REVIEW ARTICLE

Cutaneous Wound Closure Materials: An Overview and Update

Introduction: On a daily basis, dermasurgeons are faced with different kinds of wounds that have to be closed. With a plethora of skin closure materials currently available, choosing a solution that combines excellent and rapid cosmetic results with practicality and cost-effectiveness can be difficult, if not tricky. **Objectives:** We aimed to review the available skin closure materials over the past 20 years and the scientific claims behind their effectiveness in repairing various kinds of wounds. **Materials and Methods:** The two authors independently searched and scrutinised the literature. The search was performed electronically using Pub Med, the Cochrane Database, Google Scholar and Ovid as search engines to find articles concerning skin closure materials written since 1990. **Conclusion:** Many factors are involved in the choice of skin closure material, including the type and place of the wound, available materials, physician expertise and preferences, and patient age and health. Evidence-based main uses of different skin closure materials are provided to help surgeons choose the appropriate material for different wounds.

KEYWORDS: Adhesive, bonding, closure, cutaneous, cyanoacrylate, glue, skin, soldering, staple, surgery, suture, tape, wound, zipper

INTRODUCTION

Ideally, a wound closure method should be cost-effective, time-efficient, easy to perform, and produce the optimal cosmetic result. The primary goals of treating wounds in general and skin incisions in particular are rapid closure with the creation of a functional and esthetic scar.[1] Although sutures are used frequently in surgery, there are few reviews available in the literature that compare or review the attributes and qualities of sutures. Over the years, research on acute wound healing has resulted in the development of technologies such as staples and adhesives (e.g., glues and adhesive tapes) to allow surgeons to replace their tedious suturing techniques with simple, non-operator-dependent, safe, and rapid techniques, resulting in the optimal cosmetic appearance of the scar and avoiding infections by immediately sealing the wounds by using wide varieties of skin closure materials. As such, many investigators in both the medical and applied science disciplines have experimented with different materials, tissues and models to close wounds, including laser-assisted tissue bonding (LTB).

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MATERIALS AND METHODS

The two authors independently searched the literature electronically using Pub Med, the Cochrane Database, Google Scholar and Ovid as search engines. Articles concerning skin closure materials written in the English language since 1990 were included. The search was performed with the keywords: sutures, needles, staples, tapes, tissue adhesives, tissue healing, absorbable sutures, non-absorbable sutures, multi-filament sutures, monofilament sutures, natural sutures, synthetic sutures, surgical gut sutures, chromic gut sutures, fast-absorbing gut sutures, polydioxanone, polyglycolic acid, polyglactin, polytrimethylene carbonate, polyglecaprone, silk, nylon, polyester, polybutester, polypropylene, skin wound, laser-bonded healing and nano-suturing. The reference lists of the included studies and previous relevant, systematic reviews, and trial registers were also hand searched.

DISCUSSION

Tissue adhesives

There are several methods for wound closure, and sutures are the most common. Newer alternatives, however, have

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been introduced recently, such as adhesive paper tape and tissue adhesives.[2] In 1949, a German chemist developed a cyanoacrylate tissue adhesive that was clinically used for the first time by a British plastic surgeon in 1959.[3] Octyl-2-cyanoacrylate (OCA) was approved for use in 1998 by the Food and Drug Administration.[4] OCA usually starts to function upon application within 10 seconds. The stabiliser is neutralised by partially ionised water molecules on the skin surface, which ultimately cause polymerisation of the molecules.[5] Interestingly, the OCA breaking strength is approximately five times the strength of monofilament nylon sutures.[6] High-viscosity OCA (HVOCA) is a newer formulation that is thicker than the original OCA. Higher viscosity is advantageous in reducing the risk of migration of the adhesive away from the wound and thus may improve wound cosmesis.[7] Within 5-10 days, as the wound re-epithelialises, the adhesive generally sloughs off.[7] Premature sloughing of the adhesive might result from topical ointment and frequent cleansing of wounds treated with OCA.[7] Several recent reports have demonstrated the effectiveness of OCA in skin closures in a wide array of clinical settings and surgical subspecialties. Wounds must be evaluated before adhesive application for placement of subcutaneous sutures to decrease wound tension, eliminate subcutaneous dead space and maximise skin edge eversion [Table 1].[8]

Uses

Tissue adhesives have been used for many years in major and minor procedures of skin closure. They have widespread indications and applications, and have been used for fixation of implants, tissue adhesion, closure of cerebrospinal fluid leaks and embolisation of blood vessels.[8] In addition, tissue adhesives are now being used for facial wounds, groin wounds, hand surgery, blepharoplasty, laparoscopic wounds, hair transplantation and lacrimal punctum closure.[9,10]

Advantages

There are many advantages of tissue adhesives over suturing and other methods of wound closure, such as a lower infection rate, less operating room time, good cosmetic results, lower costs, ease of use, immediate wound sealing, faster return to athletic and work activities, elimination of needle-stick injuries and eliminating the need for post-operative suture removal.[8,11] Tissue adhesives are also easier and more friendly for use in children.[8] Moreover, OCA has a good safety record; there have been no reports of adverse effects or carcinogenicity.[6] Interestingly, a recent study showed that OCA use inhibits bacterial growth and prevents Gram-positive bacterial wound infections.[9] Furthermore, OCA can be a good method for wound closure in patients who are at risk for keloid or hypertrophic scar formation.[12] Therefore, surgeons may consider tissue adhesives as an alternative to sutures.

Disadvantages

There are limitations in the use of OCA owing to its cost, which may be more than four times as expensive as sutures; in addition, OCA needs proper patient selection and is only for external use.[5] Moreover, OCA use requires a meticulous technique, as there should be no gap between the skin margins or bleeding. Even with very small gaps, the tissue adhesive may seep through and prevent normal epithelialisation, ultimately disrupting the wound healing.[13]

Contraindication

Contraindications to tissue adhesives include the presence of infection, gangrene or ulceration, bleeding or oozing from the incision, incisions under tension requiring sutured approximation or oedematous wound edges, partial-thickness skin loss, burns, animal bites, mucosal surfaces or across mucocutaneous junctions, areas of high moisture or dense hair, and areas of high tension, such as joints.[4,11] Tissue adhesives are also contraindicated in patients at risk for delayed wound healing (diabetics or patients with collagen vascular diseases) and in those allergic to OCA.[8]

Table 1: Uses, advantages and disadvantages of tissue adhesives

Uses	Advantages	Disadvantages	Contraindications
Fixation of implants	A lower infection rate	Cost	Infection
Lacrimal punctum closure	Reduce the operating time	Proper patient selection	Bleeding or oozing from the incision
Hair transplantation	Good cosmetic results	Limitation to external use	Incisions under tension or at areas of high tensions such as joints
Laparoscopic wounds	Lower costs	Meticulous technique	Edematous wound edges
Blepharoplasty	Ease of use		Partial-thickness skin loss
Tissue adhesion	Immediate wound sealing		Burns
Closure of cerebrospinal fluid leaks	Fast return to routine activities		Animal bites
Embolisation of blood vessels	No risk of needle-stick injury		Mucosal surfaces or across mucocutaneous junctions
Facial wounds and groin wounds	No need for post-operative suture removal		Areas of high moisture or dense hair
			Patients at risk for delayed wound healing

Comparison

The first prospective randomised trial was done by Maartense *et al*., to compare methods of closure using OCA, adhesive paper tape or poliglecaprone in elective laparoscopic surgery.[2] They found that closure of laparoscopic trocar wounds with OCA reduces the operating room time, but was the most expensive of the three methods.[2] Adhesive paper tape was the fastest, cheapest, and most cost-effective method. The cosmetic result was significantly better for OCA than adhesive paper tape.[2] In addition, OCA was associated with fewer wound infections than were sutures. Several other studies have shown the antimicrobial effect of tissue adhesives.[2] A recent Cochrane review concluded that there were no differences in the rates of wound infections or wound dehiscence between HVOCAs and sutures.[7] A randomised controlled trial by Zempsky *et al*., achieved similar cosmetic results with reduced cost using adhesive tape closure than with tissue glue in facial lacerations in children.[14] Bernard *et al*., demonstrated an improved cosmetic outcome when suturing was used to close wounds involving tissue excision, resulting in higher wound tension.[15] Equivalent cosmetic results with OCA and sutured closure use was reported by Toriumi and colleagues.[8] A prospective, randomised, controlled trial showed that skin closure in traumatic wounds using 2-octylcyanoacrylate yielded results that were comparable to standard sutured closures with regard to wound infection rates, dehiscence and long-term cosmetic outcome.[16]

Adhesive tapes

Suture-less skin closure was first evaluated by Gillman.[17] Surgical adhesive tapes usually contain an adhesive backing consisting of iso-octo-acrylate and *n*-vinyl-pyrolidone.[18] An ideal surgical adhesive tape should be non-allergenic, non-irritating, water resistant, vapour permeable and must strictly adhere to skin. Adhesive tapes are used most frequently as adjunctive wound support after staples or sutures are removed, in conjunction with buried dermal sutures, or with absorbable running subcuticular sutures in low-tension wounds.[19] Applying the surgical adhesive tapes in a parallel, non-overlapping fashion after coating the entire application area with adjuvant adhesive is the optimal application technique that provided the best adherence over time.[19] There are many important factors in tape application, including dry skin, accurate apposition of edges, strict homeostasis, and the use of an adhesive adjunct; in addition, the tension should be distributed along the entire tape to prevent blisters [Table 2].

Advantages

Suture-less skin closure with adhesive tape can prevent local skin tension, decrease the overall cost and reduce the time spent in the operation room. Moreover, this technique allows for faster restoration of tensile strength equal or superior at 10 days than with sutured wounds.[20] Skin tension is equal throughout the length of the incision and this method avoids post-operative "railroad track" scarring from sutures.[17] Microporous strips allow the passage of gas and water from the skin surface, which make the environment unsuitable for bacterial proliferation and therefore lead to less wound infections.[19] Carpendale *et al*., and Marples *et al*., demonstrated that wounds closed with skin tapes were resistant to infection.[21,22] In addition, Conolly *et al*., reported a lower rate of infection for taped wounds (3.8% vs. 14% for sutured wounds) in patients with clean contaminated wounds.[23]

Disadvantages

Tapes were reluctantly used routinely in the early years following their introduction, because of unacceptable variability and poor reliability in their adhesive properties.[24] They can lose their adhesiveness with time, thereby leading to wound dehiscence. The variability in adhesiveness is related to the difference in the skill and knowledge of the operator using the tape. The major disadvantages of tape are the difficulty to ensure accurate skin edge apposition and skin edge eversion.[19] Furthermore, the operating room time-saving advantage has been questioned.[19] Gibson *et al*., found that skin edges were often difficult to approximate accurately.[25] To secure adhesion of the tape, skin edges must be dry and strict haemostasis must be absolute.[19] Adhesive tape

Table 2: Uses, advantages and disadvantages of adhesive tapes

Uses	Advantages	Disadvantages
As adjunctive wound support	Prevent the local skin tension	Unacceptable variability
In conjunction with buried dermal sutures	Less wound infections	Poor reliability in their adhesive properties
With absorbable running Subcuticular sutures in low-tension wounds	Avoid the post-operative "railroad track" scarring	Lose their adhesiveness with time, thereby leading to wound dehiscence
	Maintains faster restoration of tensile strength	Difficulty to ensure accurate skin edge apposition and skin edges eversion
	Skin tension is equal throughout the length of the incision	Adhesiveness is related to the skill and knowledge of the operator using the tape
	Decreases the overall costs	Adhesive tape can cause injury to the epidermis during placement or removal
	Reduces the time spent in the operation room	

can also cause injury to the epidermis during placement or removal. A study by Sarifakioglu *et al*., compared the adhesive strength of tincture of benzoin and transparent film dressing spray, clearly demonstrating that the tincture of benzoin increases the adhesiveness of adhesive tapes by approximately 7-fold, whereas only a 2-fold increase was observed using transparent film dressing spray.[17]

Sutures

Egyptian scrolls dating back to as early as 3500 BC described wound closure using suture material.[26] In the past centuries, there have been many suture materials, including animal tendons, horsehair, leather strips, vegetable fibres, and human hair.[27] In 1806, Philip Syng Physick developed a sturdy absorbable suture made from buck skin,[27] essentially inventing the modern technique of suturing. From time to time in surgical literature, there have been discussions of 'the ideal suture material'. For skin repair, the ideal material should be inert in the tissue, induce no foreign body reaction, have a fine calibre and a smooth surface, and be strong and easy to handle. In addition, it should possess secure knotting characteristics and minimal trauma should result from its insertion. Furthermore, suturing material must have certain handling qualities to be effectively used.[28] Suture strength, infection risk, tissue-holding power, incision type and suturing technique are important factors for deciding the type of suture for wound closure.[28] Sutures or staples are used most commonly because they provide the needed mechanical support.[28] A wide choice of suture materials is available to surgeons today. The choice of suture for a particular procedure should be based on the known physical and biological properties of the suture material, suturing technique and the healing properties of the sutured tissues. However, the availability of the suture material and the personal preference of the surgeon play important roles.

Types of sutures

Sutures available today are classified as permanent or absorbable, natural or synthetic, and multi-filament or monofilament. Multi-filament or braided sutures are easy to handle and have favourable knot-tying qualities. However, bacteria can enter the braided interstices and escape phagocytosis, potentially leading to suture infection, granulomas and sinuses. By contrast, monofilament sutures cause significantly fewer tissue reactions and glide easily through tissue.[29] Their disadvantages include high retention of package shape, difficult handling, knot insecurity, and potentially cutting through tissue [Table 3].[30]

Absorbable suture materials

Absorbable sutures are characterised by the loss of most of their tensile strength within 60 days after placement. They should be absorbed with little or no tissue reaction at a predictable rate appropriate for the duration of the needed tissue support. They are used primarily as buried sutures to close the dermis and subcutaneous tissue and to reduce wound tension. Absorbable sutures traditionally have not been recommended for skin closure, primarily due to unsightly railroad track formation. The only natural absorbable suture available is surgical gut or catgut sutures. Synthetic multi-filamentous materials include polyglycolic acid (Dexon; Syneture) and polyglactin 910 (Vicryl; Ethicon). Monofilamentous forms include polydioxanone (PDS; Ethicon), polytrimethylene carbonate (Maxon; Syneture), poliglecaprone (Monocryl; Ethicon), glycomer 631 (Biosyn; Syneture) and polyglytone 6211 (Caprosyn; Syneture) [Tables 4 and 5].

Non-absorbable suture materials

Non-absorbable sutures are characterised by their resistance to degradation by living tissues, and they are most useful in percutaneous closures. Surgical steel, silk, cotton and linen are examples of natural materials. Synthetic non-absorbable monofilament sutures are most commonly used in cutaneous procedures and include nylon, polypropylene and polybutester. Synthetic non-absorbable multi-filament sutures composed of nylon and polyester are used infrequently in dermatologic surgery [Tables 4 and 6].

In general, braided sutures potentiate more infections than non-braided sutures. Contaminated wounds closed by a braided Vicryl™ suture resulted in a 100% wound

Table 3: Advantages of non-absorbable monofilament sutures

Easy gliding through tissue
Easy handling
Unlikely to break prematurely
Elicit minimal inflammatory response
Advantages of absorbable sutures:
No need for suture removal
Save time
Decrease patient anxiety and discomfort.
Easy to handle
Have low reactivity
Excellent tensile strength

Table 4: Types of non-absorbable sutures and absorbable sutures

Non-absorbable sutures	Absorbable sutures
Surgical steel	Surgical gut or catgut.
Silk	Polyglycolic acid (Dexon; Syneture)
Linen	Polyglactin 910 (Vicryl; Ethicon)
Nylon	Polydioxanone (PDS; Ethicon)
Polypropylene	Polytrimethylene carbonate (Maxon; Syneture)
Polybutester	Glycomer 631 (Biosyn; Syneture)
Coton	Polyglytone 6211 (Caprosyn; Syneture)
	Poliglecaprone (Monocryl; Ethicon)

Table 5: Commonly used absorbable sutures. (courtesy of Elsevier: Bolognia J (2008) DERMATOLOGY. 2nd ed. Mosby Elsevier)

Suture	Configuration	Tensile strength	Ease of handling	Knot security	Tissue reactivity	Uses
Surgical gut (plain)	Virtually monofilament	Poor at 7-10 days	Fair	Poor	Moderate	Rarely used today in skin
Surgical gut (chromic)	Virtually monofilament	Poor at 21-28 days	Poor	Poor	Less than plain	Skin grafts; surface sutures for mucosae
Surgical gut (fast-absorbing)	Virtually monofilament	50% at 3-5 days	Fair	Poor	Low	Skin grafts, surface sutures
Polyglycolic acid (Dexon®)	Braided	20% at 21 days	Good	Good	Low	
Polyglactin (Vicryl®, Polysorb®)	Braided	75% at 14 days; 50% at 21 days	Good	Fair	Low	Subcutaneous closure, vessel ligature
Polydioxanone (PDS II®)	Monofilament	70% at 14 days; 50% at 30 days; 25% at 42 days	Poor	Poor	Low	Subcutaneous closure (high- tension areas)
Glycolide and trimethylene carbonate (Maxon®)	Monofilament	81% at 14 days; 59% at 28 days	Fair	Good	Low	Subcutaneous closure (high- tension areas)
Poliglecaprone 25 (Monocryl®)	Monofilament	50-60% at 7 days	Good	Good	Minimal	When minimal tissue reactivity is essential
Glycomer 631 (Biosyn®)	Monofilament	75% at 14 days; 40% at 21 days	Good	Poor	Minimal	Subcutaneous closure (high- tension areas)

Table 6: Commonly used non-absorbable sutures. (courtesy of Elsevier: Bolognia J (2008) DERMATOLOGY. 2nd ed. Mosby Elsevier

Suture	Configuration	Tensile strength	Ease of handling	Knot security	Tissue reactivity	Uses
Silk	Braided	None in 365 days	Gold standard	Good	Moderate	Mucosal surfaces
Nylon:						
Ethilon®	Monofilament	Decreases 20% per year	Good to fair	Poor	Low	Skin closure
Dermalon®	Monofilament	Good	Good to fair	Poor		
Surgilon®	Braided	Good	Good	Fair		
Nurolon®	Braided	Good	Good	Fair		
Polypropylene (Prolene®, Surgilene®, Surgipro®)	Monofilament	Extended	Good to fair	Poor	Minimal	Running subcuticular suture
Polyester (Dacron®, Mersilene®, Ethibond®)	Braided	Indefinitely	Very good	Good (coating decreases)	Minimal	Mucosal surfaces
Polybutester (Novafil®)	Monofilament	Extended	Good to fair	Poor	Low	

infection rate. By contrast, contaminated wounds closed by non-braided sutures showed a significantly reduced incidence of wound infection.[30] Many surgeons prefer non-absorbable monofilament sutures for their easy gliding through tissue, easy handling, minimal inflammatory response and unlikeliness to break prematurely.[29] Other surgeons prefer absorbable sutures because there is no need for suture removal, and they save time and decrease patient anxiety and discomfort.[29] The main disadvantage of non-absorbable sutures is the need for their removal between 5 and 10 days after being placed. This requirement necessitates an additional physician visit, often leading to missed work and higher cost. LaBagnara, in his review of absorbable suture materials used in head and neck surgery, noted that absorbable sutures are easy to handle, have low reactivity and excellent tensile strength, and cost less than non-absorbable sutures.[26] Several other studies comparing absorbable and non-absorbable sutures showed that there are no significant differences with respect to wound appearance and infection rates, concluding that clean facial wounds have very low infection rates regardless of the method of repair.[27] Luck *et al*., reported no clinically significant differences in cosmetic appearance between absorbable and non-absorbable sutures after 3 months.[27] Karounis *et al*., also did not detect any clinical difference in cosmetic scores between plain catgut versus nylon sutures in paediatric lacerations after 4-5 months.[31] They found that the three-point corner stitch had the highest capillary blood flow at the tip in the early post-operative period.[32] In comparison with absorbable sutures, monofilament nylon sutures diminish the risk of hypertrophic scarring mainly in sternotomy scars.[33] Three out of five randomised controlled trials comparing staples with sutures found that the complication rate was lower with sutures.[34] Interestingly, two of the five studies found sutures to be superior cosmetically.[34] Shetty *et al*., reported a higher rate of complication in superficial wounds closed with metallic staples than those with subcuticular vicryl.[35] Parell and colleagues concluded that there were no differences in the long-term cosmetic results of repairs with permanent or absorbable suture material in adult patients with clean wounds of the face or neck.[28]

Vicryl, a synthetic absorbable suture, is composed of a polymer of glycolide and lactide coated with a mixture of glycolide, lactide and calcium stearate.[36]

There is a new formulation of Vicryl called Vicryl Rapide, which consists of smaller molecules of the same components as Vicryl.[37] Vicryl Rapide is produced by gamma irradiation of polyglactin 910, which degrades more rapidly than Vicryl.[37] Its tensile strength is reduced by 50% after 5 days, in comparison to Vicryl, which has a 35% reduction at 14 days; furthermore, there is no traction left after 14 days.[37] Vicryl Rapide is fully absorbed after 42 days, whereas Vicryl takes around 56-70 days.[38] Irradiated polyglactin 910 is advantageous for its low inflammatory properties and rapid degradation in 7-10 days, thus precluding the need for suture removal.[39] The characteristics of irradiated polyglactin 910 make it ideal for full-thickness skin grafts. Linberg found an equal efficacy of Vicryl and nylon sutures in preventing wound dehiscence in an *in vivo* rat model of oculoplastic surgery.[40]

Joshi and co-authors carried out a prospective randomised study to evaluate different suture techniques for closure of blepharoplasty incisions.[41] They found significant differences between suture materials and techniques and concluded that a fast-absorbing gut suture along with two interrupted Prolene sutures had the lowest rates of complications and the best cosmetic results [Table 7].[41]

Stapler

Disposable mechanical skin staplers are a rapid and effective method for closing long skin incisions. A three- to four-fold reduction in the time for skin closure was noticed with staple use for wound closure; however, more time is required for their removal post-operatively.[42,43] The Insorb™ (Incisive Surgical, Inc., Plymouth, MN) dermal stapler is a U.S. Food and Drug Administration–approved device for wound closure. [Figure 1]

Absorbable staples were designed as an alternative to sutures for closure of surgical wounds. These devices are U-shaped absorbable staples composed of a polylactic/polyglycolic copolymer, which maintains 40% of its strength at 14 days and is completely absorbed over a period of months (tissue half-life of 10 weeks).[44] These skin staplers are placed in the sub-cuticular tissue to hold the wound together without puncturing the epidermis and are designed to combine the cosmetic result of absorbable sutures with the rapid closure times in addition to eliminating the need for metal staple removal post-operatively.[29] External skin staples penetrate the epidermis on both sides of the incision to provide closure and might cause skin irritation, discomfort to the patient, require painful removal and leave puncture holes in the epidermis that may result in unacceptable scarring [Table 8].[29] External staples carry the risk of wound contamination since the epidermal integrity is breeched.[29] For contaminated wounds, Insorb™ staples were found to be superior to Vicryl™ sutures because they have a lower incidence of infection.[29] The Insorb™ staples may be superior to metal staples with respect to inflammation, pain and cosmetic outcome.[29] Fick and colleagues showed superior outcomes of the dermal stapler device compared with absorbable dermal sutures in animal models, including reduced inflammatory response, improved wound healing and cosmetic appearance.[45] In addition, in a porcine model of skin wounds contaminated with *Staphylococcus aureus*, incisions closed with the dermal stapler resulted in a 67% reduction in wound infections and harboured significantly fewer bacteria than braided absorbable sutures.[29] Cross *et al*., conducted the first reported randomised, controlled, and blinded clinical study of the absorbable dermal stapler in human subjects.[46] Their study demonstrated that closing the skin with the absorbable dermal stapler can have many advantages, such as reduced operating room and anaesthesia time and cost-effectiveness; in addition, this method can provide safe and consistent surgical results with good cosmetic benefits.[46]

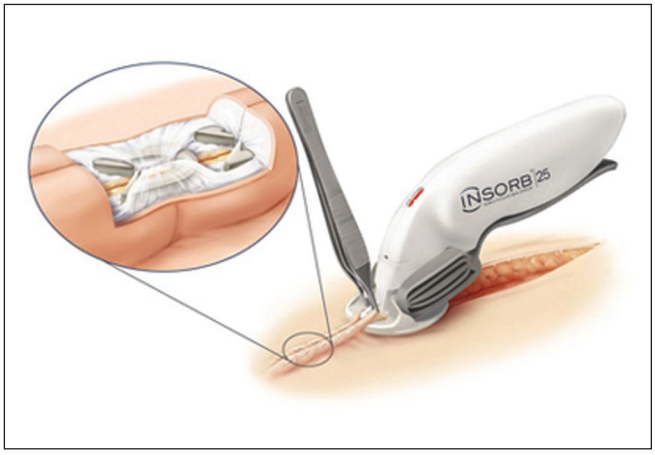

Figure 1: INSORB dermal stapler. (courtesy of Insorb company)

Table 7: Factors involved in choosing sutures

Suture strength
Risk of infection
Tissue holding power
Incision type
Suturing technique
Healing properties of the sutured tissues
Availability of the suture material
Personal preference

Table 8: The advantages and disadvantages of external skin staple

Advantages	Disadvantages
Rapid and effective method for closing long skin incisions	Penetrates the epidermis which may result in unacceptable scarring
Three- to four-fold reduction in time for skin Closure	Skin irritation
	Discomfort to the patient
	Requiring painful removal
	Risk of wound contamination

Tellis *et al*., studied the use of absorbable sub-cuticular staples in renal transplant incision, concluding that they are secure and effective and therefore preferable to metal staple closures even in renal transplant recipients receiving immunosuppressants.[47]

Although the absorbable sub-cuticular skin staplers are easy to use and yield a cosmetically acceptable results and time savings in the operating room, they have not been tested for long-term cosmetic results and cost around $25 for each patient [Tables 9].[48]

Miscellaneous

Surgical zipper

A new form of non-invasive skin closure system, the Medizip surgical zipper, was introduced to the field.[27] [Figures 2 and 3] Rookler *et al*., reported no significant differences in the cosmetic results or complications of the scar in comparison with sutures.[44] The zipper could be a safe alternative to conventional suture material for skin closure.[27] The zipper is useless in high-tension or wet wounds, wounds with substantial curves of more than 20 degrees and in obese patients.[27] There are many advantages in using Medizip, including that it can be opened for wound inspection. In addition, this technique is comfortable for the patient, reduces the time for skin closure in the operating room and does not need removal, and therefore potentially enhancing the cosmetic outcome. This method is very useful in paediatric patients and adults affected by neoplastic disease.[49] Onuminya and colleagues carried out a randomised controlled prospective study to evaluate the outcome of the Medizip surgical zipper technique.[49] They reported that the Medizip surgical zipper is preferable in the closing of surgical wounds with regard to the cosmetic outcome of scars and associated problems.[49] Roolker and co-authors concluded that Medizip presents a safe option for surgical wound treatment as a non-invasive skin-closure system.[44] Massone *et al*., demonstrated that Medizip is an effective skin-closure system because it is easy and quick to handle, it exhibits favourable cosmetic results and it entails non-invasive removal. Its use is of especially great value in paediatric and young oncology patients receiving combined treatments [Table 10].[50]

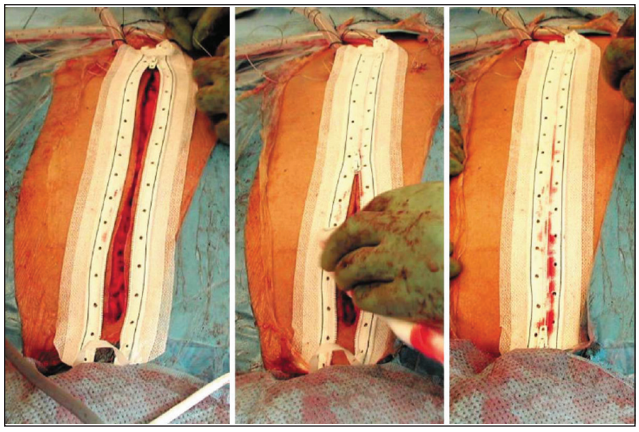

Figure 2: Medizip surgical zipper showing the method of puncture-free skin closure (courtesy of Elsevier: Eur J Cardiothorac Surg. 2002 Aug;22(2):271-7)

Laser tissue bonding

Different types of laser welding/soldering techniques were tried to increase the quality of healing for skin

Table 9: The advantages and disadvantages of INSORB dermal stapler

Advantages	Disadvantages
No epidermal puncture	Untested for its cosmetic results (long-term more than 1 year),
Reduced operating room and anaesthesia time	It costs around $25 to each patient
No need to remove staples	
A lower incidence of infection	
Better wound healing	
Ease of use	
Cosmetically acceptable result	

Table 10: Advantages and disadvantages of surgical zipper

Advantages	Disadvantages
It can be opened for wound inspection	Useless in high tension
Comfortable for the patient	Not to be used in wet wounds
Reduce operating time for skin closure	Useless in wounds with substantial curves of more than 20 degrees
There is no need to remove suture material	Not to be used for obese patients.
Very useful in paediatric patients	
Useful in adults affected by neoplastic disease	
Ease of handling	
Very good cosmetic results	

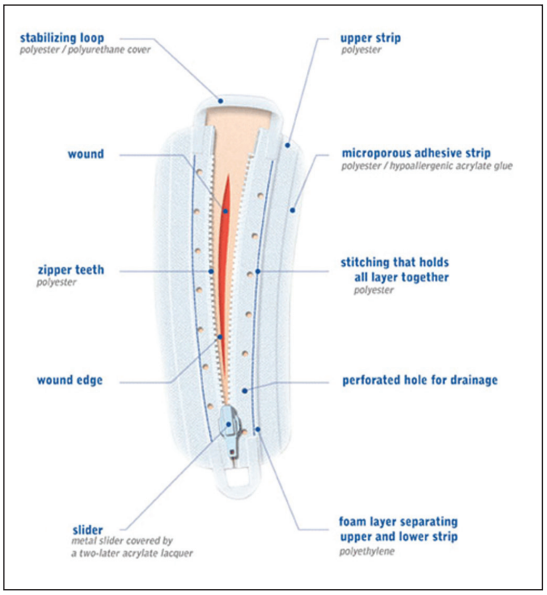

Figure 3: The structure of the SURGIZIP™ Surgical Zipper (courtesy of SURGIZIP™)

incisions. The use of wavelength-specific dye-absorbers such as indocyanine green (ICG) and adhesive proteins such as albumin to laser welding process may lead to faster and stronger close up of tissues than the traditional suture technique.[51] Various types of laser systems were investigated.[52] In all biological tissues, water is the main constituent (65.3%) and the water absorption capability becomes an important parameter for the laser wavelength choice.[53,54] Holinium:YAG and CO_2 lasers are highly absorbed by water, causing sudden increase in temperature, which may result in undesired, irreversible tissue damage or carbonisation.[55,56] For this reason, they need to be used under a temperature-controlled system. Nd:YAG (1,064 nm) is another infrared laser used in tissue welding, due to its water and melanin absorption coefficient values.[57] It can be used with or without albumin soldering.[58] Also, diode lasers are becoming more popular in welding studies. The welding effect of 780-830 nm diode lasers is enhanced by using ICG–albumin mixture, because diode laser alone does not cause enough tissue temperature increase for welding.[59] High absorption by water in the near-infrared region can be achieved by using high-power 980-nm diode laser compared to other (780-nm diode, 815-nm diode, 1,064-nm Nd:YAG, and 10,600-nm CO_2) infrared laser sources.[57]

A fast and efficient method for wound closure, laser-assisted tissue bonding (LTB) was recently developed.[52,60] This technique can be subdivided into two main sub-phases: (1) photochemical tissue bonding (PTB) and (2) photothermal tissue bonding. The latter can be further sub-divided into two different systems: laser tissue welding (LTW) and laser tissue soldering (LTS).[61] In LTW, concentrated laser energy is introduced to the apposed wound margins that causes their initial liquefaction and is followed by fusion of the two edges. By contrast, LTS, which refers to a protective proteinaceous barrier (e.g. semi-solid/solid serum albumin), uses an additional component known as a 'solder' that enhances the adherence of the two wound margins.[62] The conversion of photonic energy into heat energy takes place during laser tissue welding,[63] causing a thermal effect during laser welding and thus promoting adhesion of tissue edges; in addition, the collagen fibres are altered and become fused, intertwined, swollen and dissolved.[56,64] Different types of laser welding/soldering techniques have been tried to increase the quality of healing for skin incisions.[65] Katzir *et al*., hypothesised that the use of IR-based optic fibres, with a non-contact temperature measuring system and the use of albumin as a solder, may improve tensile strength and eliminate thermal injury.[60] Bass and McNally suggested that laser heating of collagen strand fibres on both sides of the wound margins will induce them to intertwine and generate an immediate wound seal followed by immediate integration of the extracellular matrix network,[52] therefore resulting in faster re-epithelialisation and reduced granulation tissue formation and fibroplasia, as demonstrated by scar width and macroscopic appearance. The use of wavelength-specific dye-absorbers such as indocyanine green (ICG) and adhesive proteins such as albumin to the laser welding process may lead to faster and stronger close up of tissues than the traditional suture technique.[51,61,62]

Laser-assisted tissue bonding (LTB) offers a fast and efficient method for incision closure, thereby diminishing scar formation and reducing the development of complications. Experimental and clinical data have accumulated to support the concept of performing laser tissue soldering for improved wound healing after reconstructive surgery.[63] The laser soldering system has been applied in several animal models for vascular, skin, intestinal, ureteral, corporeal body, dural, urethral, vesical and vas-epididymal anastomoses.[64] Kirsch *et al*., used laser tissue soldering via a low-power laser coupled to a protein solder for repair of hypospadias, aiming to decrease the complications of conventional suturing.[64] Their results indicate that repair of hypospadias by laser tissue soldering can be performed in a nearly suture-less fashion and more rapidly than conventional suturing.[64] In addition, several animal studies showed that using fewer sutures in the laser group results in reduced inflammatory responses.[64] Therefore, compared with conventional methods, laser soldering may be a better approach to close wounds.[64] Using injured skin of small laboratory porcine models, Simhon *et al*., found that sutured incisions resulted in notably thicker scars with crosshatch marks compared with soldered incisions, resulting in thinner and almost undetectable scars as early as 7 days post-operation [Table 11].[66]

Table 11: The advantages and disadvantages of the temperature-controlled laser soldering procedure

Advantages	Disadvantages
Minimal tissue handling	Impaired wound healing
Maximal tissue alignment	Low initial tensile strength
Water-tightness	Decrease long-term tensile strength
Early re-epithelialisation	
Maximal tensile strength during early healing	
Absent foreign body reaction	
Minimal scar formation	
Procedure faster and relatively non-operator-dependent	
Faster and more efficient wound repair, which could shorten hospital stay and reduce post-operative complications	
Improved cosmetic results without crosshatch marks across the suture line	
A needle-free alternative	
Avoids the need for stitch removal with its discomfort	

Table 12: Evidence based uses of different wound closure materials

Tissue adhesives	Adhesive tapes	Vicryl rapide and fast absorbing gut sutures	Insorb™ staples	Surgical zipper	Laser bonding
Lacerations	Adjunctive wound support	Skin grafts	Contaminated wounds	Wounds need frequent inspection	Repair of hypospadias
Paediatric patients	Lacerations	Blepharoplasty	Long wounds	Oncology patients	
Laparoscopic wounds	Clean contaminated wounds	If suture removal visit is difficult or not possible			
Lacrimal punctum closure					
Closure of cerebrospinal fluid leaks					

Advantages

The temperature-controlled laser soldering procedure (TCLS) was shown to be advantageous over the traditional tissue-bonding modalities.[56] The major claimed advantages of the TCLS system are: (1) minimal tissue handling; (2) maximal tissue alignment; (3) water tightness; (4) early re-epithelialisation; (5) maximal tensile strength during early healing; (6) no foreign body reaction; (7) minimal scar formation; (8) faster and relatively non-operator-dependent procedure; (9) more efficient wound repair, which could shorten hospital stay and reduce post-operative complications; (10) improved cosmetic results without crosshatch marks across the suture line; (11) a needle-free alternative; (12) avoids the need and discomfort of stitch removal and (13) compatibility with minimally invasive surgery.[65]

Disadvantages

Only a few studies of LTB have been conducted in human subjects,[64] perhaps because of its perceived potential for thermal damage, resulting in impaired wound healing.[52] Another concern for LTB is its low initial tensile strength and the weak long-term tensile strength. In addition to the cost of equipment and required technology that may not be available to all practitioners, which preclude its routine use in clinical practice.[67]

CONCLUSION

Many factors are involved in the choice of the skin closure material, including the type and place of the wound, available materials, physician expertise and preferences, patient age and health. Table 12 provides the main uses of different skin closure materials for helping surgeons choose the appropriate material for different wounds according to the best available evidence.

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