JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

"Pioneering Precision: Recent Advances in Endodontic Microsurgery"

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Abstract

Endodontic microsurgery represents the pinnacle of contemporary endodontic retreatment, integrating sophisticated microsurgical techniques to address complex anatomical structures with precision. This literature review elucidates the significant advancements in endodontic microsurgery, highlighting the pivotal roles of the surgical operating microscope, advanced microsurgical instruments, and biocompatible materials such as Mineral Trioxide Aggregate (MTA). The evolution of imaging modalities, including Cone-Beam Computed Tomography (CBCT) and three-dimensional (3D) printed surgical guides, has markedly enhanced diagnostic accuracy and procedural efficacy. These innovations, coupled with the implementation of minimally invasive techniques, underscore a transformative shift towards patient-centric, outcome-oriented interventions. Technological advancements, such as the three-dimensional dynamic navigation system (3D-DNS) and piezoelectric surgery, have further refined surgical precision and efficiency, ensuring optimal clinical outcomes. The review also explores the necessity and contraindications for endodontic microsurgery, emphasizing the strategic application of biomaterials in periapical tissue regeneration. Additionally, it examines the clinical outcomes, success rates, and management of postoperative complications, underscoring the critical importance of guided tissue regeneration (GTR) in enhancing healing outcomes. Looking ahead, the integration of artificial intelligence (AI) and robotic-assisted procedures heralds a new era of precision in endodontic microsurgery. This comprehensive review underscores the transformative impact of technological advancements in endodontic microsurgery, highlighting the continuous evolution towards achieving superior precision, efficiency, and patient outcomes.

Keywords :- Endodontic Microsurgery (EMS), Operating Microscope, Micro instruments, Cone-Beam Computed Tomography (CBCT), Ultrasonic Tips, Mineral Trioxide Aggregate (MTA), Guided Tissue Regeneration (GTR), Three-Dimensional Dynamic Navigation System (3D-DNS), Biocompatible Materials, Piezoelectric Technology

1) Introduction

Endodontic microsurgery, a highly sophisticated surgical intervention, is characterized by the meticulous treatment of exceedingly minute and complex anatomical structures under the guidance of an operating microscope. This modern technique synergistically combines enhanced magnification and illumination afforded by the microscope with the precise application of innovative micro instruments [1].

Endodontic microsurgery (EMS) represents the zenith of contemporary surgical endodontic retreatment methodologies, amalgamating advanced microsurgical techniques. These include the utilization of an operating microscope or endoscope, ultrasonic tips for root-end cavity preparation, and the deployment of more biocompatible materials for root-end filling [2].

The surgical management of abscessed teeth has undergone a profound evolution over the centuries, marked by seminal developments:

- 1845: Hullihen pioneered the technique of surgical trephination.
- 1871: Smith executed the inaugural root-end resection.
- 1880s: Curettage was introduced to excise diseased tissue surrounding the apex.
- 1880: Farrar delineated a procedure for abscessed teeth, termed "apicotomy."
- 1886: G.V. Black performed apical amputation of the root in cases of chronic abscesses using a fissure bur.
- 1916: Garvin, Luks, and Gaerny innovated the use of root-end preparations and fillings with amalgam.
- 1926: Neumann described the split-thickness surgical flap, presently recognized as the Oschenbein-Luebke Flap.
- 1939: Tangerud BJ invented a miniature handpiece specifically designed for root-end preparations [1].

Figure 1: A contemporary clinical milieu wherein the microscope affords both clinical precision and ergonomic superiority.

2) The Necessity of Endodontic Microsurgery

A) Indications for Endodontic Microsurgery:

- Iatrogenic or Developmental Anomalies:
- Circumstances that preclude orthograde treatment due to issues such as ledging, fractured instruments, restorations with posts, or significantly sclerosed canals.
- **Note**: These are not absolute indications, as specialists equipped with advanced tools (e.g., microscopes) might address these non-surgically.

- Failure of Orthograde Treatment:
- When the likelihood of successful retreatment is minimal or non-existent, surgical intervention becomes necessary.
- Assessment of the initial treatment's quality often relies on radiographs, which might not provide a comprehensive evaluation of the treatment's efficacy.

- Coronal Disassembly Risks:
- Situations where disassembling the existing restoration would compromise the tooth's prognosis or is deemed excessively costly or time-consuming.
- Engage the patient in discussions regarding surgical alternatives or other options.

- Biopsy:
- In cases where the diagnosis of apical lesions remains ambiguous, a surgical approach permits histopathological analysis for definitive diagnosis.

- Surgical Exploration:

- Valuable for diagnosing suspected fractures or perforations not readily discernible through CBCT imaging.

- Retrieval of Displaced Materials or Instruments:

- When non-healing lesions are caused by foreign materials or instruments that cannot be retrieved through conventional canal systems, surgical retrieval is warranted.

- Patient Factors:

- Scenarios where patients are unable to endure prolonged retreatment sessions due to conditions like trismus, intolerance to rubber dams, or chronic pain [3].

B)Contraindications for Endodontic Microsurgery:

1. Internal Factors:

- Lack of adequate surgical expertise, training, or support infrastructure.

2. Medical or Psychological Factors:

- Conditions such as severe dental anxiety, the patient's inability to maintain complex restorations, or a preference against surgical procedures.
- Informed consent capacity and pertinent medical history may also contraindicate surgical intervention.

3. Dental Factors:

1. Unstable Oral Disease: Avoid in patients with unstable dentitions.
2. Unusual Root Configuration: Access difficulties due to root anatomy (e.g., lower incisors, lingual canals on lower posterior teeth, palatal roots of upper teeth) or challenges such as elongated roots or restricted mouth opening.
3. Proximity to Vital Structures: Risks associated with vital structures like the inferior dental, mental, and lingual nerves, maxillary sinuses, and adjacent tooth roots.
4. Compromised Periodontal Status: Insufficient periodontal support post-surgery.
5. Compromised Restorative Status: When the existing coronal restoration is too deteriorated to facilitate successful surgical outcomes [3].

3)Comparison of traditional and micro surgical approaches in endodontic surgery [4]

Differentiating factors	Traditional approach	Microsurgical approach
Identification of the apex	Challenging	Highly precise
Osteotomy size	Approximately 8–10 MM	3–4 MM
Inspection of resected root surface	Absent	Consistently performed
Bevel angle	Large (45°)	Minimal (<10°)
Isthmus identification and treatment	Practically impossible,	Consistently achieved,
Root end preparation	Performed with a bur	Precisely within the Canal
Root end Preparation instrument	Lacking precision	Ultrasonic tip,
Root end Filling material	Roughly applied rarely within the canal,	Precisely positioned
Suture	4–0 silk	5–0, 6–0 monofilament
Suture removal	7-Days, post-operative	2–3 days, post-operative
Healing success(Over 1 Year)	Ranges from 40% – 90%	Ranges from 85% – 96.8%

4) Technological Advances in Endodontic Microsurgery:

The triad essential to endodontic microsurgery—magnification, illumination, and instruments—is indispensable. The absence of any of these elements would render microsurgery unfeasible [4]. The surgical operating microscope, which provides both magnification and illumination, has revolutionized the field of endodontic microsurgery, fundamentally transforming its execution [5].

Advantages of Utilizing a Surgical Microscope [1,6,7]:
- Enhanced magnification
- Superior evaluation capabilities
- Reduced necessity for radiographs
- Capability for video recording
- Improved communication
- Diminished occupational stress
- Comprehensive case documentation

Application of Magnification [5]:
- Low (x3 to x8): Orientation and alignment of the surgical tip
- Mid-range (x10 to x16): Execution of surgery, surgical procedures, and retrograde preparation
- High (x16 to x30): Inspection and observation of fine details

Surgical Instruments [8]:

Microsurgical Instruments in Endodontic Surgery:
- **Standard Instruments (Figure 2):**
  - Dental mirror
  - Periodontal probe
  - Endodontic explorer

- **Micro mirrors (Figure 3):**
  - Essential for inspecting resected surfaces
  - Available in various shapes
  - Flexible mirror necks are crucial

- **Incision and Elevation Instruments (Figure 4):**
  - 15C Blade and Handle: Ideal for microsurgery, suitable for interproximal papilla and vertical incisions
  - Soft Tissue Periosteal Elevators

- **Advancements:**
  - Piezoelectric Ultrasonic Instrument (Figure 5): Significant for root-end preparation

- **Additional Instruments:**
  - Micro scissors (e.g., Laschal micro-scissors) (Figure 6): Small-beaked scissors for suture management
  - Castroviejo Needle Holder: Utilized for handling 5-0 or 6-0 synthetic sutures

Figure 2:Standard Instrument

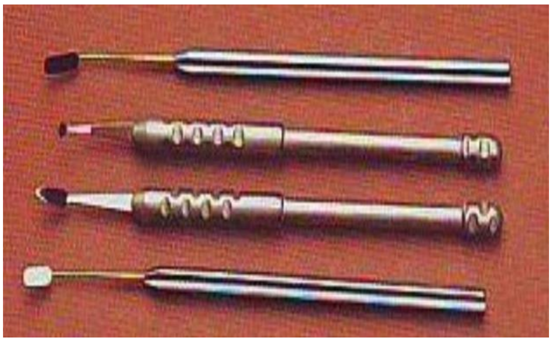

Figure 3: micro mirrors

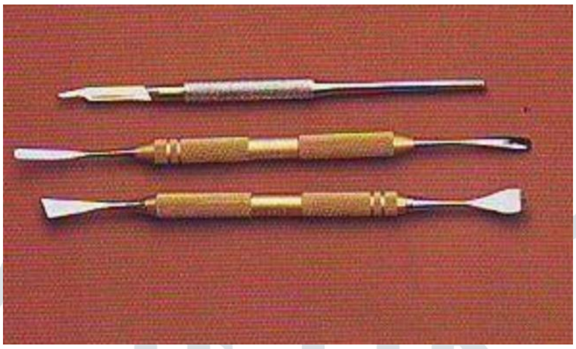

Figure 4: incision and elevation instruments

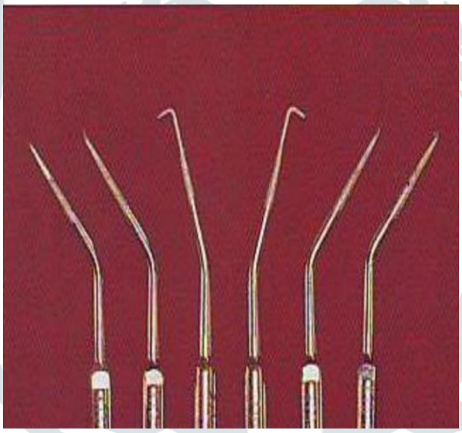

Figure 5: Piezoelectric ultrasonic instruments

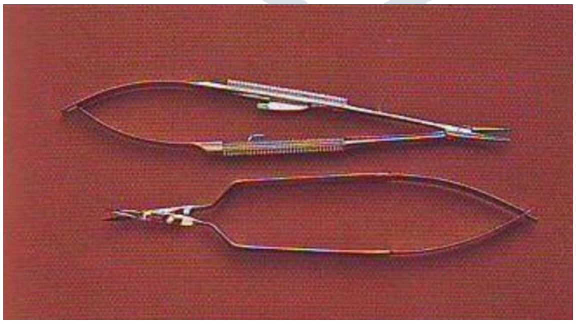

Figure 6: micro scissors

Materials [9]:

The primary root-end filling materials are as follows:

- Gutta-Percha (GP) (Figure 7,a)
- Intermediate Restorative Material (IRM) (Figure 7,b)
- Super EBA Cement (Super EBA) (Figure 7,c)
- Calcium Silicate-Based Root Repair Material (RRM) (Figure 7,d)
- Mineral Trioxide Aggregate (MTA) (Figure 7,e)

(a)


STANDARD PACKAGE
IVORY
DENTSPLY
IN#2124290
IRM®
Intermediate
Restorative Material
Material de restauración intermedio
Matériau de restauration intermédiaire
Temporäres Füllungsmaterial
Materiale per restauro provvisorio
TYPE III, CLASS 1
DENTSPLY
IRM®
Intermediate
Restorative Material
TYPE III, CLASS 1

(b)


Bosworth SuperEBA
All Purpose Lining and Cement with Alumina

(C)

(d)

(e)

Figure 7: Root End Filling Materials(a) Gutta-Percha(b) Intermediate Restorative Material(c) Super EBA Cement (d) Calcium Silicate-Based Root Repair Material (e) Mineral Trioxide Aggregate

Applications of Ultrasonics:

Ultrasonic technology is extensively employed in dentistry, particularly for scaling, root planing, and root canal therapy, encompassing both orthograde and retrograde treatments. Its utilization in endodontics has markedly enhanced the quality of clinical procedures, especially in complex cases. Ultrasonics is instrumental in accessing canal openings, cleaning, shaping, obturating root canals, removing intracanal obstructions, and performing endodontic surgery [10].

These technological advancements underscore the critical role of sophisticated tools and materials in elevating the precision and efficacy of endodontic microsurgical procedures, thereby optimizing patient outcomes.

5) Imaging and Diagnostic Innovations:

A)CBCT:
Endodontic microsurgery (EMS) is an exceptionally effective modality for addressing periapical lesions. However, its efficacy may diminish when dealing with molar teeth, apicomarginal lesions, symptomatic lesions, and large apicocoronal lesions. Such complex cases necessitate meticulous planning, underscored by the utilization of Cone-Beam Computed Tomography (CBCT) to identify perforations, lateral canals, and root cracks or fractures. Given these diagnostic imperatives, CBCT should be an indispensable component of the preoperative assessment, and patients must be apprised of the potential for a less favorable prognosis in these scenarios [11].

B)3D Imaging Techniques:

The integration of Cone-Beam Computed Tomography (CBCT) digital imaging and communications in medicine (DICOM) files, subsequently converted into stereolithographic files, facilitates the production of three-dimensional printed surgical guides (3DSGs) for implant placement. This advancement is particularly significant in targeted endodontic microsurgery (TEMS), where challenging anatomical configurations demand precise osteotomy. Moreover, the burgeoning interest in Magnetic Resonance Imaging (MRI) for radiation-free diagnostic imaging, which offers superior soft-tissue contrast and detailed evaluation of specific tissues such as the alveolar inferior nerve, holds promise for enhancing the fabrication of 3D templates. Consequently, 3D-printed templates are becoming increasingly instrumental in enabling minimally invasive, accurate guided endodontic procedures [12].

C)Navigation and Real-Time Imaging System:

A study conducted by Sara A. Aldahmash et al. rigorously evaluated the accuracy and efficiency of the three-dimensional dynamic navigation system (3D-DNS) for minimally invasive osteotomy (MIO) and root-end resection (RER) in endodontic microsurgery (EMS). The investigation involved 48 tooth roots in cadaver heads, divided equally between the 3D-DNS ($n = 24$) and freehand ($n = 24$) techniques. The findings revealed that the 3D-DNS exhibited significantly lower two-dimensional and three-dimensional virtual deviations, reduced angular deflection, and minimized osteotomy size and volume compared to the freehand method ($P < .05$). Additionally, the resection angle was more favorable, and the viability of root-end cavity preparation (RECP) and root-end fill (REF) was achieved at 100%, with an average REF depth of approximately 3 mm. Importantly, the procedural times for osteotomy, RER, and the overall procedure were significantly abbreviated using the 3D-DNS ($P < .05$) [13].

These advancements underscore the critical role of cutting-edge imaging and diagnostic technologies in enhancing the precision and efficacy of endodontic microsurgical interventions, thereby optimizing clinical outcomes.

6) Surgical Techniques and Protocols:

Proper flap design and meticulous soft tissue management constitute critical facets of successful endodontic microsurgery. The primary objectives encompass ensuring optimal access to underlying bone and root structures while promoting scar-free healing. Four primary flap designs are employed: submarginal rectangular, submarginal triangular, sulcular rectangular, and sulcular triangular, each meticulously executed to ensure comprehensive exposure and minimal postoperative complications, thereby enhancing esthetic outcomes. Both the surgeon and assistant collaborate in the delicate retraction of flaps, employing gentle techniques to mitigate postoperative edema and optimize healing aesthetics. Ensuring instruments rest securely on sound bone enhances procedural efficiency and safety, minimizing fatigue during intricate maneuvers [14].

Root-End Resection and Preparation:

1. Initial Assessment and Access

- Preliminary assessment using radiographs to evaluate tooth and surrounding structures.
- Administration of precise anesthesia and meticulous incision to create a surgical flap, exposing the underlying bone.

2. Osteotomy

- Removal of overlying bone atop the root apex using a high-speed handpiece, ensuring copious irrigation to prevent overheating and tissue damage, thereby establishing a clear access pathway.

3. Apicectomy

- Resection of 3 mm of the root apex at an angle of 0-10° relative to the root's long axis, eliminating infected or damaged tissue and exposing the root canal system with precision.
- Emphasis on clean, precise cuts to facilitate effective cavity preparation and subsequent filling.

4. Root-End Cavity Preparation

- Utilization of ultrasonic retro-tips to prepare a 3 mm deep cavity in the resected root end, leveraging their ability to achieve meticulous cavity preparation with minimal trauma to surrounding tissues.

5. Hemostasis

- Achievement of hemostasis through the application of agents like epinephrine, calcium sulfate, or specialized hemostatic agents, ensuring a dry surgical field conducive to optimal visualization and cavity filling.

6. Filling the Root-End Cavity

- Introduction of biocompatible materials such as Mineral Trioxide Aggregate (MTA), bioceramics, or reinforced zinc oxide-eugenol cement into the prepared cavity.
- Methodical compaction of the material to achieve a hermetic seal, crucial for preventing microleakage and facilitating optimal tissue healing.

7. Verification and Closure

- Validation of filling quality through meticulous radiographic assessment.
- Thorough irrigation of the surgical site followed by careful repositioning and suturing of the flap to ensure meticulous soft tissue closure and minimize scar formation [15].

Retrograde Filling Materials:

In the context of apicoectomy procedures, the selection of an appropriate root-end filling material assumes paramount importance. A comprehensive review spanning two decades has identified multiple materials, among which amalgam remains prevalent but is overshadowed by more effective alternatives such as IRM, Super EBA, and MTA. Super EBA, characterized by reduced cytotoxicity compared to IRM owing to its lower eugenol content, is often preferred. However, MTA stands out prominently due to its superior capabilities in leakage prevention, biocompatibility, and facilitation of hard tissue formation, despite its drawback of an extended setting time. Consequently, MTA frequently emerges as the optimal choice for achieving successful root-end fillings in clinical practice [16]. This underscores the evolving role of advanced biomaterials in enhancing procedural outcomes and patient satisfaction in endodontic microsurgery.

7) Biomaterials in Endodontic Microsurgery

In the realm of endodontic microsurgery, biomaterials play a pivotal role in promoting periapical tissue regeneration. Key among these biomaterials are bone grafts, membranes, and bioceramics such as Mineral Trioxide Aggregate (MTA), renowned for their ability to effectively seal retrograde cavities. Bioceramics, particularly MTA, are highly favored for their biocompatibility and osteogenic properties, facilitating favorable outcomes in surgical interventions.

It is noteworthy that while endodontic microsurgery alone often suffices for complete healing of periapical lesions, the adjunct use of biomaterials becomes essential in specific cases. These include scenarios necessitating enhanced tissue regeneration or preventing potential bone collapse post-surgery [17]. This underscores the strategic application of biomaterials in optimizing clinical outcomes and underscores the evolving role of advanced materials in modern endodontic practice.

8) Clinical Outcomes and Success Rates

A meticulous retrospective study evaluated the determinants influencing the success of endodontic microsurgery (EMS), utilizing cone-beam computed tomography (CBCT) scans across a cohort of 161 cases. This comprehensive analysis revealed that variables such as the resection angle, depth of retrograde filling, and the length of the resected root did not exhibit a statistically significant impact on the outcomes of EMS. However, the study elucidated that the incorporation of guided tissue regeneration (GTR) significantly enhanced radiographic healing outcomes, particularly in cases characterized by apical lesions or those with larger volumes of bone destruction. Of the cases assessed, 18 (11.18%) were classified as failures, whereas 143 (88.82%) were deemed successful post-surgery [11].

Moreover, another comparative study was conducted to ascertain the clinical outcomes of endodontic microsurgery over follow-up periods of one year and four years. This study encompassed 115 cases evaluated in accordance with Rud's criteria. The findings demonstrated an overall success rate of 91.3% at the one-year mark, which slightly diminished to 87.8% after four years. Statistical analysis indicated no significant difference in success rates between the two follow-up intervals ($P = 0.344$). Consequently, the study concluded that the clinical outcomes of endodontic microsurgery remain stable over extended follow-up periods, thereby underscoring the long-term efficacy and reliability of the procedure [18].

These studies collectively highlight the critical importance of GTR in enhancing healing outcomes and affirm the sustained success of endodontic microsurgery over time. This underscores the necessity for ongoing research and refinement in surgical techniques and adjunctive therapies to further augment clinical outcomes.

9) Complications and Their Management

Postoperative complications in endodontic surgery encompass a range of adverse events, including pain, swelling, ecchymosis, hemorrhage, paresthesia, and serious infections. These complications can significantly impact patient recovery and the overall success of the surgical procedure [1].

Management Strategies:

The management of these complications in contemporary endodontic surgery underscores not only the necessity for precise root-end preparation and sealing but also the meticulous care of soft tissues to achieve superior esthetic outcomes. Preserving the health and aesthetic integrity of soft tissues is imperative for maintaining optimal attachment levels and averting postoperative recession.

To this end, the foremost objectives include the attainment of complete, recession-free healing of gingival tissues. This is achieved through the implementation of atraumatic surgical techniques, the utilization of non-irritating suture materials, and the employment of meticulous suturing techniques. Such measures ensure minimal disruption to the delicate oral tissues and promote expedited healing.

Furthermore, the adoption of anatomically appropriate incision types and strategic flap designs, grounded in robust clinical and scientific evidence, is recommended. These strategies facilitate enhanced wound closure and foster predictable tissue healing, thereby reducing the incidence of postoperative complications.

Overall, these comprehensive management strategies strive to integrate both current and innovative approaches in endodontic surgery. The goal is to minimize complications while maximizing esthetic success, ensuring that patients receive the highest standard of care and optimal surgical outcomes [19].

10) Future Directions and Research-Emerging Trends:

A. Piezoelectric Surgery:
- The advent of piezoelectric technology heralds a new era of precision in endodontic microsurgery. This technology facilitates meticulous bone cutting, root resection, and root-end preparation, thereby minimizing trauma, expediting healing, and significantly enhancing patient outcomes.

B. CBCT Healing Assessment:
- The utilization of cone-beam computed tomography (CBCT) is on the rise for the precise evaluation of periapical healing following surgical interventions. This technique promises to supplant traditional healing categories with volumetric assessments, offering a more nuanced and accurate monitoring of post-surgical recovery.

C. Guided Techniques and Artificial Intelligence:
- The implementation of guided endodontic microsurgery, leveraging CBCT-based surgical templates, ensures exceptional precision in osteotomy and root resection, thereby elevating procedural accuracy. The integration of artificial intelligence (AI) into this domain enhances diagnostic capabilities through computer-aided design (CAD) systems and augments treatment planning. Looking ahead, the potential for robotic-assisted procedures guided by AI looms on the horizon, promising unprecedented advancements in the field [20].

11) Conclusion

Endodontic microsurgery, epitomizing the forefront of dental surgical innovation, synergistically integrates advanced magnification, illumination, and cutting-edge instruments to address complex endodontic pathologies with unparalleled precision. This literature review highlights the pivotal advancements in the field, emphasizing the indispensable role of the surgical operating microscope, refined microsurgical instruments, and biocompatible materials such as Mineral Trioxide Aggregate (MTA). The introduction of three-dimensional imaging and navigation technologies, including CBCT and 3D-printed surgical guides, has significantly augmented diagnostic accuracy and procedural efficacy. Furthermore, the implementation of minimally invasive techniques and the strategic application of biomaterials underscore the evolution towards patient-centric, outcome-oriented interventions. Despite the inherent complexities and potential complications, meticulous surgical protocols and advanced management strategies have bolstered clinical success rates, achieving long-term stability and superior esthetic outcomes. Looking ahead, the integration of piezoelectric surgery, AI, and robotic-assisted procedures promises to revolutionize the field, enhancing precision and patient outcomes. Collectively, these advancements underscore a transformative shift in endodontic microsurgery, heralding a new era of precision, efficiency, and clinical excellence.

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