Chapter

Surgical Wound Closure and Healing

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Abstract

This chapter will review the most recent advances in surgical wound closure devices and how they impact and support surgical wound healing. An overview of surgical wound healing and its potential complications will be provided. Wound closure technologies will be described with a focus on how they may also minimize complications of surgical wound healing such as infection, dehiscence, and incisional hernia. Evidence will be summarized to support these effects along with an explanation of mechanisms of action. Broad categories of wound closure technologies to be discussed will include absorbable suture materials, antibacterial sutures, surgical staples, and topical skin adhesives.

Keywords: surgical wound, wound closure techniques, postoperative complications, incisional hernia, surgical wound infection, surgical wound dehiscence, sutures, antibacterial sutures, absorbable sutures, topical skin adhesives

1. Introduction

Surgical wounds are unique in the spectrum of acute and chronic wounds. They are technically acute wounds that progress through the phases of normal healing, resulting in wound closure within an expected timeframe of about 4 weeks [1]. They differ however from all other acute wounds in three important ways. First, they are planned and executed under the best of conditions, second, they present as incisions or excisions with clean edges and minimal tissue damage or loss, and third, their edges are precisely approximated with the mechanical support of a wound closure device to facilitate healing [2]. Wound closure devices are essential tools in surgery but can entail both benefits and risks to successful wound healing. The major categories of surgical wound closure devices will be described and discussed from the standpoint of their potential impact on both surgical wound healing and surgical wound complications.

2. Classifications and healing of surgical wounds

The global volume of surgery was estimated to be 312.9 million procedures in 2012, which represented an increase of 38.2% from a prior estimate in 2004 [3]. Almost all of these surgical procedures begin with the creation of an incisional wound to provide

access to the organ or anatomy of interest and end with the closure of the incision. Surgical incisions can be made at any location on the body, be of any length, variable depths, and different shapes. With over fourteen surgical specialties creating multiple types of incisions, classifying these wounds can be complex [4]. There are however, two classification systems for surgical wounds that are widely used [5, 6].

In the first, surgical wounds are classified preoperatively into one of four categories according to the likelihood and degree of wound contamination at the time of operation [5]. The Centers for Disease Control and Prevention (CDC), using an adaptation of the American College of Surgeons' wound classification schema, divides surgical wounds into four classes [5]. Class I or clean wounds are defined as uninfected operative wounds in which no inflammation is encountered and the respiratory, alimentary, genital, or uninfected urinary tracts are not entered [5]. Class II or clean-contaminated wounds are defined as operative wounds in which the respiratory, alimentary, genital, or urinary tracts are entered under controlled conditions and without unusual contamination [5]. Operations involving the biliary tract, appendix, vagina, and oropharynx are included in this category provided no evidence of infection or major break in sterile technique is encountered [5]. Class III or contaminated wounds are defined as open, fresh, accidental wounds. In addition, operations with major breaks in sterile technique (e.g., open cardiac massage) or gross spillage from the gastrointestinal tract, and incisions in which acute, nonpurulent inflammation is encountered [5]. Class IV or dirty-infected wounds are defined as old traumatic wounds with retained devitalized tissue and those that involve existing clinical infection or perforated viscera [5]. This definition suggests that the organisms causing postoperative infection were present in the operative field before the operation [5].

The second classification system for surgical wounds is determined postoperatively and refers to when and how they are closed and will heal. Primary wound closure refers to the immediate closure of a surgical incision (usually within 4–8 h) and is also known as healing by primary intention [6]. Wounds that heal by primary intention are those with little or no tissue loss in which the wound edges can be easily approximated or brought together [6]. Primary intention healing occurs via epithelization and connective tissue deposition [7]. Most incised surgical wounds will heal by primary intention [6]. Secondary wound closure, also known as healing by secondary intention, applies to wounds with significant tissue loss in which the wound edges cannot be approximated. Secondary intention healing requires a granulation tissue matrix to form and fill the defect prior to epithelialization of the surface [7]. Less frequently, surgical wounds are managed by tertiary or delayed primary closure, also known as healing by tertiary intention [6]. This approach is usually taken in wounds where there is not significant tissue loss but an elevated risk or presence of infection [7]. Examples include traumatic injuries such as animal bites or lacerations involving foreign bodies. These wounds can usually be surgically closed, or skin grafted after thorough cleansing, debridement of any necrotic tissue, and observation for up to 7 days to ensure adequate tissue viability and perfusion [8].

Wound healing, whether in chronic wounds or acute wounds like closed surgical incisions involves a complex series of molecular and cellular events that culminate in fibrotic repair or a scar [9]. These wound healing events can be described as four overlapping phases of hemostasis, inflammation, proliferation (collagen formation) and maturation (collagen remodeling) [9]. Hemostasis begins at the moment of incision with a complex series of enzymatic events that result in the formation of a fibrin clot [9]. The clot establishes a temporary extracellular matrix and subsequent platelet mediated stimuli recruit neutrophils to the wound environment to initiate the

inflammatory phase with the initial function of defending against bacterial infection [9]. Within 2–3 days, monocytes from the bloodstream enter the tissues and transition into macrophages [9]. Early wound macrophages phagocytize dead neutrophils, bacteria, and tissue debris [9]. Later these macrophages take on an anti-inflammatory role in preparation for tissue repair and begin to secrete a variety of growth factors to stimulate fibroblast migration and activation [9]. The acute inflammatory phase can last 3–7 days dependent on tissue type [7]. During this phase of healing, a surgical incision does not gain appreciable tensile strength, and is dependent upon the wound closure material to hold it in approximation [7]. The arrival of fibroblasts signals the beginning of the proliferative phase [9]. The fibroblasts and endothelial cells begin to produce a highly vascularized extracellular matrix composed of glycosaminoglycans, proteoglycans, and collagen called granulation tissue [9]. The ratio of type III to type I collagen in granulation tissue is higher than in unwounded tissue or mature/remodeled scar and it accounts for the weaker tissue strength in a healing wound [9]. Although collagen deposition by fibroblasts is at its maximal level around 3 weeks after injury, wound strength is still at a minimum [9]. Surgical incisional wounds have minimal to no tissue loss, so the proliferative phase may be attenuated with lower volume of granulation tissue relative to wounds with significant tissue loss. Epithelial cells resurface the wound only after granulation in wounds with tissue loss, however in incisional wounds with close wound edge approximation, epithelization is complete within about 48–72 h [10]. The maturation phase begins after proliferation subsides and involves remodeling of the newly deposited matrix with changes in collagen fibril orientation and a shift toward a higher proportion of type I to type III collagen [9]. This remodeling process results in a mature scar that can regain up to 80% of the strength of normal skin after 3–4 months [9]. Remodeling involves reorganization of extracellular matrix by matrix metalloproteinases and collagenases and is accompanied by decreased cellularity and vascularity of scar tissue [7]. Epithelial appendages such as hair follicles, sweat glands, and sebaceous glands are not reformed, so a healed scar is an acellular arrangement of epithelialized extracellular matrix composed primarily of collagen [9].

There are many elements of an operative procedure that can impact the surgical wound healing process [7]. The patient's overall health status will affect the duration of healing with many factors to be considered, including but not limited to age, BMI, nutrition, hydration, diabetes, tobacco use, blood supply, polypharmacy, and immunodeficiencies [7]. Likewise, there are factors related to the surgical procedure itself, such as the length and orientation of the incision, dissection technique, tissue handling, elimination of dead space, closing tension, and the choice of wound closure materials [7].

3. Surgical wound healing complications

Several of the most common surgical wound healing complications which can be impacted by wound closure materials or technique will now be briefly discussed.

3.1 Surgical site infection

Surgical incisions are made under sterile conditions, however multiple infection prevention measures must be observed pre-, post-, and intraoperatively to minimize risks of post-operative infections. Surgical site infection (SSI) is the most common

surgical wound complication, affecting up to one-third of patients who have undergone a surgical procedure [11]. SSIs are commonly classified as one of three types: superficial incisional (involving only the skin or subcutaneous tissue of the incision), deep incisional (involving the deep soft tissues of the incision, such as fascia and muscle layers) or organ/space (involving any part of the anatomy which was opened or manipulated during an operation other than the incision) [5]. It has been estimated that two-thirds of SSI are confined to the incision [5].

Infection occurs when microorganisms in a wound proliferate to a level that produces a local and/or systemic response [12]. Many of the factors that impact surgical wound healing also affect the potential for infection. Risk factors for SSI include patient-specific and process/procedural-specific variables. Some variables are not modifiable, such as patient age and gender, however, others can be improved to reduce the risk of infection such as nutritional status, tobacco use, correct timing and dosing of antibiotics and aspects of intraoperative technique [11]. A particular risk factor for SSI is the presence of foreign bodies in the wound which can provide a surface for bacteria colonization and biofilm formation [13]. While such foreign bodies are often thought to be exemplified by larger, permanent implantable medical devices such as joint protheses or heart valves, devices for wound closure such as surgical sutures can present similar risks for surgical wound infection [13]. Clinical data as early as the 1950s has shown that the presence of suture in an incision can reduce the infective dose of bacteria by 10,000-fold; from a dose of millions down to hundreds [14]. The rationale for this is that within hours, small numbers of bacteria released into the wound from lower layers of the stratum corneum and dermal appendages during creation of the surgical incision can colonize the suture surface and develop into a biofilm which is resistant to phagocytic immune cells as well as to antibiotics [15].

Surgical site infections are the most common of all healthcare associated infections (HAI) [16]. A 2022 retrospective analysis of the largest all-payer US inpatient databases—the Agency for Healthcare Cost and Utilization Project's 2016 National Inpatient Sample, provides some of the most up-to-date information on the incidence of HAI [16]. This database covers more than 97% of the US population and contains data from more than 35 million inpatient admissions [16]. The analysis considered all inpatient encounters with primary or secondary ICD-10 diagnosis codes corresponding to infection with catheter-associated urinary tract infections (CAUTI), catheter- and line-associated bloodstream infections (CLABSI), SSI, ventilator-associated pneumonia (VAP), and infection with *Clostridioides difficile* (CDI) to determine incidence [16]. For the 280,575 admissions with HAI as a primary diagnosis, SSI was the most frequent at 47%, followed by CDI as 37.4%, CLABSI at 10.2%, CAUTI at 5% and VAP at 0.4% [16]. The additional costs associated with these SSI were 3.7 billion USD [16].

3.2 Surgical wound dehiscence

Surgical wound dehiscence (SWD) is a wound healing complication that has a wide range of definitions [17]. It can refer broadly to any separation of a surgical incision ranging from a superficial separation of part of the incision to complete separation of the full thickness of the incision with exposure of organs or surgical implants [17]. Conversely, the term can be used specifically to describe the failure of an abdominal incision and evisceration of the abdominal contents [17]. Further, literature reports may use a variety of alternative descriptors for SWD such as wound disruption, wound opening, wound breakdown, fascial dehiscence, or surgical site failure, among others [17]. A standardized definition of SWD for all closed surgical

incision types was proposed in 2018 by the World Union of Wound Healing Societies to facilitate accurate identification and reporting as well as management [17]. The definition is as follows: "Surgical wound dehiscence (SWD) is the separation of the margins of a closed surgical incision that has been made in the skin, with or without exposure or protrusion of underlying tissue, organs, or implants. Separation may occur at single or multiple regions, or involve the full length of the incision, and may affect some or all tissue layers. A dehisced incision may, or may not, display clinical signs and symptoms of infection." [17].

Dehiscence can be caused by technical issues with incision closure such as failure of the closure material or technique, postoperative mechanical stresses placed on the incision by local edema or patient activity levels, endogenous healing issues or any combination of these [17]. There is also a correlation between SWD and other surgical wound complications, such as seroma, hematoma, incisional hernia, and SSI [17].

Determination of SWD incidence is hampered by the lack of a uniform definition and rates in the literature vary widely by surgical procedure type and surgical wound classification [17]. SWD rates have been reported to range from 0.65% in cardiothoracic surgery up to 41.8% in pilonidal sinus surgery [17].

3.3 Incisional hernia

Incisional hernias (IH) are a common surgical wound complication after abdominal surgical procedures (especially midline incisions) and are defined as "abdominal wall gaps around postoperative scars, perceptible or palpable by clinical examination or imaging" [18]. Incisional hernias develop because of the failure of the abdominal wall to close properly due to patient related factors, disease related factors and or technical factors related to surgical technique or wound closure materials [19]. Wound infection, obesity, and suture closure technique (in particular a suture length/wound length ratio > 4/1) are thought to be the most important risk factors for the development of IH [19].

The incidence of IH after midline laparotomy ranges from 0 to 44% in the literature; however, a pooled rate of 12.8% has been reported at two years postoperatively from a systematic review and meta-analysis of 56 papers involving 14,618 patients [18].

4. Surgical wound closure options and impact on healing

While there are different approaches to the closure of surgical incisions, the goals of all are to (1) facilitate the natural healing process leading to restoration of tissue function, (2) supply exogenous strength until tissue strength is restored by the endogenous healing process, and (3) avoid potential complications through appropriate closure technique and choice of closure approach [7]. Hence, clinicians closing wounds are concerned about the wound closure strength provided by the device they select, with not interfering with endogenous wound healing and ideally avoiding or minimizing complications [7]. Apposition of tissue edges by a wound closure device is maintained until the endogenous healing process restores enough wound tensile strength such that the wound becomes self-supporting [7]. The duration of time that a wound is completely dependent on the closure device for its initial holding strength is often referred to as the "critical wound healing period" [20]. The critical wound healing period is longer or shorter depending on the tissue type as well as on an individual patient's healing ability based on their health status as described earlier [20].

Surgeons have several types of wound closure devices/materials to choose from when closing a surgical incision. There is no single wound closure choice that is ideal for all situations, the physician must decide which material is best suited to a particular wound and situation based on their knowledge and experience [21]. Surgeons may choose to close the tissue layers that have been separated by the incision in two general ways; en masse (e.g., using a single closure material and technique to close multiple tissue layers at once) or layer by layer (e.g., making specific wound closure choices of material and technique for different tissue layers) [21]. There are differing opinions on closing specific tissue layers separately versus en masse. For example, some surgeons question the need of separately closing the subcutaneous fat layer because it has little tensile strength due to its composition, which is mostly water, whereas others believe it is necessary to place at least a few sutures in a thick layer of subcutaneous fat to prevent dead space, where tissue fluids can accumulate to create seromas or hematomas which can delay healing and potentiate infection [7].

Regarding the tissue layers, there are multiple types of devices for skin (epidermal) closure including sutures, staples, and topical skin adhesives. For the tissue layers below the epidermis—dermis, subcutaneous fat, fascia, muscle—sutures are still the only option for wound closure [7].

4.1 Sutures for wound closure

4.1.1 Suture technique and impact on healing

A suture is any strand of material attached to a surgical needle designed to carry that material through tissue with minimal trauma to approximate two opposing tissue edges [7]. Regardless of the type of suture material selected, an important aspect of their use is how they are deployed by the surgeon. Suturing techniques require considerable skill by surgeons and affect wound closure outcomes. The method of where the suture enters and exits the tissue, the distance between throws, the distance from the wound edges, the suture length to wound length ratio, the way knots are performed, etc. are all aspects of suture technique [22]. Frequently used suturing techniques for tissue approximation include, but are not limited to simple interrupted, continuous (also referred as a running), mattress (horizontal or vertical), and subcuticular (interrupted or continuous) [22].

Suturing technique alone can have an impact on wound closure success [22]. For example, the European Hernia Society undertook a systematic review of the literature to establish guidelines for the optimal wound closure technique for elective midline incisions of the abdominal wall with the goal of decreasing the occurrence of the surgical wound complications of both burst abdomen and incisional hernia [23]. These guidelines were intended for all surgeons performing abdominal incisions in any type of surgery including visceral, gynecological, aortic vascular, urological, or orthopedic, and for both open and laparoscopic approaches [23]. Their final recommendations regarding the optimal suture technique included using a continuous suturing in a single layer aponeurotic closure technique without separate closure of the peritoneum [23]. Further, a small bites technique (stitches placed 5 mm apart and 5–8 mm from the wound edges) with a suture to wound length (SL/WL) ratio of at least 4/1 was recommended [23]. They went on to make specific recommendations also regarding the optimal suture material and suggested the use of slowly absorbable monofilament suture when using this closure technique [23].

4.1.2 Suture materials

Most sutures used today are composed of either natural materials such as gut or silk or an increasing variety of manmade synthetic polymers [23]. Their physical formats can be either monofilament, multifilament (braids) or barbed monofilaments [23]. They can be nonabsorbable (permanent) or absorbable (temporary) [7]. Desirable characteristics of sutures include pliability for ease of handling, adequate tensile strength, knot security, minimal tissue reactivity, infection resistance, and good elasticity and plasticity to accommodate wound swelling or tissue growth [7]. The choice of a suture material depends on factors such as the number of tissue layers involved in wound closure, the critical wound healing period for the tissue involved, tension across the wound, depth of suture placement, presence of edema, and expected time of suture removal among others [24].

4.1.3 Absorbable versus nonabsorbable sutures

While sutures can be made of many different natural and synthetic materials, the most significant categorization is that of their status as nonabsorbable versus absorbable sutures [21]. Nonabsorbable sutures which cannot be removed (e.g., those used below the skin surface) persist in the body even after tissue has regained enough tensile strength to be self-supporting and may elicit a foreign body response as they become encapsulated by fibrous connective tissue [7]. They may also be palpable and perceived as painful by the patient. Ideally, a suture material will remain strong enough to support the wound through the critical healing period and then gradually be absorbed [20]. With the advent of synthetic absorbable polymers for suture in the late 1960s, it became possible to design suture material that maintained its wound holding strength for specific durations of time (also called breaking strength retention or BSR) and were then absorbed by the body via hydrolysis and required no return visit for suture removal if used for skin closure [24]. The breaking strength retention times can be specifically controlled through the molecular composition of the polymers [21]. Among the various types of synthetic absorbable sutures, there are polymers that retain their breaking strength for one, two, four or six weeks before the absorption process significantly reduces it (**Table 1**).

The surgeon will choose the type of absorbable suture with the breaking strength retention period appropriate for the tissue being approximated and the specific clinical scenario [21]. For example, in a rapidly healing tissue such a mucosa, a short-term absorbable suture such as low molecular weight polyglactin with a BSR of one week may be the optimal choice but for a longer healing tissue subject to mechanical stresses such as abdominal fascia, a slowly absorbable polydioxanone monofilament may be the best choice [7]. In fact, the EHS Guidelines just discussed have made that specific recommendation for fascial closure in elective midline incisions [23].

An initial concern with the advent of synthetic absorbable suture materials was their ability to maintain effective wound closure in different tissue types as compared to nonabsorbable suture materials [25]. There have been multiple meta-analyses performed to compare the performance of absorbable and nonabsorbable sutures for wound closure in various tissue types including skin, dermis, fascia, and muscle and comparing rates of wound healing complications [18, 25–28]. The largest such comparison across multiple procedure types reviewed outcomes post absorbable and nonabsorbable suture use in 25 randomized controlled trials and 5781 patients and

Approximate % of original strength remaining[a] at:						
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
LMW Polyglactin (Vicryl Rapide)	50%	0				
Poliglecaprone (Monocryl)	60%	30%		0		
Polyglactin 910 (Vicryl)		75%	40–50%	25%	0	
Polyglycolic acid (Dexon II)		65%	35%			
Polyglyconate (Maxon)	80%	75%	65%	50%		25%
Polydioxanone (PDS II)		80%		70%		60%

[a]*Data taken from respective suture instructions for use.*

Table 1.
Breaking strength retention times of different absorbable polymers.

found no significant differences in surgical site infection, dehiscence, or other post-operative complications [25] A 2016 meta-analysis compared outcomes for absorbable versus nonabsorbable sutures in skin closure (1748 patients in 19 RCTs) and confirmed that an absorbable suture for skin closure was an acceptable alternative for traditional nonabsorbable sutures with no significant differences between the two suture types in the incidence of wound infections, cosmetic outcomes, wound dehiscence, or patients' or caregivers' satisfaction [26]. In three large meta-analyses (56 RCT/14618 patients, 55 RCT/19174 patients, 8 RCT/426 patients) comparing the use of absorbable versus nonabsorbable sutures in fascial closure of laparotomy incisions, none demonstrated any significant differences in the surgical healing complication outcomes of incisional hernia, surgical wound dehiscence, or surgical site infection [18, 27, 28]. It should be noted that these comparisons focused on absorbable versus nonabsorbable sutures in general and not on specifically on slowly absorbable sutures which have been recommended by the European Hernia Society as the optimal fascial closure choice for elective midline incisions based on reduced risks of incisional hernia and dehiscence as previously discussed [23].

4.1.4 Antibacterial sutures versus non-antibacterial sutures

Sutures with antibacterial coatings were developed to address an underappreciated yet known risk factor for surgical site infection– bacterial colonization and biofilm formation on the suture [24]. Currently, the only globally available antibacterial sutures are those coated with triclosan (Plus Antibacterial Sutures, Ethicon, Inc., Somerville NJ). There have been multiple randomized controlled trials (RCT) of triclosan coated sutures compared to non-triclosan sutures with the primary outcome of SSI within 30 days [29]. These studies have been performed in various procedure types encompassing all surgical wound classifications (clean, clean-contaminated, contaminated, and dirty) [30]. Subsequently, there have been serial meta-analyses of these randomized trials published over time. **Table 2** presents the most recent meta-analyses of triclosan coated sutures versus non-triclosan-coated sutures [29–33]. While each of these meta-analyses incorporates largely the same RCT data, none of the listed analyses completely replicates the data in another, either due to timing or to included surgical procedure types. Each meta-analysis, whether including all types of surgical procedures or limited to specific types of surgical procedures, found a

Procedure type	Author Yr. (#RCT, #pts)	Relative risk of surgical site infection
Multiple	Ahmed 2019 (25 RCT, 11,957 pts)	RR 0.73 (0.65–0.82) P = < 0.00001
Gastrointestinal surgery	Uchino 2018 (10 RCT, 3488 pts)	RR 0.67 (0.48–0.94) P = 0.02
Colorectal surgery	Uchino 2018 (9 RCT, 2433 pts)	RR 0.69 (0.49–0.98) P = 0.04
Abdominal fascial closure	Henriksen 2017 (8 RCT, 3641 pts)	OR 0.67 (0.46–0.98) P = 0.04
Multiple	de Jonge 2017 (21 RCT, 6462 pts)	RR 0.72 (0.60, 0.86) P < 0.001
Multiple	Leaper 2017 (34 studies, mean #pts./study 493)	OR 0.61 (0.52, 0.73) P = 0.001

Table 2.
Recent meta analyses of triclosan coated antibacterial sutures versus non-antibacterial sutures.

significant difference in the performance outcome of reduced risk of SSI with the use of triclosan coated sutures. The average reduction in risk of SSI ranged from 27 to 33% [29, 31]. A large meta-analysis focused primarily on economic outcomes included observational studies as well as RCT and found a risk reduction of 39% [32].

Two meta-analyses also employed trial sequential analysis (TSA) to quantify the statistical reliability of data in the cumulative meta-analysis adjusting significance levels for sparse data and repetitive testing on accumulating data [30, 32]. TSA is increasingly used as a tool to quantify the reliability of a meta-analytic outcome [30]. The TSA outcome of the meta-analysis of abdominal fascial closure was that triclosan coated sutures decrease the risk of SSI significantly and that further RCTs will not change that outcome [33]. The TSA outcome in the meta-analysis of triclosan coated sutures for any tissue closure was similar, concluding that the effect of the sutures was robust, and that additional data are unlikely to alter the summary effect [30]. No meta-analysis of triclosan-coated sutures reported any significant differences in any safety outcomes. These data collectively support the conclusion that triclosan-coated sutures are a valuable technology for wound closure in a wide variety of tissue types and procedures encompassing all surgical wound classifications with the intention of reducing the risk of SSI.

Furthermore, given that systematic reviews and meta-analysis cannot directly calculate the pooled SSI-attributable excess costs to healthcare, one investigator conducted an economic study to estimate the potential clinical and economic impact for NHS of using these sutures compared with conventional non-antimicrobial-coated absorbable sutures for wound closure [32]. Results showed that antimicrobial sutures may result in significant savings across various surgical wound types [32].

In 2021 the National Institute for Health and Care Excellence (NICE) commissioned an external assessment center to analyze the evidence base for Ethicon's Plus triclosan coated sutures as an innovative technology which consisted of 31 RCT involving over 14,000 patients [34]. Their analysis consisted of six de novo meta-analyses to establish the overall pooled effect size associated with Plus Sutures on the incidence of surgical site infections [34]. The primary outcome was the relative risk of developing a surgical site infection between Plus Sutures and control groups [34]. The six separate meta-analyses were done using: (1) all studies that provided enough

Meta analysis	#RCT	#Pts	Fixed effects RR	Random effects RR
All	28	13,667	**0.72** [0.64; 0.80] p < 0.001	**0.71** [0.59; 0.85] p < 0.001
Adults	25	9757	**0.73** [0.65; 0.82] p < 0.001	**0.74** [0.62; 0.88] p < 0.002
Children	2	1692	**0.52** [0.32; 0.87] p < 0.012	—
Clean wounds	15	6035	**0.75** [0.62; 0.90] p < 0.003	**0.71** [0.53; 0.96] p < 0.029
Non-clean wounds	12	2841	**0.66** [0.54; 0.80] p < 0.001	**0.67** [0.48; 0.92] p < 0.019
Sensitivity	31	13,821	**0.71** [0.64; 0.79] p < 0.001	**0.70** [0.58; 0.84] p < 0.001

Table 3.
NICE meta-analyses of triclosan coated suture evidence.

data; (2) a subset of studies in adults; (3) a subset of studies in children; (4) a subset of studies in patients with clean wounds; (5) a subset of studies in patients with non-clean wounds; and (6) all studies of Plus Sutures including STRATAFIX Plus that provided enough data, as a sensitivity analysis. The details and results of these meta-analyses are shown in **Table 3** and led to NICE making the following recommendations to the United Kingdom's National Health Service:

Recommendation 1.1: Evidence supports the case for adopting Plus Sutures as part of a bundle of care for preventing surgical site infection in the NHS for people who need wound closure after a surgical procedure when absorbable sutures are an appropriate option [34].

Recommendation 1.2: Cost modeling shows that Plus Sutures is cost saving compared with non-triclosan absorbable sutures by an average of £13.62 per patient. These savings are from reduced surgical site infections. Cost savings will vary by surgery type and baseline risk of surgical site infection [34].

4.2 Suture alternatives for skin closure

4.2.1 Staples

Skin staplers are medical devices that can be used to place "metallic sutures" or staples for closure of skin incisions. Skin staples provide a fast method for wound closure which allows for good eversion of skin edges without strangulation of tissue and minimal scarring [35]. Most modern skin staples are made from stainless steel. Skin staplers may be designed with a fixed head, a multi-directional release head or a 360° rotating head to improve visibility and facilitate access to wound areas, and with ergonomic handles (pistol-grip). The staples may have a dry film coating to facilitate removal which is accomplished with a special instrument called a staple extractor. The jaws of the device are used to grab the crossbar of the staple and bend the points out of the skin for removal. Both nonabsorbable/metallic and absorbable polymer-based skin staples are available [35].

Staples are often used for skin closure due to the rapidity of deployment compared to sutures [35]. A 2020 systematic review and meta-analysis of 42 RCT involving 11,067 patients comparing staples to sutures for skin closure in adults undergoing any type of surgery in a hospital setting examined primary outcomes of any SSI and severe SSI (defined as deep incisional or organ/space) and secondary outcomes of post-operative hospital stay, rates of readmission for wound complication, adverse events within 30 days and patient satisfaction with cosmetic results [36]. It was

noted that overall, the body of evidence was low to very low quality and that many of the studies did not report on all desired outcomes [36]. The authors concluded that sutures may reduce pain and provide better satisfaction with the cosmetic results than staples; however, it was uncertain whether using sutures decreased the risk of overall and severe SSI, readmission rates, adverse events and postoperative pain compared to wound closure with staples [36]. A more recent meta-analysis compared staples to sutures for skin closure elective knee and hip arthroplasties with primary outcomes of SSI [37]. Eight RCT involving 1120 patients were included. The studies were classified using the Cochrane risk of bias tool: two were low risk, four had some concerns and two were high risk. Five of the studies involved knees only, two involved hips only, and one involved both knees and hips. When all eight studies were combined for meta-analysis, no significant differences in the risk of SSI were found between sutures and staples; but when limited to only the studies with low risk of bias, there was a significantly higher risk of SSI with staples versus sutures [37]. After additional subgroup analysis, the authors concluded that "stapling might carry a higher risk of surgical site infection than suturing in elective knee and hip arthroplasties, especially in hip arthroplasty" [37].

4.2.2 Topical skin adhesives

Tissue adhesives are a newer and potential alternative method of skin closure in surgical wounds (deeper tissue layers must still be closed with suture) [7]. Topical skin adhesives are commonly used in the emergency room setting for closure of acute traumatic lacerations and offer the advantage of reduced application time and reduced pain with no need for anesthesia as compared with standard wound-closure methods, which can be especially useful in pediatric patients [7]. Additionally, patients also avoid the need to return for removal of stitches or staples.

Topical skin adhesives come in a liquid monomer formulation and undergo a polymerization reaction when encountering moisture or a chemical initiator, leading to a slightly exothermic reaction and bonding to skin [38]. A chemical initiator can ensure consistent, dependable, and predictable polymerization times and is often located in the tip of the liquid adhesive applicator [38]. Monomers used in topical skin adhesives are cyanoacrylate-based (including n-butyl or 2-octyl side chains) and may contain other formulation additives to enhance strength, flexibility, or modulate viscosity and adherence to the skin [38]. Some topical skin adhesives incorporate a mesh patch. The purpose of combining a mesh patch with a topical adhesive as a system is to allow for temporary approximation of wound edges, (as opposed to digital approximation) prior to deployment of the liquid adhesive component which provides the definitive wound closure strength [39]. This temporary approximation can be especially useful in longer incisions where digital approximation along the length of the incision can be time-consuming [39]. In addition, the mesh component can provide added strength to the closure.

Topical skin adhesives can be used alone or in conjunction with other skin closure methods (sutures, staples). They provide sufficient strength to maintain skin edges approximation and distribute tension along the entire incision, preventing skin gaps from forming when the skin is stressed [38]. They can also create a strong, flexible barrier to prevent exogenous bacteria from entering the incision until the epidermis has fully resurfaced to re-establish the skin barrier [38]. Although initially widely used in the emergency room, surgeons are increasingly using topical skin adhesives for closure of surgical incisions in the operating room.

The most recent Cochrane systematic review of topical skin adhesives for closure of surgical incisions identified 33 RCT with 2793 patients [40]. Adhesives were compared to other methods of skin wound closure for outcomes of surgical wound dehiscence and infection and cosmesis. Meta-analysis found that sutures performed significantly better than adhesives for reducing the risk of wound dehiscence, but there were no significant differences between sutures and adhesives for wound infection or cosmesis [40].

5. Evidence based guidelines with wound closure recommendations

In addition to the 2015 European Hernia Society guidelines on the closure of abdominal wall incisions, there are two other evidence-based guidelines with specific recommendations for choice of wound closure materials [11, 41]. Both focus on reducing the risk of SSI. The 1999 CDC Guidelines for Prevention of Surgical Site Infection were finally updated in 2017 [41]. The update did not reevaluate a number of strong recommendations from the 1999 version as they were deemed to be accepted practice for the prevention of SSI. The 2017 update does however include a new recommendation for the choice of wound closure material—there is a specific Category II recommendation to "Consider the use of triclosan-coated sutures for the prevention of SSI" [41].

In addition to the CDC 2017 guideline, the WHO Global Guidelines for the Prevention of Surgical Site Infection 2018), also included a recommendation for wound closure: "The panel suggests the use of triclosan-coated sutures for the purpose of reducing the risk of SSI, independent of the type of surgery." [11]. This recommendation was categorized as Conditional Strength based on Moderate Quality of Evidence [11].

6. Conclusion

As acute wounds created under sterile conditions, the healing of surgical incisions is typically expected to occur without incident within an expected timeframe [1]. However, surgical wounds are atypical in that they depend on a wound closure device to facilitate their progress during a critical wound healing period [20]. The most common surgical wound healing complications of infection, dehiscence, and incisional hernia can all be impacted by the choice and method of wound closure [11, 17, 23, 41]. Sutures are a ubiquitous tool in surgical wound closure however, not all sutures are created equally. Absorbable and nonabsorbable sutures vary in terms of their initial and duration of tissue holding strengths, and some may be better choices than others for specific tissues [7]. Absorbable sutures are available with a range of different breaking strength retention times enabling surgeons to select the one that is strong enough long enough to support the healing timeframe dictated by the specific tissues and patient conditions and then resorb to reduce the potential for foreign body sensation and pain [24]. Absorbable antibacterial sutures are now available which have been shown to reduce the risk of surgical site infection in a wide variety of procedures and all surgical wound classes [30]. As the SSI is not only the most common surgical wound healing complication [16], but a risk factor for other complications such as wound dehiscence and incisional hernia [17], antibacterial sutures technology may have an impact on these healing complications

as well. For example, while it is accepted that slowly absorbing sutures decrease the risk of incisional hernia after midline closure relative to faster absorbing sutures [23], a fast-absorbing antibacterial suture did not increase the incisional hernia rate compared to non-antibacterial slowly absorbing suture in a 3-year follow-up study of over one thousand patients [42]. Understanding the features and clinical benefits of different wound closure choices can be an important contribution to optimal surgical wound healing.

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Conflict of interest

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