

Beyond Traditional Sutures: Exploring Current Trends and Future Perspectives in Oral and Maxillofacial Surgery

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ABSTRACT

Surgical sutures are essential for approximating tissues and promoting the healing of wounds caused by surgery or trauma. They are broadly classified into absorbable and nonabsorbable types. Recent advances have led to the development of specialized suture materials designed to enhance tissue approximation and wound healing. This review highlights current and emerging innovations in suture technology, including knotless barbed sutures, antimicrobial sutures, bioactive variants such as drug-eluting and stem cell-seeded sutures, and smart sutures with elastic and electronic properties. These advancements extend the role of sutures beyond passive wound closure to active biological systems capable of delivering therapeutic agents and cells, offering significant potential in both treatment and diagnostic applications.

Keywords: Sutures, Antimicrobial sutures, Drug-eluting sutures, Barbed sutures, Smart sutures, Stem cell seeded sutures, Surgical zippers.

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INTRODUCTION

Suturing represents a fundamental step in both oral and general surgical procedures, playing a crucial role in effective tissue repair. The choice of suture material significantly influences healing outcomes, particularly in achieving primary wound closure after oral surgical interventions. Sutures are commonly classified as absorbable or non-absorbable and may further be categorized based on their structure as monofilament or multifilament types. A range of materials is available for intraoral use, including nylon, silk, cotton, polyglecapron, polylactic acid, and polyglycolic acid, each selected according to the specific clinical requirements and tissue response (1).

The choice of an appropriate suture material should be guided by factors such as patient-related considerations, the nature of the wound, the type of tissue involved, and the specific anatomical site (2). Some suture materials may adversely affect the healing process and contribute to increased scar formation. An ideal suture material should possess adequate tensile strength, provide reliable knot security, and allow for ease of handling during placement (3).

Characteristics of an Ideal Suture

Suture materials used in oral surgery must meet specific requirements due to the distinct environment of the oral cavity, which involves variable tissue textures, continuous saliva exposure, high vascularity, and functional demands such as speech, chewing, and swallowing. (4)

An ideal suture material should demonstrate the following qualities:

- Allow smooth and convenient handling during clinical use
- Produce minimal or no adverse tissue response

- Possess sufficient tensile strength to support wound closure
- Prevent trauma or tearing of the surrounding tissues
- Be supplied in a sterile condition
- Remain chemically inert and non-electrolytic
- Not provoke allergic reactions
- Be economical and easily accessible for routine use

Suture Material

A suture is a thread-like material employed to tie off blood vessels and to bring together tissues that have been incised or damaged. Over time, numerous materials—both natural and synthetic—have been used for suturing purposes, such as linen, horsehair, flax, silkworm-derived fibers, kangaroo tendon, umbilical tape, ligaments, cotton, and various metals including iron, stainless steel, gold, and silver, along with plant-based fibers like bark.

Sutures can be categorized according to different criteria, including their degradability (absorbable versus non-absorbable), source (natural or synthetic), and physical configuration (monofilament or multifilament/braided). They are commonly supplied in standard lengths of about 18 to 27 inches, although shorter variants, such as 8–9 inches or 10 inches, are also produced to suit specific surgical requirements. (5)

ABSORBABLE SUTURE MATERIALS

Suture materials are classified as absorbable when they gradually lose their tensile strength and are broken down within the body after placement, typically over a defined period. Among natural options, surgical gut (commonly known as catgut) remains the primary absorbable material. In contrast, a variety of synthetic absorbable sutures are

available, including braided types such as polyglycolic acid (Dexon) and polyglactin 910 (Vicryl, Ethicon), as well as monofilament materials like polydioxanone, polytrimethylene carbonate, poliglecaprone (Monocryl), glycomer 631 (Biosyn), and polyglyte 6211 (caprosyn).

Surgical gut is derived from purified collagen obtained from the intestines of animals such as sheep, cattle, or goats, and is processed into twisted fibers. It is available in different forms, including plain, chromic-treated, and rapidly absorbing variants (ethicon). Plain gut generally retains its tensile strength for about 7–10 days and is fully absorbed within approximately 70 days. Chromic-treated gut, due to chemical modification, maintains strength for a longer duration of around 10–21 days, with complete absorption occurring by about 90 days. Fast-absorbing gut, on the other hand, loses its strength within 5–7 days and is typically resorbed within 2–4 weeks. (6).

The first synthetic absorbable suture, polyglycolic acid (PGA), was introduced in 1970. It demonstrates good initial tensile strength, retaining approximately 60% at 7 days, 35% at 14 days, and only 5% by 28 days. Complete absorption typically occurs within 60–90 days. Due to its predictable degradation profile, it is commonly used in wounds with an increased risk of infection.

Polydioxanone (PDS), introduced in 1982, exhibits a slower rate of degradation. It retains approximately 74% of its tensile strength at 14 days and 58% at 28 days, with gradual loss thereafter. Complete hydrolysis occurs over 180–210 days, making it suitable for contaminated wounds or those at high risk of infection where prolonged support is required.

Polymethylene carbonate (Maxon), introduced in 1985, maintains about 84% of its tensile strength at 14 days, 54% at 28 days, and 30% at 6 weeks, providing extended wound support during healing.

Poliglecaprone 25 (Monocryl), introduced in 1993, offers high initial tensile strength among absorbable sutures, retaining approximately 20–30% strength at 14 days. It undergoes complete hydrolysis within 90–120 days. An antibacterial variant (Monocryl Plus, Ethicon) is also available, designed to reduce the risk of surgical site infection. (7,8)

NON-ABSORBABLE SUTURE MATERIALS

A nonabsorbable suture is defined as a material that resists degradation by biological tissues and retains its tensile strength for prolonged periods. These sutures are most commonly used for percutaneous wound closure and in situations where long-term tissue support is required.

Nonabsorbable sutures may be derived from natural or synthetic sources. Natural materials include surgical steel, silk, cotton, and linen, whereas synthetic sutures are more widely utilized in dermatologic and modern surgical practice due to their predictable properties and reduced tissue reactivity.

Silk, one of the earliest suture materials, was widely introduced into surgical use in the late 19th century and is derived from silkworm larvae. Although traditionally classified as nonabsorbable, silk undergoes gradual degradation in vivo, typically losing its strength over a period of approximately two years. (9)

Nylon, introduced in 1940, was the first widely used synthetic suture material. It gained popularity for wound closure due to its high tensile strength and minimal tissue reactivity. Owing to these properties, it is most commonly employed for percutaneous suturing.

Polyester is a synthetic braided suture with handling characteristics similar to braided nylon. However, due to its higher cost and braided structure, it is rarely used for skin closure. Instead, it is preferred for deeper tissues such as tendons and fascia, where strong and durable support is required.

Polypropylene, introduced in 1962, is a synthetic monofilament suture characterized by low friction and excellent biocompatibility. Its smooth surface facilitates easy passage through tissues, and when used as a buried suture, it provides reliable long-term dermal support.

Polybutester, a newer synthetic monofilament nonabsorbable suture, exhibits unique elastic properties. This elasticity allows it to accommodate tissue swelling, making it particularly useful in wounds where oedema is anticipated. (2)

RECENT AND DEVELOPING TRENDS

In recent years, suture technology has advanced significantly with the development of materials incorporating additional functional properties. These include the integration of antimicrobial agents and bioactive molecules such as DNA, drugs, antibodies, proteins, growth factors, and silver, aimed at improving wound healing and reducing postoperative complications.

Modern sutures now encompass a range of specialized categories, including antimicrobial sutures, drug-eluting sutures, and stem cell-seeded sutures, each designed to enhance therapeutic outcomes. Furthermore, the emergence of smart sutures represents a significant innovation in this field. These include shape-memory sutures, elastic sutures, and electronic sutures, which are engineered to respond dynamically to the wound environment and provide improved functional performance (10). These advanced sutures are specifically designed to address common postoperative complications, including infection, excessive scarring, pain, and inflammation. Such innovations hold significant promise in enhancing clinical outcomes and are expected to play a pivotal role in the fields of tissue engineering, regenerative medicine, and minimally invasive surgery.

KNOTLESS BARBED SUTURES

Conventional suturing techniques require the placement of knots to secure the suture material and maintain adequate tension across the approximated wound margins. However, intraoral suturing presents several clinical challenges associated with knot placement. Knots can act as a nidus for food debris accumulation and microbial colonization. Additionally, excessive pressure exerted by knots over the wound site may compromise local blood supply, leading to ischemia and thereby increasing the risk of postoperative infection (11). Knotless sutures represent an advanced innovation in suture technology and offer a promising alternative to overcome the limitations of conventional suturing techniques. These sutures are designed with barbs

distributed along their length, which facilitate secure tissue engagement and maintain wound approximation without the need for knot placement. The knotless suture consists of tiny barbs along its entire surface, arising from opposite directions on either side of a central non-barbed segment to engage the soft tissue appropriately and to provide adequate closure. By eliminating knots, they reduce complications associated with conventional suturing. The successful application of knotless sutures in the oral cavity was first reported by Kasi Ganesh et al (12). The potential advantages of this suture system include a reduction in wound closure time and enhanced wound stability due to the presence of barbs, which provide additional anchorage. These barbs help maintain uniform tension along the approximated tissues and promote improved eversion during flap re-approximation, thereby contributing to more favourable healing outcomes (13).

ANTIMICROBIAL SUTURES

Sutures are essential in oral surgery for wound closure and healing; however, they are susceptible to bacterial adhesion and colonization. This is influenced by intrinsic factors (e.g., braided vs monofilament structure) and extrinsic factors such as fibrinogen and fibronectin deposition. Bacterial retention on sutures increases the risk of postoperative infection, making its minimization crucial for optimal surgical outcomes (19). Black braided silk remains one of the most commonly used sutures in oral surgery due to its ease of handling, reliability, and stability. However, its association with delayed healing has prompted the development of alternative materials. Antibacterial sutures, coated with agents such as triclosan or chlorhexidine, have been introduced to enhance healing and reduce postoperative infections (15).

Common examples include absorbable polymers such as polyglactin 910, poliglecaprone 25, and polydioxanone. Triclosan, a phenolic antimicrobial agent with broad activity against Gram-positive and limited Gram-negative bacteria, has been incorporated into sutures such as Vicryl Plus since 2003, with well-established biocompatibility and prior use in oral hygiene products. Chlorhexidine demonstrates a broad spectrum of antimicrobial activity, exhibiting both bacteriostatic and bactericidal effects along with high biocompatibility. It is effective against a wide range of Gram-positive and Gram-negative bacteria (16).

DRUG ELUTING SUTURES

Drug-eluting sutures, depending on the incorporated therapeutic agent, can reduce postoperative complications such as surgical site infections and enhance wound healing (17). By delivering drugs locally, they maintain effective concentrations at the target site for prolonged periods while minimizing systemic toxicity and reducing the need for additional medications. These sutures are fabricated through techniques such as dip coating (18,19), grafting (20), and electrospinning (21,22) with the key challenge being to achieve optimal drug release without compromising mechanical integrity—often addressed through controlled polymer degradation strategies.

Braided sutures, particularly silk, are more prone to bacterial adhesion and retention, increasing infection risk

(17). Antimicrobial coatings such as tetracycline (23) and levofloxacin (combined with polycaprolactone) have shown greater efficacy against *E. coli* than *S. aureus*, with acceptable cytocompatibility and adequate tensile strength. However, such modifications may alter properties like friction and stiffness (24). Additionally, approaches like vancomycin grafting (25) onto polypropylene sutures using acrylic polymers have demonstrated sustained drug release, highlighting the potential of advanced drug-delivery suture systems.

Casalini et al. (26) developed a theoretical model of a bioresorbable polycaprolactone suture loaded with lidocaine, demonstrating that higher drug diffusion and longer half-life enhance release efficiency. Lidocaine release provided sustained local analgesia for up to 75 hours, reducing postoperative pain.

Similarly, Weldon et al. (24) fabricated bupivacaine-eluting PLGA sutures via electrospinning, showing good mechanical properties and effective drug diffusion at the incision site. Drug release was concentration-dependent, providing analgesia for 7–10 days, with peak effect during the first 3 days. Tissue response was comparable to standard FDA-approved PLGA sutures, with no adverse reactions.

Additionally, electrospun core–sheath yarn designs offer improved strength and flexibility, enabling incorporation of bioactive agents and their application in multifilament sutures for broader clinical use (27).

STEM CELL SEEDED SUTURES

Wound healing occurs through inflammation, proliferation, and remodelling, regulated by autocrine and paracrine signals. Mesenchymal stem cells (MSCs) are central to this process due to their multilineage differentiation and regenerative potential. In addition to differentiation, Mesenchymal stem cells (MSCs) release bioactive factors that promote immunomodulation, cell migration, and tissue repair by creating a supportive microenvironment. Their combination with biomaterials has shown promising outcomes, including accelerated healing of cutaneous wounds (28)

Biodegradable scaffolds are extensively used in tissue engineering as carriers for stem cell delivery and differentiation (29). In this context, sutures functionalized with growth factors or stem cells can serve as effective delivery systems to target sites (30,31). Bioactive sutures offer suitable tensile strength and controlled degradation, supporting rapid tissue regeneration after implantation (30).

The main goal of stem cell-seeded sutures is to enhance local cell concentration at injury sites, thereby accelerating repair and regeneration (30). However, while suture-based cell delivery is promising, maintaining optimal mechanical and physical properties alongside biological functionality remains a significant challenge (32).

Sutures functionalized with growth factors and/or stem cells can serve as an alternative to traditional scaffolds in tissue engineering and regenerative medicine. As carriers for cell-based therapies, they have shown improved clinical outcomes, including enhanced mechanical function in cardiac repair, tendon healing, tracheal anastomosis, and

wound closure, with faster recovery and tissue regeneration.

In tendon repair, these bioactive sutures demonstrate superior tensile strength, reduced gap formation, and accelerated healing, indicating strong potential for application in complex orthopaedic injuries (33,34)

SMART SUTURES

Smart sutures in Oral and Maxillofacial Surgery (OMFS) represent a significant advancement from conventional passive wound closure materials to multifunctional systems that actively promote healing, reduce infection, and enable real-time monitoring of the surgical environment. Their relevance is particularly pronounced in the oral cavity, where continuous exposure to saliva, a diverse microbiome, and mechanical forces predisposes wounds to contamination, delayed healing, and dehiscence (35).

A major advancement in smart suture technology is the development of sensor-integrated or “electronic” sutures, which incorporate micro- and nanoscale sensing elements within the suture structure. These systems transform sutures into diagnostic tools capable of continuously monitoring the wound microenvironment in real time, thereby enabling early detection of complications and more precise postoperative management.

These smart sutures are engineered to detect critical physiological parameters associated with wound healing, including:

- pH variations, which can indicate early infection due to bacterial metabolism and biofilm formation
- Temperature changes, reflecting local inflammation or infection
- Mechanical strain or tension, which may signal excessive stress on wound margins and risk of dehiscence

Electronic sutures capable of monitoring, sensing, and responding to biological changes offer a promising approach for localized tissue health assessment. Recent developments have introduced smart electronic sutures integrating ultrathin, flexible silicon-based sensors within polymer or silk substrates for real-time wound monitoring. These sutures are designed in a serpentine configuration to enhance flexibility and incorporate temperature sensors made of silicon and platinum nanomembranes, along with gold-based microheaters (36). Such systems can accurately detect localized temperature changes, aiding in early identification of infection, while microheaters help maintain optimal thermal conditions to support healing. Importantly, these electronic sutures retain desirable mechanical properties, including flexibility, pliability, and adequate tensile strength, allowing easy handling, needle threading, and secure knotting without compromising device integrity, as demonstrated in preclinical models.

The integration of flexible electronics and biocompatible conductive materials allows these sutures to transmit data wirelessly or through external interfaces, facilitating continuous monitoring without the need for invasive procedures. The development of an electronic suture capable of real-time wound monitoring, including temperature and strain sensing, highlighting its potential for early detection of infection and impaired healing (37).

SHAPE-MEMORY AND ELASTIC SUTURES

Shape-memory polymer (SMP)-based smart sutures enable self-tightening knots, offering an effective alternative to conventional sutures, especially in deep or minimally invasive procedures. These sutures are pre-stretched into a temporary shape and, upon exposure to stimuli such as body heat, revert to their original form, generating controlled and optimal tension across the wound (38). This temperature-responsive property ensures precise wound closure, reduces surgical complexity, and provides good flexibility, strength, and reliable tissue approximation.

These sutures are fabricated from thermoplastic polymers possessing both shape-memory and biodegradable properties. They are initially applied in a relaxed, temporary configuration, with the ends secured in place (39). Upon exposure to temperatures above their thermal transition point—typically near physiological body temperature—the sutures contract, tightening the knot and generating optimal tension across the wound. This property is clinically significant, as it allows controlled and consistent knot tightening during surgery.

Additionally, advanced smart sutures incorporating plastic or silk filaments embedded with temperature sensors and microheaters can monitor local thermal changes, enabling early detection of infection at the surgical site (40,41).

SURGICAL ZIPPERS

The surgical zipper is a tape-based wound closure device that offers a minimally invasive and efficient alternative for tissue approximation. First developed in Germany by H. Y. Kaessmann in 1989, it integrates a zipper mechanism with adhesive strips, allowing rapid application and improved cosmetic outcomes (42). Although widely utilized in specialties such as gynecology, orthopedics, pediatrics, and plastic surgery, its adoption in the maxillofacial region—particularly in India—remains relatively limited. Adhesive strips of bandage cause minimal tissue trauma. Zip stitch, helps surgeons to apply desired tension, causing mild eversion of wound margins, achieved by approximating the interlocking arms.

Advantages of Zip Stitch (Adhesive Bandage Closure System): (43)

- Eliminates skin punctures, ensuring greater patient comfort
- Prevents stitch marks and related complications
- Removes the need for suture removal or additional clinical visits
- Provides improved cosmetic outcomes with minimal scarring
- Enables rapid and efficient wound closure
- Can be applied without the need for anesthesia
- Reduces the risk of cross-contamination
- Allows adjustable tension for optimal wound approximation
- Simplifies postoperative care and management
- Disadvantages of Zip Stitch (43)
- No reversal of applied tension over wound margins
- Requires dry conditions for optimal adhesion over margin, is prone to fall off otherwise

CYANOACRYLATES

Sutures remain essential for wound closure; however, they are associated with certain limitations, including secondary tissue trauma from needle penetration, potential for inflammation or infection, delayed healing, and the risk of needle-stick injuries.

Alternative approaches to wound management include platelet-rich fibrin (PRF) and collagen sponges, which promote haemostasis and enhance tissue regeneration. Additionally, tissue adhesives such as cyanoacrylate glue have been utilized as effective options for wound closure and bleeding control (44). Bio-adhesives encompass tissue glues, films, and sealants that may be either biodegradable or biostable (45). These materials adhere to biological tissues upon application, maintaining tissue approximation by distributing mechanical stresses across the wound interface.

Tissue adhesives are broadly classified into two categories: natural polymer-based adhesives, such as fibrin, albumin, and gelatin; and synthetic adhesives, including those derived from cyanoacrylate (CA), poly(ethylene glycol) (PEG), catechol, and methacrylic anhydride (46).

Among bio-adhesives, cyanoacrylates (CAs) are widely used for wound closure in skin, mucosa, and various soft tissues, including the oral cavity. These synthetic adhesives possess strong bonding and undergo rapid exothermic polymerization upon contact with moisture (e.g., blood or tissue fluids), forming a stable adhesive film within seconds. Cyanoacrylates provide immediate haemostasis, adhere effectively to both hard and soft tissues in moist environments, and exhibit a relatively long functional duration. Their ease of application reduces operative time, and they do not require removal during follow-up. Additionally, they are biocompatible, biodegradable, and demonstrate bacteriostatic properties, making them particularly suitable for intraoral use. Clinically, cyanoacrylate adhesives have been successfully employed for intraoral wound closure, helping to avoid ischemic changes associated with sutures. They also promote healing in procedures such as free gingival graft donor sites and act as effective haemostatic agents in high-risk extractions, including third molar surgeries (47,48), alveoloplasty (49), Socket Sealing in Alveolar Ridge Preservation (50), Soft Tissue Closure in Stage II Implant Recovery Procedure (51).

DISCUSSION

Knot formation is a critical step in conventional suturing, as it provides stability and secures the suture in place (52). However, irrespective of the knotting technique employed, the process of twisting and tightening the suture material can reduce its tensile strength by up to 50%, thereby significantly altering its mechanical properties. Consequently, the knot represents the weakest point in a surgical suture.

To address the limitations associated with knotted sutures, knotless suturing techniques have emerged as an effective alternative, particularly for intraoral wound closure (53). The use of barbed sutures eliminates the need for knot tying, resulting in reduced operative time due to more efficient wound closure (54). Additionally, the absence of

knots removes a potential nidus for infection, thereby minimizing food particle entrapment, microbial colonization, and adverse tissue reactions (55).

Barbed sutures facilitate uniform distribution of tension along the wound margins during the early postoperative period (56). This even tension helps maintain stable wound approximation without the need for additional manipulation. As a result, patients may experience reduced discomfort, a lower inflammatory response, improved oral hygiene maintenance, and better preservation of normal form and function.

Antimicrobial-coated sutures are largely braided, except for polyglycaprone 25 with triclosan (57,58). Common coatings include triclosan and chlorhexidine. Triclosan provides broad-spectrum activity against Gram-positive and Gram-negative bacteria and has proven intraoral efficacy in medical devices and dentifrices. Chlorhexidine, widely used in oral care, acts bacteriostatically at low concentrations and bactericidally at higher levels through cell lysis. Both agents are effective and safe for use as suture coatings; however, their ability to consistently reduce bacterial load remains debated.

With the growing adoption of minimally invasive surgery and advances in suture technology, electronic sutures integrated with sensors for pH, temperature, oxygen, wound exudates, bacterial load, and enzymatic activity offer significant potential for precise monitoring and improved healing of both acute and chronic wounds (59,60). Although multiple biomarkers have been explored, clinically relevant parameters such as pH, oxygen levels, uric acid, hemoglobin, infection indicators (e.g., temperature and odour), and protease activity are currently the most utilized for wound assessment (59).

Furthermore, the incorporation of force sensors with feedback systems into sutures enables real-time measurement of tension applied during wound closure. This allows surgeons to maintain optimal tension, minimizing the adverse effects of excessive or insufficient force on healing. The integration of sensing capabilities into advanced designs, such as barbed sutures, further expands their utility in monitoring infection and enhancing wound management, particularly in minimally invasive surgical procedures (61).

The choice of wound closure method should be guided by factors such as patient risk profile, cosmetic outcomes, ease of application, cost-effectiveness, and overall patient comfort. Although zip stitch adhesive bandages have been studied in fields like orthopedics, gynecology, laparoscopy, and cardiothoracic surgery, there is limited evidence regarding their use in the maxillofacial region. Available observations indicate that zip stitch application is associated with minimal complications, with no significant incidence of wound dehiscence or gaping during healing. Favorable cosmetic outcomes, including minimal scarring, have been reported up to two months post-application. As a tape-based wound closure technology, zip stitch demonstrates promising results and potential as an effective alternative for maxillofacial wound management. Further research is warranted to evaluate its application across a broader range of wound types and to establish its versatility and long-term clinical benefits. (43)

Cyanoacrylate (CA) adhesives can serve as a reliable alternative to conventional wound closure methods in various dental surgical procedures. Their advantages are particularly notable in free gingival grafting and donor site management, where they reduce operative time, improve patient comfort, and support satisfactory healing. Although they may not consistently demonstrate superiority in procedures such as third molar extractions or periodontal flap closures, cyanoacrylates remain a dependable option—especially in situations where postoperative compliance or suture removal is a concern.

CONCLUSION

Surgical sutures play a vital role in wound management as an essential therapeutic modality. Selection of an appropriate suture material requires careful consideration of its duration of tensile strength and its interaction with the surrounding tissues, ensuring optimal support during the healing process while minimizing adverse tissue reactions (62). Advancements in suture materials have significantly enhanced the ability of clinicians to select sutures tailored to specific surgical procedures. Recent innovations have addressed many challenges associated with surgical wound closure while also contributing to a reduction in postoperative infection rates. It is therefore essential for clinicians to have a thorough understanding of the physical and biological properties of available suture materials in order to select the most appropriate option for different types of wounds (63). A thorough understanding of the principles outlined in this review article, combined with the precise application of appropriate surgical techniques, can significantly enhance procedural outcomes. This, in turn, contributes to improved wound healing, greater postoperative patient satisfaction, and overall surgical success.

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