76 Gouw-Soares S, Tanji E, Haypek P, Cardoso W, Eduardo CP. The use of Er:YAG, Nd:YAG and Ga-Al-As lasers in periapical surgery: a 3-year clinical study. J Clin Laser Med Surg. 2001;19(4):193-8.

77 Martins GL, Puricelli E. Bone healing after bur and Er:YAG laser ostectomies. J Oral Maxillofac Surg. 2011;69:1214–1220.

78 Tavares W, Fonseca F, Maia L, de Carvalho Machado V, França Alves Silva N, Junior G, Ribeiro Sobrinho A. 3D Apicoectomy Guidance: Optimizing Access for Apicoectomies. J Oral Maxillofac Surg. 2020;78(3):357.e1-357.

79 Antal M, Nagy E, Braunitzer G, Fráter M, Piffkó J. Accuracy and clinical safety of guided root end resection with a trephine: a case series. Head Face Med. 2019; 21;15(1):30.

80 Popowicz W, Palatyńska-Ulatowska A, Kohli MR. Targeted Endodontic Microsurgery: Computed Tomography-based Guided Stent Approach with Platelet-rich Fibrin Graft: A Report of 2 Cases. J Endod. 2019 ;45(12):1535-42.

81 Antal M, Nagy E, Sanyó L, Braunitzer G. Digitally planned root end surgery with static guide and custom trephine burs: A case report. Int J Med Robot. 2020 ;16(4):e2115.

82 Lin LM, Gaengler P, Langeland K. Periradicular curettage. Int Endod J. 1996 Jul;29(4):220-7.

83 De Deus QD. Frequency, location, and direction of the lateral, secondary, and accessory canals. J Endod 1975;1:361–6.

84 Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol. 1984 Nov; 58(5) :589-99.

85 Blasković-Subat V. Ucestalost apeksnih, lateralnih i furkacijskih akcesornih kanalića Frequency of apical, lateral and furcational accessory canals. Acta Stomatol Croat. 1990;24:85-95.

86 Camargo Villela Berbert FL, deFaria J unior NB ,Tanomaru Filho M. An invitro evaluation of apicoectomies and retropreparations using different methods. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:57–63.

87 Morgan L, Marshall J . The topography of root ends resected with fissure burs and refined with two types of finishing burs. Oral Surg 1998;85:585–91.

88 Nedderman TA, Hartwell GR, Protell FR. A comparison of root surfaces following apical root resection with various burs: scanning electron microscopic evaluation. J Endod 1988;14:423–7.

89 Weston G, Moule A, Bartold P. A scanning electron microscopic evaluation of root surfaces and the gutta-percha interface following root-end resection in vitro. Int Endod J 1999;32:450–8.

90 Stabholz A, Khayat A, Ravanshad SH, et al. Effects of Nd:YAG laser on apical seal of teeth after apicoectomy and retrofill. J Endod 1992;18:371–5.

91 Duarte MA, Domingues R, Matsumoto MA, Padovan LE, Kuga MC. Evaluation of apical surface roughness after root resection: a scanning

electron microscopic study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;104(6):e74-6.

92 Bernardes RA, de Souza Junior JV, Duarte MA, et al. Ultrasonic chemical vapor deposition-coated tip versus high- and low-speed burs for apicoectomy: time required for resection and scanning electron microscopy analysis of the root-end surfaces. J Endod 2009;2:265–8.

93 Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod 2006;32:601–23.

94 Gutmann J, Pitt Ford T. Management of the resected root end: a clinical review. Int Endod J 1993;233:273–83.

95 Gutmann J, Saunders W, Nguyen L. Ultrasonic root end preparation. Part 1. SEM: analysis. Int Endod J 1994;27:318–24.

96 Walivaara D, Abrahamsson P, Samfors K. Periapical surgery using ultrasonic preparation and thermoplasticized gutta-percha with AH Plus sealer or IRM as retrograde root-end fillings in 160 consecutive teeth: a prospective randomized clinical study. Oral Surg Oral Med Oral Pathol Radiol Endod 2009;108: 784–9.

97 Peters C, Peters O, Barbakow F. An in vitro study comparing root end cavities prepared by diamond coated and stainless steel ultrasonic retrotips. Int Endod J 2001;34:142–8.

98 Ishikawa H, Sawada N, Kobayashi C, Suda H. Evaluation of root-end cavity preparation using ultrasonic retrotips. Int Endod J. 2003;36(9):586-90.

99 Del Fabbro M, Tsesis I, Rosano G. Scanning electron microscopic analysis of the integrity of the root-end surface after root-end management using piezoelectric device: a cadaveric study. J Endod 2010;36:1693–7.

100 Liu Z, Zhang D, Li Q, et al. Evaluation of root-end preparation with a new ultrasonic tip. J Endod 2013;39:820–3.
101 Palma PJ, Marques JA, Casau M, Santos A, Caramelo F, Falacho RI, Santos JM. Evaluation of Root-End Preparation with Two Different Endodontic Microsurgery Ultrasonic Tips. Biomedicines. 2020; 28;8(10):383.

102 Bigham-Sadegh, A.; Oryan, A. Basic concepts regarding fracture healing and the current options and future directions in managing bone fractures. Int. Wound J. 2015, 12, 238–247

103 Loi F, Córdova LA, Pajarinen J, Lin TH, Yao Z, Goodman SB. Inflammation, fracture and bone repair. Bone. 2016;86:119-30.
104 Lee SM, Yu YH, Wang Y, Kim E, Kim S. The Application of "Bone Window" Technique in Endodontic Microsurgery. J Endod. 2020 Jun;46(6):872-80.

105 Remedios, A. Bone and Bone Healing. Vet. Clin. N. Am. Small Anim. Pract. 1999, 29, 1029–44

106 Rud J, Andreasen JO, Jensen JE. Radiographic criteria for the assessment of healing after endodontic surgery. Int J Oral Surg. 1972;1(4):195-214.
107 Molven O, Halse A, Grung B. Observer strategy and the radiographic classification of healing after endodontic surgery. Int J Oral Maxillofac Surg. 1987;16(4):432-9.
108 Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008;106(1):106-14.

109 Patel S, Wilson R, Dawood A, Foschi F, Mannocci F. The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography - part 2: a 1-year post-treatment follow-up. Int Endod J. 2012;45(8):711-23.

110 Schloss T, Sonntag D, Kohli MR, Setzer FC. A comparison of 2- and 3-dimensional healing assessment after endodontic surgery using cone-beam computed tomographic volumes or periapical radiographs. J Endod 2017; 43: 1072-9.

111 Kang S, Ha SW, Kim U, Kim S, Kim E. A One-Year Radiographic Healing Assessment after Endodontic Microsurgery Using Cone-Beam Computed Tomographic Scans. J Clin Med. 2020 Nov 19;9(11):3714

112 Evans G, Bishop K, Renton T. Update of guidelines for surgical endodontics - the position after ten years. Br Dent J. 2012; 212(10):497-8.

113 Han B, Wang Y, Zheng C, Peng L, Sun Y, Wang Z, Wang X. Evaluation of a dynamic navigation system for endodontic microsurgery: study protocol for a randomised controlled trial. BMJ Open. 2022; 13;12(12):e064901.

114 Nakkeeran KP, Saravanan K, Babu P, John RR. Evaluation of bone regeneration in periapical osseous defects with and without platelet rich plasma, combined calcium sulfate and autologous bone graft - A comparative study. J Stomatol Oral Maxillofac Surg. 2019;120(3):196-202.

115 Hurwitz E, Simon M, Vinta S, Zehm C, Shabot S, Minhajuddin A, Abouleish A. Adding Examples to the ASA-Physical Status Classification Improves Correct Assignment to Patients. Anesthesiology. 2017;126(4): 614-22.

116 Weine F, Pasiewicz R, Rice R. Canal configuration of the mandibular second molar using a clinically oriented in vitro method. J Endod. 1969;14:207-13.

117 Weine F. Endodontic Therapy. 3rd ed. St. Louis: CV Mosby; 1982. p. 256-340.

118 Kasam S, Mariswamy AB. Efficacy of Different Methods for Removing Root Canal Filling Material in Retreatment - An In-vitro Study. J Clin Diagn Res. 2016;10(6):06-10.

119 Adl A, Shahravan A, Farshad M, Honar S. Success Rate and Time for Bypassing the Fractured Segments of Four NiTi Rotary Instruments. Iran Endod J. 2017;12(3):349-53

120 Gandevivala A, Parekh B, Poplai G, Sayed A. Surgical removal of fractured endodontic instrument in the periapex of mandibular first molar. J Int Oral Health. 2014;6(4):85-8.

121 Terauchi Y, Ali W, Abielhassan M. Present status and future directions: Removal of fractured instruments. Int Endod J. 2022;55 Suppl 3:685-709

122 Theodoros Lambrianidis. Ledging and blockage of root canals during canal preparation: causes, recognition, prevention, management, and outcomes. 2009, 15, 56 –74.

123 Mantri S, Kapur R, Gupta N, Kapur CA. Type III apical transportation of root canal. Contemp Clin Dent. 2012;3(1):134-6.

124 Llaquet Pujol M, Vidal C, Mercadé M, Muñoz M, Ortolani-Seltenerich S. Guided Endodontics for Managing Severely Calcified Canals. J Endod. 2021;47(2):315-321.

125 An HJ, Yoon H, Jung HI, Shin DH, Song M. Comparison of Obturation Quality after MTA Orthograde Filling with Various Obturation Techniques. J Clin Med. 2021;16;10(8):1719

126 Drukteinis, S. Root canal obturation techniques with hydraulic calcium silicate-based materials. Clin Dent Rev. 2021;(5): 5-22

127 Silva J, Andrade P, Sotto-Maior B, Souza Picorelli Assis N, Pires Carvalho A, Devito K. Influence of lip retraction on the cone beam computed tomography assessment of bone and gingival tissues of the anterior maxilla. Oral Surg Oral Med Oral Pathol Oral Radiol. 2017;123:714-20.

128 Raz E, Nossek E, Sahlein DH, Sharashidze V, Narayan V, Ali A, Esparza R, Peschillo S, Chung C, Diana F, Syed S, Nelson PK, Shapiro M. Principles, techniques and applications of high resolution cone beam CT angiography in the neuroangio suite. J Neurointerv Surg. 2023;15(6):600-7.

129 Wang C, Xu P, Ren L, Dong G, Ye L. Comparison of post-obturation pain experience following one-visit and two-visit root canal treatment on teeth with vital pulps: a randomized controlled trial. Int Endod J. 2010;43(8):692-7.

130 Peñarrocha-Diago M, Maestre-Ferrín L, Peñarrocha-Oltra D, Gay-Escoda C, von-Arx T, Peñarrocha-Diago M. Pain and swelling after periapical surgery related to the hemostatic agent used: anesthetic solution with vasoconstrictor or aluminum chloride. Med Oral Patol Oral Cir Bucal. 2012; 1;17(4):594-600.

131 Laureano Filho JR, de Oliveira e Silva ED, Batista CI, Gouveia FM. The influence of cryotherapy on reduction of swelling, pain and trismus after third-molar extraction: a preliminary study. J Am Dent Assoc. 2005;136(6):774-8;

132 Karlson G, Tengvall H. The accuracy of apical palpation and percussion when diagnosing apical periodontitis. Malmö högskola/Odontologiska fakulteten; 2013. 1-29

133 Miller, S. C. (1950). Textbook of periodontia: Oral medicine. Philadelphia: Blakiston.

134 Berthold C, Holst S, Schmitt J, Goellner M, Petschelt A. An evaluation of the Periotest method as a tool for monitoring tooth mobility in dental traumatology. Dent Traumatol. 2010;26(2):120-8.

135 Aoki A, Mizutani K, Mikami R, Taniguchi Y, Ohsugi Y, Meinzer W, Izumi Y, Iwata T. Residual periodontal pocket treatment with Er:YAG laser-assisted comprehensive periodontal pocket therapy: a retrospective study. Clin Oral Investig. 2022;26(1):761-71.

136 Budenz AW, Osterman SR. A review of mandibular anesthesia nerve block techniques. J Calif Dent Assoc. 1995;23(9):27-34.

137 Park WB, Park JS, Han JY, Kang P. Utilizing Previously Grafted Sinus as Intraoral Donor Site for Successful Augmentation in Peri-Implant Osseous Defect: A Case Report. Medicina (Kaunas). 2022 Apr 27;58(5):598.

138 Dragovic M, Pejovic M, Stepic J, Colic S, Dozic B, Dragovic S, Lazarevic M, Nikolic N, Milasin J, Milicic B. Comparison of four different suture materials in respect to oral wound healing, microbial colonization, tissue reaction and clinical features-randomized clinical study. Clin Oral Investig. 2020;24(4):1527-41.

139 Elsawy H., Saleh H., Ahmed, W. Accuracy Of Ultra Low Dose And Standard Dose Cbct Protocols In Volumetric Measurements Of Simulated Bone Defects Versus Real Measurements: Experimental Study. Egyptian Dental Journal, 2023; 69(1): 273-83

140 Rana M, Modrow D, Keuchel J, Chui C, Rana M, Wagner M, Gellrich NC. Development and evaluation of an automatic tumor

segmentation tool: a comparison between automatic, semi-automatic and manual segmentation of mandibular odontogenic cysts and tumors. J Craniomaxillofac Surg. 2015;43(3):355-9

141 Sarkar MR, Augat P, Shefelbine SJ, Schorlemmer S, Huber-Lang M, Claes L, Kinzl L, Ignatius A. Bone formation in a long bone defect model using a platelet-rich plasma-loaded collagen scaffold. Biomaterials. 2006;27(9):1817-23.

142 Kröpil P, Hakimi AR, Jungbluth P, Riegger C, Rubbert C, Miese F, Lanzman RS, Wild M, Schek A, Scherer A, Windolf J, Antoch G, Becker J, Hakimi M. Cone beam CT in assessment of tibial bone defect healing: an animal study. Acad Radiol. 2012;19(3):320-5.

143 Jang SM, Kim E, Min KS. An Update on Endodontic Microsurgery of Mandibular Molars: A Focused Review. Medicina (Kaunas). 2021 ; 16;57(3):270.

144 Pallarés-Serrano A, Glera-Suarez P, Tarazona-Alvarez B, Peñarrocha-Diago M, Peñarrocha-Diago M, Peñarrocha-Oltra D. Prognostic Factors after Endodontic Microsurgery: A Retrospective Study of 111 Cases with 5 to 9 Years of Follow-up. J Endod. 2021;47(3):397-403.

145 Kim JE, Shim JS, Shin Y. A new minimally invasive guided endodontic microsurgery by cone beam computed tomography and 3-dimensional printing technology. Restor Dent Endod. 20;19 25;44(3):e29.

146 Burns PB, Rohrich RJ, Chung KC. The levels of evidence and their role in evidence-based medicine. Plast Reconstr Surg. 2011;128(1):305-10.

147 Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, McQuay HJ. Assessing the quality of reports of

randomized clinical trials: is blinding necessary? Control Clin Trials. 1996;17(1):1-12.

148 Lim CH, Han JY, Cha SH, Kim YH, Yoo KY, Kim HJ. Effects of high versus low inspiratory oxygen fraction on postoperative clinical outcomes in patients undergoing surgery under general anesthesia: A systematic review and meta-analysis of randomized controlled trials. J Clin Anesth. 2021;75:110461

149 Gerstein A, Phillips T, Rogers G, Gilchrest B. Wound healing and aging. Dermatol Clin. 1993;11(4):749-57.

150 Amini-Nik S, Abdullahi A, Vinaik R, Yao RJR, Yu N, Datu A, Belo C, Jeschke MG. Aging Impairs the Cellular Interplay between Myeloid Cells and Mesenchymal Cells during Skin Healing in Mice. Aging Dis. 2022 ;1;13(2):540-51

151 van Dijk J, Zaslansky R, van Boekel R, Cheuk-Alam J, Baart S, Huygen F, Rijsdijk M. Postoperative Pain and Age: A Retrospective Cohort Association Study. Anesthesiology. 2021;1;135(6):1104-19.

152 Padda J, Khalid K, Hitawala G, Batra N, Pokhriyal S, Mohan A, Zubair U, Cooper AC, Jean-Charles G. Depression and Its Effect on the Menstrual Cycle. Cureus. 2021;21;13(7):e16532.

153 Gan TJ. Poorly controlled postoperative pain: prevalence, consequences, and prevention. J Pain Res. 2017 25;10:2287-98

154 Iqbal MK, Kratchman SI, Guess GM, Karabucak B, Kim S. Microscopic periradicular surgery: perioperative predictors for postoperative clinical outcomes and quality of life assessment. J Endod. 2007;33(3):239-44.

155 Sunildath M, Mathew J, George L, Vineet R, Thomas P, John D. Canal transportation and centering ability of root canals prepared using rotary and reciprocating systems with and without pathfiles in cone-

beam computed tomography-based three-dimensional molar prototypes. J Conserv Dent. 2021;24(3):246-51.
156 Malagise CJ, Khalighinejad N, Patel YT, Jalali P, He J. Severe Pain after Endodontic Surgery: An Analysis of Incidence and Risk Factors. J Endod. 2021;47(3):409-14.
157 Zahedi S, Mostafavi M, Lotfirikan N. Anatomic Study of Mandibular Posterior Teeth Using Cone-beam Computed Tomography for Endodontic Surgery. J Endod. 2018;44(5):738-43.
158 Rubinstein RA, Kim S. Short–term observation of the results of endodontic surgery with the use of a surgical operation microscope and Super-EBA as root-end filling material. J Endod 1999;25:43– 8.
159 Kaya S, Yavuz I, Uysal I, Akkuş Z. Measuring bone density in healing periapical lesions by using cone beam computed tomography: a clinical investigation. J Endod. 2012;38(1):28-31.
160 Karan NB, Aricioğlu B. Assessment of bone healing after mineral trioxide aggregate and platelet-rich fibrin application in periapical lesions using cone-beam computed tomographic imaging. Clin Oral Investig. 2020;24(2):1065-72.
161 Anderson O, Wearne I. Informed consent for elective surgery. what is best practice?. J R Soc Med. 2007;100(2):97-100.
162 Shah P, Thornton I, Turrin D, Hipskind J. Informed Consent. 2021(14) StatPearls [Internet]; 1-10
163 Agozzino E, Borrelli S, Cancellieri M, Carfora FM, Di Lorenzo T, Attena F. Does written informed consent adequately inform surgical patients? A cross sectional study. BMC Med Ethics. 2019;7;20(1):1.
164 Nair PN. On the causes of persistent apical periodontitis: a review. Int Endod J. 2006;39(4):249-81.
165 Martin RL, Monticelli F, Brackett WW, Loushine RJ, Rockman RA, Ferrari M, Pashley DH, Tay FR. Sealing properties of mineral

trioxide aggregate orthograde apical plugs and root fillings in an in vitro apexification model. J Endod. 2007;33(3):272-5.
166 Paños-Crespo A, Sánchez-Torres A, Gay-Escoda C. Retrograde filling material in periapical surgery: a systematic review. Med Oral Patol Oral Cir Bucal. 2021 ;1;26(4):422-9
167 Abuelniel GM, Duggal MS, Kabel N. A comparison of MTA and Biodentine as medicaments for pulpotomy in traumatized anterior immature permanent teeth: A randomized clinical trial. Dent Traumatol. 2020;36(4):400-10.
168 Andelin WE, Browning DF, Hsu GH, Roland DD, Torabinejad M. Microleakage of resected MTA. J Endod. 2002;28(8):573-4.
169 Adel M, Salmani Z, Youssefi N, Heidari B. Comparison of Microleakage of Mineral Trioxide Aggregate Apical Plug Applied by the Manual Technique and Indirect Use of Ultrasonic with Different Powers. J Dent (Shiraz). 2021;22(4):290-5.
170 Premjith, Shetty D, Kailar A, Pare S, Kumar P, Ragher M. The Effect of Root End Cavity Preparation Using Er,Cr:YSGG Laser, Ultrasonic Retrotip, and Bur on the Apical Microleakage of Retrograde Cavity Filled with MTA Plus. J Pharm Bioallied Sci. 2020 Aug;12(Suppl 1):S299-S303.
171 Peng L, Zhao J, Wang ZH, Sun YC, Liang YH. Accuracy of root-end resection using a digital guide in endodontic surgery: An in vitro study. J Dent Sci. 2021;16(1):45-50.
172 Pinsky HM, Champleboux G, Sarment DP. Periapical surgery using CAD/CAM guidance: preclinical results. J Endod. 2007;33(2):148-51.
173 Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: a systematic review. Int J Oral Maxillofac Implants. 2014;29 Suppl:25-42.

174 Komiyama A, Pettersson A, Hultin M, Näsström K, Klinge B. Virtually planned and template-guided implant surgery: an experimental model matching approach. Clin Oral Implants Res. 2011;22(3):308-13.
175 Yi C, Li S, Wen A, Wang Y, Zhao Y, Zhang Y. Digital versus radiographic accuracy evaluation of guided implant surgery: an in vitro study. BMC Oral Health. 2022 ; 24;22(1):540.
176 Park JH, Lee GH, Moon DN, Yun KD, Kim JC, Lee KC. Creation of Digital Virtual Patient by Integrating CBCT, Intraoral Scan, 3D Facial Scan: An Approach to Methodology for Integration Accuracy. J Craniofac Surg. 2022 ;1;33(4):396-8.
177 Revilla-León M, Zandinejad A, Nair MK, Barmak AB, Feilzer AJ, Özcan M. Accuracy of a patient 3-dimensional virtual representation obtained from the superimposition of facial and intraoral scans guided by extraoral and intraoral scan body systems. J Prosthet Dent. 2022;128(5):984-93.
178 Almeida e Silva JS, Erdelt K, Edelhoff D, Araújo É, Stimmelmayr M, Vieira LC, Güth JF. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig. 2014;18(2):515-23.
179 Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital Versus Conventional Impressions in Fixed Prosthodontics: A Review. J Prosthodont. 2018;27(1):35-41.
180 Bahar E, Yoon H. Lidocaine: A Local Anesthetic, Its Adverse Effects and Management. Medicina (Kaunas). 2021 ; 30;57(8):782.
181 Parirokh M, Yosefi M, Nakhaee N, Manochehrifar H, Abbott PV, Reza Forghani F. Effect of bupivacaine on postoperative pain for inferior alveolar nerve block anesthesia after single-visit root canal treatment in teeth with irreversible pulpitis. J Endod. 2012;38(8):1035-9.

182 Grandi C, Pacifici L. The ratio in choosing access flap for surgical endodontics: a review. Oral Implantol (Rome). 2009;2(1):37-52.
183 Alamoudi RA, Alghamdi NS, Alqahtani SM, Alamoudi RAS, Baghlaf K. Gingival Recession after Surgical Endodontic Treatment and Quality of Life: A Systematic Review and Meta-analysis. Oral Health Prev Dent. 2021;7;19(1):235-43.
184 Lakshmiganthan M, Gokulanathan S, Shanmugasundaram N, Daniel R, Ramesh S. Piezosurgical osteotomy for harvesting intraoral block bone graft. J Pharm Bioallied Sci. 2012 ;4(Suppl 2):S165-8.
185 Nagy E, Fráter M, Antal M. Guided modern endodontic microsurgery by use of a trephine bur. Orv Hetil. 2020 ;161(30):1260-5.
186 Cáceres Madroño E, Rodríguez Torres P, Oussama S, Zubizarreta-Macho Á, Bufalá Pérez M, Mena-Álvarez J, Riad Deglow E, Hernández Montero S. A Comparative Analysis of the Piezoelectric Ultrasonic Appliance and Trephine Bur for Apical Location: An In Vitro Study. J Pers Med. 2021;15;11(10):1034.
187 AlSarhan, Mohammed A. A Systematic Review of the Tensile Strength of Surgical Sutures. Journal of Biomaterials and Tissue Engineering. 2019; 9(11); 1467-76.
188 Łęcka M.Pain assessment and the role of verbal descriptors of pain in the English language. InAnnales Academiae Medicae Silesiensis 2013.4; 268-75.
189 Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res (Hoboken). 2011;63 Suppl 11:S240-52.

190 Sjöström B, Dahlgren LO, Haljamäe H. Strategies in postoperative pain assessment: validation study. Intensive Crit Care Nurs. 1999;15(5):247-58..

191 Cho H, Lynham AJ, Hsu E. Postoperative interventions to reduce inflammatory complications after third molar surgery: review of the current evidence. Aust Dent J. 2017;62(4):412-19.

192 Al-Maawi S, Becker K, Schwarz F, Sader R, Ghanaati S. Efficacy of platelet-rich fibrin in promoting the healing of extraction sockets: a systematic review. Int J Implant Dent. 2021; 19;7(1):117.

193 Mousa MR, Hajeer MY, Burhan AS, Heshmeh O, Darwich K. Assessment of Patient-Centered Outcomes When Treating Palatally Impacted Canines Using Conventional Versus Accelerated Minimally Invasive Corticotomy-Assisted Orthodontic Treatment: A Randomized Controlled Trial. Cureus. 2022; 17;14(10):e30392.

194 von Arx T, Vinzens-Majaniemi T, Bürgin W, Jensen SS. Changes of periodontal parameters following apical surgery: a prospective clinical study of three incision techniques. Int Endod J. 2007;40(12):959-69.

195 Sharma G, Abraham D, Gupta A, Aggarwal V, Mehta N, Jala S, Chauhan P, Singh A. Comparison of healing assessments of periapical endodontic surgery using conventional radiography and cone-beam computed tomography: A systematic review. Imaging Sci Dent. 2022;52(1):1-9.

196 Patel S, Brown J, Pimentel T, Kelly RD, Abella F, Durack C. Cone beam computed tomography in Endodontics - a review of the literature. Int Endod J. 2019;52(8):1138-52.

197 American Academy of Oral and Maxillofacial Radiology. Clinical recommendations regarding use of cone beam computed tomography in orthodontics. Position statement by the American Academy of Oral and

Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;116(2):238-57.
198 Chen C, Zhang R, Zhang W, Li F, Wang Z, Qin L, Chen Y, Bian Z, Meng L. Clinical and radiological outcomes of dynamic navigation in endodontic microsurgery: a prospective study. Clin Oral Investig. 2023; 2.
199 Di Spirito F, Scelza G, Fornara R, Giordano F, Rosa D, Amato A. Post-Operative Endodontic Pain Management: An Overview of Systematic Reviews on Post Operatively Administered Oral Medications and Integrated Evidence Based Clinical Recommendations. Healthcare (Basel). 2022; 19;10(5):760.
200 Menziletoglu D, Basturk F, Isik BK, Esen A. A prospective split-mouth clinical study: comparison of piezosurgery and conventional rotary instruments in impacted third molar surgery. Oral Maxillofac Surg. 2020;24(1):51-55..
201 Goyal M, Marya K, Jhamb A, Chawla S, Sonoo PR, Singh V, Aggarwal A. Comparative evaluation of surgical outcome after removal of impacted mandibular third molars using a Piezotome or a conventional handpiece: a prospective study. Br J Oral Maxillofac Surg. 2012;50(6):556-61.

202 Liu J, Hua C, Pan J, Han B, Tang X. Piezosurgery vs conventional rotary instrument in the third molar surgery: A systematic review and meta-analysis of randomized controlled trials. J Dent Sci. 2018;13(4):342-9.

203 Isoda Y, Imamura E, Ueno D, Akaike T, Hamada Y. Use of a trephine bur and curette for minimally invasive harvesting of particulate cancellous bone and marrow from the iliac crest: a case of alveolar ridge reconstruction. Int J Implant Dent. 2016;2(1):1-6

204 Saraiva Amaral J, Marto CM, Farias J, Alves Pereira D, Ermida J, Banaco Á, Campos Felino A, Caramelo F, Matos S. A Pilot Randomized Controlled Clinical Trial Comparing Piezo Versus Conventional Rotary Surgery for Removal of Impacted Mandibular Third Molars. Bioengineering (Basel). 2022; 25;9(7):276.

205 Mouraret S, Houschyar KS, Hunter DJ, Smith AA, Jew OS, Girod S, Helms JA. Cell viability after osteotomy and bone harvesting: comparison of piezoelectric surgery and conventional bur. Int J Oral Maxillofac Surg. 2014;43(8):966-71.

206 Yoo YJ, Perinpanayagam H, Kim M, Zhu Q, Baek SH, Kwon HB, Kum KY. Stress Distribution on Trephine-Resected Root-end in Targeted Endodontic Microsurgery: A Finite Element Analysis. J Endod. 2022;48(12):1517-25.

207 Morgan LA, Marshall JG. The topography of root ends resected with fissure burs and refined with two types of finishing burs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;85(5):585-91.

208 Furumori T, Ueda M, Honda Y, Hashimoto Y, Tanioka T, Kusano K, Baba S. The Effect of Different Surgical Instruments for Bone Regeneration under the Surgery of Bone Defect on Rat Calvaria. J.Hard Tissue Biology.2022; 31(2): 63-70

209 Sauveur G, Boccara E, Colon P, Sobel M, Boucher Y. A photoelastimetric analysis of stress induced by root-end resection. J Endod. 1998;24(11):740-3..

210 Mishra SK, Chowdhary R. Heat generated by dental implant drills during osteotomy-a review: heat generated by dental implant drills. J Indian Prosthodont Soc. 2014;14(2):131-43.

211 Matthews LS, Hirsch C. Temperatures measured in human cortical bone when drilling. J Bone Joint Surg Am. 1972; 54:297–308
212 Rashad A, Sadr-Eshkevari P, Heiland M, Smeets R, Hanken H, Gröbe A, Assaf AT, Köhnke RH, Mehryar P, Riecke B, Wikner J. Intraosseous heat generation during sonic, ultrasonic and conventional osteotomy. J Craniomaxillofac Surg. 2015;43(7):1072-7.
213 Robiony M, Polini F, Costa F, Vercellotti T, Politi M. Piezoelectric bone cutting in multipiece maxillary osteotomies. J Oral Maxillofac Surg. 2004;62(6):759-61.
214 Esteves JC, Marcantonio E Jr, de Souza Faloni AP, Rocha FR, Marcantonio RA, Wilk K, Intini G. Dynamics of bone healing after osteotomy with piezosurgery or conventional drilling - histomorphometrical, immunohistochemical, and molecular analysis. J Transl Med. 2013 23;11:221.
215 Garcia P, Histing T, Holstein JH, Klein M, Laschke MW, Matthys R, Ignatius A, Wildemann B, Lienau J, Peters A, Willie B, Duda G, Claes L, Pohlemann T, Menger MD. Rodent animal models of delayed bone healing and non-union formation: a comprehensive review. Eur Cell Mater. 2013,16;26:1-12.
216 Anesi A., Di Bartolomeo M., Pellacani A., Ferretti, M., Cavani F., Salvatori R., Nocini R., Palumbo C., Chiarini L. Bone Healing Evaluation Following Different Osteotomic Techniques in Animal Models: A Suitable Method for Clinical Insights. Appl. Sci. 2020, 10, 7165.
217 Di Alberti L, Donnini F, Di Alberti C, Camerino M. A comparative study of bone densitometry during osseointegration: piezoelectric surgery versus rotary protocols. Quintessence Int. 2010;41(8):639-44.
218 Chiriac G, Herten M, Schwarz F, Rothamel D, Becker J. Autogenous bone chips: influence of a new piezoelectric device

(Piezosurgery) on chip morphology, cell viability and differentiation. J Clin Periodontol. 2005;32(9):994-9.

219 Fiorellini JP. Osseous response following resective therapy with piezosurgery. The International Journal of Periodontics and Restorative Dentistry. 2005;25(6):543-9.

220 Tsai SJ, Chen YL, Chang HH, Shyu YC, Lin CP. Effect of piezoelectric instruments on healing propensity of alveolar sockets following mandibular third molar extraction. Journal of Dental Sciences. 2012 1;7(3):296-300.

الملخص العربي

بعض الحالات تتطلب التدخل الجراحي حيث انه لا يمكن علاجها بنجاح من خلال العلاج غير الجراحي أو إعادة العلاج حتى مع التقدم في أدوات المعالجة اللبية مثل التكبير، والتصوير المقطعي المحوسب بالشعاع المخروطي(CBCT) ، والمبارد الدوارة Ni-Ti والموجات فوق الصوتية.

عشرون مريضًا من الذكور تم احتسابهم من حالات هذا البحث تتراوح أعمارهم بين 18 و45 عامًا ويعانون من أسنان الرحى الأولى في الفك السفلي ويحتاجون إلى اجراء جراحة مجهرية اللبية بسبب فشل العلاج غير الجراحي أو إعادة العلاج. تم تقسيم المرضى المختارين عشوائيا إلى مجموعتين (ن = 10) وفقا لنوع أدوات القطع أثناء تحضير التجويف العظمي واستئصال نهاية الجذر. المجموعة الأولى: تحضير التجويف بمساعدة جراحة البيزو. المجموعة الثانية: تحضير التجويف بمساعدة قاطع التريفين. تم إجراء كشط قمي وإزالة الأشياء الممتدة مثل الأدوات المنفصلة أو ماده حشو الجذور المنفصلة. تم تسجيل تقييم الألم والتورم خلال خمسة أيام بعد الجراحة كل 24، 48، 72، 96، و120 ساعة بعد العمل الجراحي. تم فحص الألم المصاحب لجس اللثة والقرع الاسنان، وحركة الأسنان واختبارات مستويات اللثة من قبل الطبيب المعالج خلال 3 و6 و12 شهرا. وأخيرا، تم إجراء التحليل الشعاعي الكمي لقياس الحجم وكثافة العظام لمنطقه المستأصلة.

النتائج: لم يكن هناك فروق ذات دلالة إحصائية بين المجموعات من حيث الألم بعد الجراحة، والتورم، والألم عند القرع والجس، وحركة الأسنان واختبارات مستويات اللثة. ومع ذلك، كان هناك فرق ذو دلالة إحصائية بين المجموعات من حيث القياسات الحجمية وكثافة العظام.

الاستنتاج: تقنية تحضير التجويف بمساعدة جراحة البيزو تحسن من شفاء موقع قطع العظم، ولكنها لم تؤثر على الألم والتورم والألم بعد الجراحة عند الجس والقرع.