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Surgical endodontics: past, present, and future

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". . . every age should profit by the experience of the preceding ones; but without a record of what has been accomplished each investigator *(or clinician)* commences a new series of trials *(or treatment modalities)*, and wanders over the same ground in search of truths *(or outcomes)* which have long been discovered; or adopt theories *(or practices)* that have been long ago discarded."* **(Note: present author's inserts in italics)**
*Patrick JJR. The first period in the history of dentistry. *Dent Rev* 1889: 3: 426–437.

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Surgical endodontic intervention has emerged over the past 150 years as a significant treatment modality in the retention of sound teeth (1). While the evolution of this treatment modality and the refinement of its principles have had a long and tumultuous history, biologically based and clinically updated directives have emerged. Furthermore, the endodontic literature has ceased to support a litany of indications for surgical applications; rather, well-thought out, evidenced-based principles are guiding certain aspects of this treatment modality (2–7). Coupled with magnification through the use of the surgical operating microscope, refined principles of soft and hard tissue management, use of tissue regenerative root-end filling materials, and enhanced principles of wound closure and postoperative management, surgical endodontics has emerged as a highly predictable and relatively painless procedure (8–13). Ironically, the impetus for the evolution of contemporary surgical endodontic principles came from a better understanding of the challenges faced in enlarging, shaping, cleaning, disinfecting, and obturating the complex and unpredictable anatomy of the root canal system—an anatomy that beguiles even the most astute and experienced clinician. Although technology in non-surgical procedures has advanced significantly (14), there still remains the challenge of eradicating microbial species and their biofilms from the root canal system and dentinal tubules, primarily in the apical third of the root (15–18). Even with this dictate, it is still imperative to "consider" the choice of non-surgical root canal treatment (19) or the revision of previous less-than-ideal treatment (20) before surgical intervention, as the outcomes of non-surgical procedures are quite positive, at least on a short-term re-evaluation basis.

Surgical intervention is not a substitute for failure to properly manage the root canal system non-surgically, failure to thoroughly assess the periodontal status, and ignoring the shortcomings of the coronal restoration(s) (21,22). Knowing when to choose surgical intervention is imperative, as is the expertise in performing the surgical procedure and the judgement to be exercised in the assessment of what has been done (23). In essence, treatment planning the choice of surgery may actually be more difficult and challenging than the surgical procedure itself (24). This is especially true with the massive and irrational movement to replace every root canal-treated tooth with or without symptoms with an intraosseous implant (25–30). Retention of the natural tooth structure is still the goal of quality dental care and many previously root-treated teeth that appear to be doing quite well, yet exhibit adverse signs or symptoms, are viable candidates for non-surgical treatment revision or surgical revision of treatment (31–33). Within this scenario the advent of cone beam computed tomography (CBCT) has greatly impacted these choices (34–37), in addition to providing opportunities to enhance skills in the use of CBCT when coupled with virtual reality simulation for pre-surgical practice (38). However, with each patient who presents for treatment, the clinician is challenged to make choices that result in the best treatment possible. These choices are based on a number of factors that influence the clinician in the decision-making, problem-solving process (24,39,40). These factors include the following:

- axioms that are commonly held in endodontics and supportive disciplines;
- formative knowledge to support the choices, in particular knowledge of tooth anatomy;
- clinical skill, confidence, and experience;
- problem solving/treatment planning skills;
- patient preference after being fully informed of treatment options and rationales;
- economic factors;
- evidence-based or best-evidence concepts; and
- integrity.

Failure to take all factors into account may lead to treatment plans that are ill-advised or not in the best interest of the patient. While many teeth can be maintained with a surgical endodontic procedure, it may not be in the best interest of the patient to retain a tooth that has restorative or periodontal compromises (24). Furthermore, if a tooth cannot be returned to symptom-free function following surgical intervention, removal may be indicated. Moreover, while tooth retention is ideal for function and esthetics, at times tooth resection or removal and replacement with a fixed partial prosthesis, a removable partial prosthesis, implant, or no replacement may be in the best interest of the patient (24). Hopefully this approach to patient assessment and analysis of data will encourage more evidence-based research and long-term outcome studies to solidify or alter the concepts delineated herein.

Historical highlights and perspectives on surgical endodontics

In 1884 John Farrar indicated that root surgery was ***"a bold act, which removes the entire cause and which will lead to a permanent cure, may not only be the best in the end, but the most humane"*** (41). Historically, the plethora of indications for surgical endodontic intervention and advocated techniques reads like a cookbook in the dental literature; however, the decision to intervene surgically was often open to deliberation and debate. Extraction was the "modus operandi" for many surgeons and clinicians who ascribed to the focal infection theory, while tooth retention through the use of surgical endodontics was promoted by many others. In fact, great debates that involved major figures in dentistry occurred with respect to the value of the "periapical surgical technique" (42). At the same time, pleas were made regarding the poor assessment by the clinician of the causes and need for surgery that resulted in a "rapid picking up of the scalpel to solve the problem." Whitehouse, in the year 1884 (43)—130 years ago—chided his colleagues to minimize the extensive use of surgery and concentrate on the problem at hand: "***A few moments' consideration of the original cause of trouble at the apex of roots will enable us to realize what is required to be accomplished in the way of successful treatment. If the original cause is admitted to be irritation from decomposing pulp, its removal will in most cases effect a cure.***"

The historical focus of surgical attention was too often limited to the eradication of the soft tissue surrounding the root apex, neglecting the removal of the intracanal irritants and proper sealing of the apical foramen. Yet even today, methods do not exist which can thoroughly eliminate all intracanal debris and microorganisms, and materials to establish a predictable apical seal still elude our grasp (44,45). Moreover, recent biological investigations have severely challenged long-advocated techniques and materials used to manage the seal of the resected root end (46). Many so-called "revolutionary" or newer techniques practiced today during periapical surgery are but a mere re-emergence of surgical concepts that were lost in the archives of time, yet these too often lack a substantial biological basis (47). Lost in this focus of periapical surgery, however, is the need to consider other forms of surgical intervention that fall within the contemporary scope of endodontics (48) including crown lengthening, root repairs, diodontic implants, intentional replantations or transplantations, and root/tooth resection procedures (40,47–51).

A true appreciation for the evolution and resurgence of surgical endodontics can only be realized by reliving the past and reflecting on the valuable contributions of so many pioneers—and resolving to direct all future investigations of this treatment modality in the best interest of all concerned, both patient and practitioner.

Table 1 provides a focused evolution, highlighting developments and advancements in surgical endodontic procedures, noting the source of the techniques and importance of the concepts along with comments relative to contemporary practices when indicated. An expansion of these historical benchmarks can be found in further readings, which the reader is encouraged to pursue (1,47).

Contemporary highlights and perspectives on surgical endodontics

In the past 45 years, much of what has been seen relative to surgical endodontics has been recorded in textbooks and extensive publications (Table 2). Over and above these key comprehensive works, there have been many publications that have provided details focusing on advances in materials, techniques, tissue management, and treatment outcomes. However, rather than focusing on a litany of publications, a number of select areas that have changed significantly in surgical endodontics are highlighted.

Application of cone beam technology

The use of cone beam computed tomography (CBCT) in the diagnosis of cases that may require surgical intervention, in particular posterior teeth, has greatly enhanced the surgeon's ability to achieve success (34,121,122). CBCT is a powerful tool that can assist in determining the exact dimensions and location of a periapical lesion as well as the three-dimensional relationships of roots to neighboring anatomical structures (37,121,123).

Use of the surgical microscope

The use of the microscope and endoscopy has enhanced the delivery of surgical procedures (13,124,125) and has significantly impacted the probability of success (126–130).

Tissue anesthesia

Profound anesthesia is essential for all procedures and should provide a pain-free environment for the duration of the procedure (13,131–133). Procedures should be performed within a specific time frame (usually within 60–90 mins) to prevent loss of anesthesia in addition to loss of local hemostasis (1). The use of appropriate hemostatic agents is common-place in surgical endodontics (131,133,134) although the ideal solutions with 1:50,000 vascoconstrictor (131,133) are not always available globally, in which case 1:80,000 may have to suffice. Failure to obtain good hemostasis prior to tissue incision will make it very difficult to visualize the surgical site and to use moisture-susceptible root-end filling materials. While local hemostatic agents can be used once the surgical site has been accessed, they may not always be beneficial as compared to achieving the hemostasis with the initial anesthetic administration (1,13,132–136).

Soft tissue management

The management of the oral soft tissues during surgical endodontics should always favor ideal wound healing. Initially this would be greatly impacted by the tissue incision, reflection, elevation, retraction, repositioning, and stabilization (1,13,137–139). The base of each tissue flap should be as wide as the top so that the incision does not bisect tissue fibers and blood vessels (1,13). Flap designs have been somewhat modified to provide enhanced outcomes (12,140–146). However, the ultimate response will be highly dependent on the endodontic surgeon, the choice of flap design based on the anatomy of both the soft and hard tissue, the extent of pathosis when present, attention to detail during the surgical procedure, and management during wound closure (147).

Hard tissue access

In cases where there is minimal buccal bone overlying the root structure, the use of a straight bone curette will often enable the removal of the osseous tissue, thereby enhancing access to any periradicular pathosis with minimal trauma. When the bone must be removed with a rotating bur, it is done in a shaving manner with coolant to minimize or negate heat generation (1,148). Opening a bony window with minimal mesial-distal dimensions is favored for ultimate healing (149).

Table 1: Historical highlights on the evolution of surgical endodontic procedures

Clinician/ Investigator	Era or Year	Procedure—Technique—Instrument—Implications
Abulcasis[52]	11th century	Intentional replantation: while used, the ramifications of this procedure eluded the practitioner, such as status of the dental pulp and high potential for root resorption.
Pare[53] Fauchard P[54] Pfaff P[55] Berdmore T[56] Hunter J[57]	1561 1746 1756 1768 1778	All provided detailed accounts of replantation citing multiple clinical situations; Hunter reached the conclusion that a vital periodontal ligament was a prerequisite for successful union of the tooth and the alveolus following replantation. Pfaff and Berdmore performed root-end resections and placed root-end fillings of wax, lead, or gold. Concept of resorption still eluded the clinician. This issue was not even referred to as resorption, but rather absorption, which was detailed by Tomes in 1859.
Tomes J[58]	1859	Addressed the absorption of teeth that had been injured by disease or trauma.
Heister L[59]	1724	Managed chronic sinus tracts by opening them, cleaning them out, or burning them out.
Harris C[60]	1839	Used a lancet or sharp bistory-pointed knife to puncture a tumor of the gums to release the pus. While this may not have been considered by many as a surgical procedure, it did have an impact on tooth retention at times of severe infection and patient distress.
Desirabode AM[61] Magitot E[62]	1843 1860–1870	Claims made as to being the first to perform root-end resection. This is another example of "who did it first" and "who documented it first."
Hullihen SP[63]	1845	Surgical trephination through the soft tissue, bone, and into the pulp chamber to alleviate a congested pulp: "Hullihen Operation." The performance of this procedure has also been suggested to be attributed to the Egyptians. There is also evidence that ancient cultures in the Western Hemisphere performed this technique (see paper for references).
Bronson WA[64]	1866	After applying carbolic acid to the gums, one perpendicular slit and one transverse slit was made in the overlying tissues and an engine drill was used to drill directly through to the end of the root to relieve congestion and effect a discharge of suppuration; this approach was labeled as "barbaric" by FY Clark; approach was also questioned by JN Farrar, as he felt that this clinical situation was caused by necrosis of the root apex and therefore this tissue must be considered as a foreign substance and be removed through a resection procedure. However, Bronson claimed that this approach was able to rapidly control pain and evacuate pus caused by a devitalized pulp.
Magitot E[62]	1867	Performed complete removal or root resection (amputations).
Smith CS[65]	1871	Used root-end resection to manage a tooth with a necrotic pulp and surrounding alveolar abscess. He indicated that this may be accomplished either by cutting through the alveolus with a suitable instrument, and cutting and scraping away the necrosed portion of the root apex; or the tooth may be extracted, the necrosed portion excised, the end polished, and the tooth replaced.
Farrar JN[66]	1880	Performed a procedure on abscessed teeth referred to as an "apicotomy."
Martin C[67]	1881	Claimed by multiple authors to be the inventor of root-end resection to manage draining sinus tracts; however, evidence for Martin's documentation for this procedure was lacking.
Dunn CW[68]	1884	Amputated "fangs" using a tubular saw to enter the jaws, removing the diseased soft tissue and root end. He took a tube of appropriate diameter, the extremity of which was a saw that could be attached to an engine-driven device and cut through gum, alveolar process, and apex of the root. If lucky he also was able to remove the surrounding granulomatous tissue at the same time that he removed the apex of the root.
Farrar JN[41]	1884	Recommended the radical removal by amputation of any portion of roots of teeth that were useless. This focused primarily on roots for which the supporting alveolar bone had been destroyed by periodontal disease. His decision to perform this procedure was based on 11 years of attempting to perform palliative treatment and 9 years of actual root-end resection or full root resection.
Black GV[69]	1886	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 considered sincerely when dealing with a tooth worth saving.
Younger W[70]	1894	Reiterated Hunter's opinion on the need for a vital periodontal ligament following replantation. At that time the concept of "resorption" did not exist—rather, the focus was "absorption," which was not fully changed to resorption until the early 1930s.
Grayston LDSI[71]	1887	Used cocaine anesthesia in the surgical management of an alveolar abscess, which could not be treated through the tooth. He passed a rotating bur through the alveolar process, either following and enlarging a "fistulous" tract or cutting directly through the soft tissue and alveolus.
Fredel L[72] Scheff J[73]	1887 1890	Initiated animal experiments to address the role of the periodontal ligament (referred to as the periosteum) in the resorptive process (referred to as adsorption). They noted in dog studies that the absorptive process did not occur in teeth protected by the periodontal ligament (referred to as the periosteum) and discussed the essential nature of the periodontal ligament to ensure reunion of the tooth within the alveolus.
Rhein ML[74]	1890	Recommended complete root amputation as a radical cure for a chronic alveolar abscess. He claimed that treatment through the root canal was useless in the presence of a "necrosed apex." Once he filled the root canal, he excised the diseased portion of the root, followed by vigorous use of the bur in the surrounding pathological tissues.

Table 1: *Continued*

Clinician/ Investigator	Era or Year	Procedure—Technique—Instrument—Implications
Ottolengui R[75]	1892	Presented a succinct technique for the immediate filling of a root canal followed by resection of the root apex. However, not much thought was given to reflecting soft tissue. He used a spear drill and with it passed through the soft tissue and the root, along with its central axis as high up as was decided for the amputation. He then followed this hole with a sharp fissure bur, cutting laterally from mesial to distal. He also advocated removal of the labial plate of bone as necessary in many cases to remove the amputated root end.
Rhein ML[76]	1897	Described surgical treatment for the management of the alveolar abscess, including marsupialization. He used cocaine on the soft tissues immediately adjacent to the root end. This was followed by an engine-driven trephine bur to rapidly make an opening through the alveolar plate to the affected tissues. If the opening was large, a drain was placed, which was to be removed daily with the lesion being rinsed with a proper antiseptic solution. The opening was kept open until the tissue had granulated to fill the void around the root apex.
Partsch C[77–79]	1896–1899	Credited with the methodical development of "Wurzelspitzenresection" (root-end resection) first under chloroform anesthesia and later cocaine anesthesia; credited with packing the surgical cavity with iodoform gauze (Partsch I operation) and tissue reapproximation with suturing (Partsch II operation).
Beal M[80]	1908	Published case reports on the technique of root-end resection.
Schuster E[81] Von Hippel R[82] Ruud AF[83] Matsura SJ[84] Schupfer C[85,86] Luks S[87]	1913 1914 1950 1962 1935/1936 1974	Advocated apical slot preparation during surgery. Also developed a slot preparation that was known as the "slitsmethoden" used to clean the apical portion of the canal in the presence of a post core. Modified by Ruud in 1947 and brought to contemporary use by Matsura in 1962; changed to a transverse slot preparation in 1935 and 1936 by Schupfer and perpetuated by Luks in the 1970s.
Faulhaber B & Neumann R[88,89]	1912–1921	Published multiple books that dealt with detailed anatomical concerns and guidelines for surgical entry to the root apices on both maxillary and mandibular posterior teeth; clearly identified the use of the submarginal tissue flap.
Hunter W[90] Billings F[91] Rosenow EC[92]	1911 1916 1919	Upset the entire dental profession with his diatribe on the impact of asepsis in the oral cavity; concepts of surgery defied what was present in the tooth with significant amount of decay and sepsis under "mausoleums of gold;" slammed the dental profession on their lack of considering the extensive infections in the oral cavity and, along with the theory of elective localization by Rosenow and focal infection by Billings, greatly influenced tooth retention as teeth that may have been amenable to surgery were now being extracted.
Bažant F[93] Šmelhaus S[94] Kostečka F[95] Měštan K[96]	1913 1916 1924 1937	A forward-thinking group of clinicians from Eastern Europe who influenced periapical surgical procedures; cause of failure addressed and the psychological impact of surgery on the patient; detailed a wide range of surgical techniques applicable to all teeth as opposed to limiting the procedures to anterior teeth, which was common in the United States.
Bauer W[97,98] Euler H[99]	1922/1925 1923	Evaluated the healing of the apical tissues following surgery, indicating that the removal of the root tip places the amputation zone in a very different functional relationship with the surrounding tissues. Microscopically they inspected the resected root ends for cemental hypertrophy, which they felt was due to the difference in functionality for the root when the tip was removed and felt the cementum/bone interface was only an attachment, while gaps would exist in some areas between the two tissues.
Roy M[100] La Cronique GM[101]	1925 1927	Detailed surgical indications ad techniques to manage radicular lesions with a focus on both resection and curettage.
Neumann R[102]	1926	Provided a submarginal surgical flap design that was later characterized and claimed by Oschenbein and Leubke.
Hofer O[103] Khoury F[104]	1935 1987	Extensive treatise on Wurzelspitzenresektion und Zystenoperationen—presented in 1934 in Prague. Characterized a number of different tissue flap designs that were based on either a "periostalplastischen" or "osteoplastischen" design—this was a prelude to the procedures advocated by Khoury and known as the Knochendeckelmethode in the 1980s.
Peter K[105]	1936	Wrote one of the most extensive and comprehensive texts on root-end resection on molars, covering all phases, in particular with excellent anatomical depictions and relationships of the roots to the bone.
Tangerud BJ[106]	1939	Gave us the miniature handpiece for root-end preparations.
Weaver SM[107]	1947	Advocated the use of the "open window" or straight incision on the long axis of the root with retraction in a mesial-distal dimension.
Messing JJ[108]	1958	Introduced the use of the Messing Gun to carry root-end materials to the apical cavity preparation.
Maxmen H[109]	1959	Provided guidelines for the expanded use of surgical endodontic procedures that included open apices, fractures, perforations, resorptive defects, retained broken instruments, teeth with dowels, etc.
Rud J, Andreasen JO & Möller Jensen JE[110]	1972	Provided an extensive treatise on the evaluation of periapical surgery that encompassed radiographic assessment, histological assessment, and clinical assessment; evaluated modes of healing, correlation between histology and radiological findings, histobacteriologic assessments following surgery, operative procedures during surgical procedures, and an assessment of failures following the application of surgical techniques; all phases incorporated a high level of statistical analysis.

Table 2: Major publications specifically focused on surgical endodontics

Author(s)	Title	Country	Year
Mitsis F[111]	Endodontic Surgery	Greece	1969
Harnish H[112]	Apicoectomy	Germany	1975
Arens D et al.[113]	Endodontic Surgery	USA	1981
Barnes IE[114]	Surgical Endodontics	England	1984
Panzoni E[115]	Chirurgia Endodontica	Italy	1985
Tetsch P[116]	Wurzelspitzenresektionen	Germany	1986
Gutmann JL & Harrison JW[1]	Surgical Endodontics	USA	1991
Bellizzi R & Loushine R[117]	Clinical Atlas of Endodontic Surgery	USA	1991
Arens D et al.[8]	Practical Lesions in Endodontic Surgery	USA	1998
Kim S et al.[13]	Color Atlas of Microsurgery in Endodontics	USA	2001
Gutmann JL (ed.)[118]	Endodontic Apical Surgery: A Delineation of Contemporary Concepts	USA	2005
Merino EM[119]	Endodontic Microsurgery	Spain	2009
Kaur S et al.[120]	A New Dimension to Surgery—Endodontic Microsurgery	India	2013

Root-end resection

Removal of 3–4 mm of the root end is commonplace and is usually required to eliminate anatomical irregularities and contaminated (biofilms, bacteria, and endotoxins) radicular hard tissues. This is done with a high-speed rotating bur and coolant, minimizing heat generation and preventing the development of root fractures. The use of an apical cut that is at right angles to the long axis of the root has been advocated (150,151) to minimize any leakage that might occur through cut dentinal tubules, although 0–10 degrees is usually acceptable and may be necessary in some cases (151–152). Identification of the canal configuration and any potential dentinal defects on the resected root anatomy is achieved using a 1% solution of Methylene blue (151–153) along with the use of magnification when available (13,152).

Root-end cavity preparation

The use of ultrasonic instruments to prepare root-end cavities is considered standard in surgical endodontics, especially in molars where the presence of uniting anastomoses or isthmi are commonplace (152,154,155). The instruments are made of stainless steel and diamond-coated stainless steel (151,155), the latter being more efficient but subject to loss of the diamond-coated surface (156). The quality and depth of the preparation has been enhanced with a number of differently shaped ultrasonic instruments (157), resulting in minimal errors such as root wall perforations (158). During cutting, especially when working in a buccal-lingual dimension, instruments are used in a sweeping motion, with periodic evaluation of the preparation under magnification. The depth of preparation is usually 3–4 mm (13,151,152); however, newer instruments have been designed to penetrate from 3 up to 9 mm (159). Removal of the smear layer in the cavity has been recommended (151) with subsequent disinfection prior to root-end filling (160).

Root-end filling

A plethora of root-end filling materials have been used in the past 45 years, with a significant reduction in the use of amalgam (161), the sporadic use of dentin-bonded modified resins (162), the continued use of IRM and Super-EBA (161,163–170), the current advocacy of mineral trioxide aggregrate (MTA) (6,152,170–172), and the emerging use of bioceramics (173–175).

Outcome assessments

Ever since the advent of evidence-based dentistry, there has been an overabundance of outcome studies that have addressed a wide range of surgical issues. However, it is often difficult to compare the studies and many may not qualify at the highest levels of evidence. Therefore it may be difficult to glean overall meaningful and applicable clinical information, although the findings when taken alone have some value in specific situations, thereby providing the clinician with reasonable directives. Often the studies have too many variables to be compared in a true scientific manner and the judgement as to what is important must be left to the clinician.

From a general standpoint, there have been both prospective and retrospective studies that have addressed outcomes. One of the most defining studies indicated that "knowledge cannot be acquired by indiscriminate review of the many available studies because they vary in the level of evidence they provide" (176). In this study, seven outcome assessments that best complied with methodology criteria were used, which indicated the following:

- 37–91% of teeth can be expected to heal;
- up to 33% can still be healing several years following surgery;
- 80–94% of teeth can function symptom-free;
- outcomes can be better in teeth with smaller lesions and excessively long or short root canal fillings;
- outcomes may be poorer in teeth treated surgically the second time;
- choice and quality of root filling may influence the outcome;
- use of a root-end preparation and filling favors healing over merely a resection and no root-end filling; and
- when feasible, periapical surgery is a treatment of choice.

More recent prognostic studies have identified general characteristics such as tooth position and arch (anterior–maxilla) as positive predictors of successful outcomes (177,178). Other factors that seem to influence outcomes on a prospective basis were gender (female) and a tooth having an isolated lesion.

Some of the more meaningful studies have dealt with outcomes that have addressed intraoperative factors such as when using different root-end filling materials and the assessment of healing using two-dimensional radiographs (6,165,172,179). Other studies have focused on soft tissue responses (180), various root-end surgical tips (181), the use of magnification and microsurgical techniques (182), and the impact of osseous deficiencies on healing (183), but here again many variables are intertwined that make it difficult to identify high-level, evidence-based information. A recent updated meta-analysis of the literature identified the need for large-scale clinical studies to further evaluate possible predicators of successful outcomes (184).

Surgical regenerative techniques

In the late 1990s and early 2000s there was an avid interest in the use of guided tissue regenerative techniques (GTR) in conjunction with periapical surgery (185,186). The application of these techniques occurred primarily when there was an apical-marginal defect identified during surgical endodontic intervention (187–191), although some also chose to use these techniques in the presence of osseous defects, which affected the complete buccal plate (192) and both the buccal and palatal plates of bone (193,194). A recent extensive literature review (195) could not provide any evidence-based guidance as to the use of guided regenerative techniques other than to indicate the possible beneficial impact of using them in the presence of apical-marginal defects, while a recent systematic review and meta-analysis found some trends in outcomes (196). GTR techniques favorably affected the outcome of surgical interventions in the presence of larger periradicular lesions and through-and-through lesions, especially when a resorbable membrane was used. However, based on the paucity of evidence-based studies, large scale prospective clinical trials are warranted to secure better clinical directives in this area.

Other considerations

Prior to looking at future prospects for surgical endodontics, a brief accounting of other surgical procedures is in order. While not commonplace with many endodontists, the following list provides a wide range of surgical interventions that fall within the scope of the specialty of endodontics and play a very important role in treatment planning the provision of tooth retention:

- root resective procedures commonly known as hemisection or root amputation;
- decoronation with the intent to bury the remaining root in order to preserve bone levels in the case of extensive root resorption;
- socket preservation techniques following the extraction of a vertically fractured tooth;
- crown-lengthening procedures;
- replantation procedures, including intentional and transplantation;
- repair of perforative or resorptive defectives; and
- surgical repositioning following an intrusive luxation.

Recognition of these procedures as being part of the specialty of endodontics is essential for all endodontists as opposed to being single-minded in thinking that this specialty only encompasses root canal procedures. The provision of these types of procedures for the patient populations served by endodontists will only enhance the recognition of the specialty as we move forward into the future.

Future perspectives on surgical endodontics

Application of lasers

Approximately 25 years ago, the first article appeared in the endodontic literature that described the use of a laser during surgical endodontics, including root-end resection and enhanced hemostasis in the surgical site (197). Subsequent studies in the early 1990s evaluated the impact of laser application on the resected dentin surface and the apical seal of the root-end cavity, with somewhat promising results (198,199). During the next 20-plus years, sporadic studies continued to address cutting efficiency, temperature variations, root-end resection, root-end cavity preparation, seal of the root-end cavity, sterlization of the surgical site, permeability of the resected dentin, pain reduction following surgery, and healing rates, using various lasers including the CO_2, Nd:YAG, holmium:YAG, Er:YAG, Ga-AL-AS, and ErCR:YSGG (200–212). There is evidence that pain may initially be decreased, while dentin permeability and apical seals are enhanced without altering the integrity of the apical cavity, with cases treated showing a tendency for better overall healing. While the routine application of lasers in surgical endodontics has not received overwhelming endorsement in many sectors and teaching programs, its potential should not be underestimated; rather, extensive prospective, randomized, controlled studies should be encouraged to determine the efficacy of this treatment modality.

Application of piezoelectric devices

Piezosurgery uses specifically engineered surgical instruments approximately three times as powerful as a conventional ultrasonic instrument (213), in which cutting occurs when it is applied to mineralized tissue, but uniquely terminates when encountering soft tissue. However, this tool must be used with adequate cooling during cutting in order to prevent heat damage to the bone. This tool is useful when bone must be cut close to important soft tissues such as nerves, vessels, the sinus membrane, or when mechanical or thermal injury must be avoided (213). This would make it an ideal tool for surgical endodontic intervention in the posterior mandible, especially approximating the mental foramen.

Piezoelectric instruments were introduced into oral surgery/periodontics for the cutting of a bony window during a sinus membrane elevation procedure (sinus augmentation) (214), with a full detailing of the piezosurgical concepts and their applications in the early 2000s (215). Since then two publications on the applications of piezoelectric surgery in endodontics have appeared, addressing the integrity of the root-end surface and root-end management when used on a cadaver (216) and its use when applied clinically (213). In the former study, when the piezoelectric tip vibrated at a constant rate during root-end cavity preparation on cadaver teeth, the power level did not affect the incidence or type of dentin cracks and the marginal quality was acceptable. When a pulsation component was added to the piezoelectric tip, significant adverse alterations were noted in the dentin.

Advantages claimed for the application of piezoelectric surgery in endodontics include (213):

- protection of soft tissues;
- optimal visualization of the surgical field;
- decreased blood loss;
- reduced vibration and noise;
- increased patient comfort; and
- protection of tooth structures.

Disadvantages include (213):

- initial financial investment in equipment;
- longer duration of the procedure; and
- discouraged use in patients with cardiac pacemakers.

Nanotechnology and bioengineered tooth units

It is highly possible that surgical endodontics as we know it today will be vastly different in the future. With the evolution in nanotechnological principles in the science of material manipulation (217–219), would it not be possible to perform a root-end resection using a cool but efficient laser in a matter of seconds in order to eliminate undesirable anatomical irregularties and destroy bacterial/biofilm concerns, followed by the nanoencapsulation of the resected root apex with nanorods, spheres, or tubes that are HA (hydroxyapatite) based to encourage the regeneration of a genetically engineered root structure? Why stop there, as the future is within our grasp now. Surgical endodontics may very well need to adopt new nomenclature and new ways to exist beyond what is commonplace at the present. For example, bioengineered tooth unit replacements as mature organs for replacement regenerative therapy are rapidly becoming a reality (220–221). At the rate science is moving forward in so many sectors, it is not a matter of decades or centuries before these visions become a reality. However, this reality can only occur if those within the specialty of endodontics who are in the position to make decisions regarding academic curricula and scientific research can grasp this vision and see beyond the scalpel, the retractor, the handpiece, and the suture material.

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