Critical Analysis of Varying Sutures and Impact on Cost Efficacy in Orthopaedic Surgery

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Objectives: Describe basic differences in sutures and the overall impact on cost efficacy.

Design: Review.

Intervention: Suture choice.

Main Outcome measurements: Cost.

Results and Conclusions: It is important for a surgeon to consider the advantages of various sutures and needles to ensure proper primary approximation, prevent infection or dehiscence, and close in a time-efficient manner. Modern-day sutures can be divided into three main categories: natural vs synthetic, monofilament vs multifilament, and non-absorbable vs absorbable. A newer monofilament barbed suture has been given increasing attention, as it reduces procedural times and ultimately operative costs.

Level of Evidence: IV, Review

Keywords: suture, barbed, cost, orthopaedic surgery, orthopedic surgery, cost analysis

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INTRODUCTION

Utilization of organic materials in closure of incisions and wounds dates back thousands of years.[1] Ancient Egyptians utilized hairs, plant fibers, tendons, and wool threads as suture materials. The oldest known surgical writing in civilized history, the Edwin Smith papyrus, describes the use of two strips of linen to stitch open wounds. The *Samhita*, the first known document to specifically discuss suture techniques, describes the use of suture made from a sheep's upper intestine. It was not until the late 19th to early 20th centuries that formal investigation into absorbable sutures began. Infection was still an issue with use of sutures at this time. Lord Joseph Lister developed one of the first techniques for sterilizing suture material: a crucial step towards the widespread use of sutures that we see today.[1]

There are now a large variety of sutures for surgeons to choose from ranging from natural to synthetic, monofilament to multifilament, non-absorbable to absorbable, and more recently, additional barbed subtypes (Figure 1). Each suture type has its advantages and disadvantages, and surgeons should have an appropriate understanding for best practice utilization. In addition, there are cost implications for suture choice in terms of operating room time, surgical complications due to suture failure, and clinic time to remove sutures. This review describes basic differences in sutures and the overall impact on cost efficacy.

Figure 1. Subclassification of various types of modern sutures available for use.

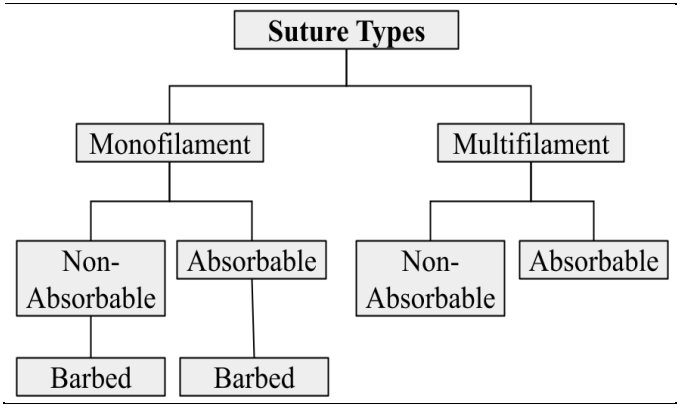


Figure 2. Comparison of unidirectional and bidirectional barbed sutures. Both variations are composed of barbs proceeding in a helical fashion, often as paired barbs as depicted, although may also be unpaired as well.

Unidirectional Barbed Suture

Bidirectional Barbed Suture

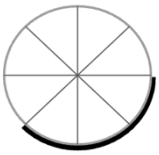
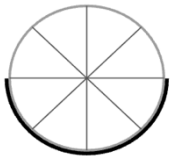
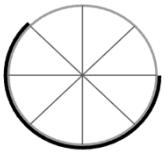
METHODS

A search was performed through MEDLINE (PubMed) for English-language literature regarding "suture cost analysis." Each abstract was independently reviewed by the authors. Articles with expected relevance were queried for full manuscript extraction and formally reviewed.

RESULTS

Initial search resulted in 819 possible articles for inclusion. Title review by two authors (J.I. and K.P) yielded 45 articles relevant to suture specific research. After abstract and full manuscript review, a total of 32 articles were considered appropriate for final review. Pertinent information was organized into appropriately fashioned subsections for individual suture and needle considerations and cost analysis.

Figure 3. Needle curve length differentiation and common uses.

3/8 Circle	1/2 Circle	5/8 Circle
		
Common uses: superficial skin closure, fascia, muscle	Common uses: deep cavities	Common uses: deep cavity, oral cavity, urogenital tract, anus

DISCUSSION

Monofilament Versus Multifilament Sutures

This decision for appropriate filament composition is based on incision location, size and appropriate tensioning for adequate closure. There are two types of suture configuration that are used to close incisions: monofilament and multifilament. Monofilaments are sutures that are composed of one strand while multifilament sutures are made up of multiple strands that are twisted or braided together.[2]

Monofilament sutures characteristically have a lower resistance when passing through tissue because there is only one smooth gliding surface moving through tissue. Monofilament sutures are therefore ideal for microvascular anastomotic surgeries and nerve repairs which requires a tensionless repair.[3] Additionally, monofilament sutures have a lower surface area and therefore lower potential to harbor bacteria, making them the preferred choice in infectious operative cases.[4] Care must be taken when using monofilament sutures because they are easily crushed with instruments, such as the needle driver, causing them to become thin and break.

On the other hand, the benefits of multifilament sutures include increased tensile strength, flexibility, and pliability, and improved handling when tying knots.[5,6] However, due to the braided configuration of the multifilament sutures, there is an increased risk of infection. The theory behind this is two-fold: (1) the braided design of multifilament sutures increases the overall suture surface area and therefore the likelihood of bacteria to attach to the material and (2) the design increases the capillarity of the material.[6,7] Capillarity refers to the suture's ability to wick and absorb surrounding fluid from the rough-cut ends of suture material. Multifilament sutures have an inherently increased capillarity due to the increased number of filaments, therefore monofilament sutures are more commonly used in cases with infection.

In effort to decrease colonization of the suture, the use of suture coating has become increasingly common among multifilament sutures. This coating improves the ease of the suture to pass through tissue but also contains antibacterial properties.[8] One of the common broad-spectrum antibacterial agents used is triclosan, which works by blocking fatty synthesis in bacteria.[9] Triclosan has been in use since 2002[10] to reduce surgical site infection[11] with proven efficacy in colorectal surgery.[12] A systematic review investigating the use of triclosan-coated sutures in a variety of different surgical subspecialty procedures found that surgical site infections were significantly reduced with its use compared to uncoated sutures.[10] However, Fowler and colleagues demonstrated that general multifilament suture material (Vicryl™ and Vicryl™ Plus Antibacterial; Ethicon Inc, USA) had the highest number of colony-forming units of bacteria compared to other monofilament and barbed sutures.[13] Presently, clinical guidelines vary on the routine use of triclosan-coated sutures with the support of the World Health Organization, however the Infectious Diseases Society of America has not advocated for its use.[14] Despite this, coated multifilament sutures are the preferred closure method for many surgeons.

Non-Absorbable Versus Absorbable Sutures

The use of non-absorbable versus absorbable sutures depends on specific wound or incisional factors including location of the lesion, presence of infection and likelihood of the patient to return for suture removal. According to Weitzel and Taylor, the definition of an absorbable suture is one that loses its tensile strength within 60 days of being placed into the tissue, whereas non-absorbable sutures maintain their tensile strength longer than 60 days.[6] Apart from surgical stainless steel, all sutures will undergo some degree of absorption the longer the suture stays in the body.

Table 1. Absorption rates of ***natural-derived*** absorbable sutures.

Suture	Tensile Integrity	Complete Absorption	Comments
Surgical gut, plain	7 to 10 days	70 days	
Fast-absorbing surgical gut	3 to 7 days	21 to 24 days	Treated with heat to increase absorption; however, this process decreases the tensile strength
Chromic surgical gut	10 to 21 days	90 days	Treated with chrome tanning salt: crosslinking the collagen molecules in the suture Avoid use in patients with chromate allergy

Table 2. Absorption rates of ***synthetic-derived*** absorbable sutures

Suture (Brand Name)	Longevity of Tensile Strength	Complete Absorption	Comments
Polyglactin 910 (Vicryl™)	50% at 3 weeks	56 to 70 days	In 2003, added triclosan this suture as an antibacterial agent (Byrne & Aly 2019)
Polyglactin 910 (Vicryl Rapide™)	50% at 5 days	42 days	Lower molecular weight compared to Vicryl™ because treated with gamma rays for sterilization (Byrne & Aly 2019, Muffly 2011)
Polydioxanone (PDS II™)	50% at 4 weeks, 25% at 6 weeks	90 to 180 days	Updated version of PDS™, increased handling compared to previous version
Polytrimethylene carbonate (Maxon)	50% at 4 weeks, 30% at 6 weeks	60 to 180 days	Higher initial tensile strength compared to PDS but has faster absorption
Poliglecaprone 25 (Monocryl)	30% at 2 weeks, Complete loss 4 weeks	90 to 120 days	Has the highest knot security of all synthetic absorbable sutures

Absorbable sutures are utilized under the premise that the body will eventually remove the suture through an inflammatory process. The natural-derived absorbable sutures (Table 1) are broken down in the body via immune reactions resulting in proteolytic degradation. On the other hand, the synthetic-derived absorbable sutures (Table 2) undergo breakdown through hydrolysis. Proteolysis is a more rapid degradation than that of hydrolysis and, in the presence of infection, the breakdown of the suture is more rapid as there is an increase in the release of proteolytic enzymes in infectious extracellular milieu.[15] Therefore, many surgeons choose the synthetic-derived absorbable PDS suture over a natural-derived chromic gut to ensure a more delayed degradation of suture material in the setting of infection.

Absorbable sutures are also preferable in patients that are less likely to be able or are unwilling to return for suture removal. While the use of absorbable sutures may require increased operative closure time, there is a decreased requirement for wound care in the early postoperative period which may allow for shorter hospital stays.[16] Further, absorbable sutures have shown to reduce the risk of wound drainage by inhibiting sinus or fistula formation.[17]

Non-absorbable sutures maintain their tensile strength for a much longer period compared to absorbable sutures and often are considered to have superior handling characteristics. The body responds to non-absorbable sutures by forming a fibrous capsule around the suture material which slows the degradation to a decreased rate when compared to absorbable sutures. Surgical stainless steel is a type of natural non-absorbable suture that has indefinite tensile strength and lacks toxic elements; however, this material must be avoided in individuals with allergies to chromium or nickel. Additionally, use of surgical stainless steel has a potential to tear tissue and injure skin. Despite this risk, surgical stainless steel is sometimes utilized in gynecologic procedures as retention sutures or for complex anterior abdominal closures.[1]

An example of a synthetic-derived non-absorbable multifilament suture is the polyethylene terephthalate suture (Ethibond Excel™; Ethicon, Inc). Ethibond Excel™ is preferred by orthopedic surgeons for repairing ligaments and tendons due its non-absorbable characteristics to accommodate the delayed healing of relatively avascular tendons and ligaments. However, Ethibond Excel™ is not ideal for procedures such as body contouring surgery or the removal of excess skin after soft tissue removal due to the increased risk of sinus formation and granulation tissue formation from the persistent foreign body.[5]

Barbed Sutures

The intention of the barbed suture's development was to decrease the need for knots which frequently cause pressure ischemia and potential necrosis, the leading cause of wound dehiscence.[18,19] The first barbed suture was developed in 1964 by a general surgeon named Dr. John Alcamo. It was a unidirectional barb, a direct mimic of the design seen in nature in that of a rose bush. Dr. Alcamo designed the suture for use in a sinusoid pattern, with the hope that the barbs would provide a more even distribution of tension throughout the tissue. Though promising, the use of the unidirectional barbed suture was restricted because the surgeon was still required to knot for proper anchorage, and the design was abandoned for a period time until the bidirectional barbed suture. First introduced by plastic surgeons, bidirectional barbed suture was originally designed for cosmetic facial surgeries, specifically that of the brow and neck.[20] Due to having higher

number of points of fixation than traditional sutures, properly placed barbed sutures are able to maintain adequate tension on tissue which provides a better environment for wound healing.[21] The tension across a barbed suture is distributed evenly over the suture length. This is a feature that circumvents problems that knotted sutures inherently present. Knots introduce focused tension that creates an unbalanced pressure on a wound, increasing the inflammatory response and enzymatic degradation.[22,23] This pressure can lead to pressure-ischemia and necrosis, two main contributing factors for wound dehiscence, because the knots can impede blood flow to the tissue.[18,24]

As discussed, the barbed suture comes in two varieties, unidirectional and bidirectional with the latter being more commonly utilized. A bidirectional barbed suture consists of a small non-barbed segment in the center of the suture that is sandwiched between sections of barbs arranged in a helical pattern (Figure 2). The suture is introduced into the center of a wound where a small non-barbed tag is secured after a first pass, then the barbed sections can be used in a J-loop fashion to secure the lateral edges of the wound. The suture is used without knots as it "self-locks" when the barbed section is tensioned trough the surrounding soft tissue. The bidirectional barbed suture is primarily utilized and is available in in both absorbable and nonabsorbable formulas. The STRATAFIX (Ethicon, Johnson and Johnson, Somerville, New Jersey) Knotless Tissue Control suture device comes in multiple variations of the bidirectional barbed suture, as well as a heavy-duty unidirectional suture targeted at fascia and deep tendon repairs.

Bidirectional barbed sutures have proven to significantly decrease operation times in multiple fields of surgery including abdominoplasty, cesarean section, and total knee arthroplasty. This is due to quicker closing times due to the facilitation of continuous suturing and lack of a need for repetitive and time consuming knot tying.[24-26] Sutton and Schmitz reviewed barbed suture utilization and concluded that the use of a bidirectional barbed suture was associated with a shorter stay in the hospital and less resource intensive discharge status than was seen in the use of conventional sutures.[26] Barbed sutures now have the additional benefit of antibacterial coating which helps mitigate surgical site infections.[27] Additionally, since barbed sutures eliminate the need for bulky knots, there is less of a focal point for infections to seed with barbed sutures when compared to more traditional sutures.[24]

There is a small learning curve with transition to barbed suture use in the operative theatre. As with all surgical techniques, a surgeon will require training to learn how to adequately place a barbed suture for proper tensioning and locking of the suture material. Suture extrusion can occur with barbed sutures greater than a size 2.0 when placed inappropriately close to the superficial dermis and should not be used as final skin closure suture.[20] As with all sutures, infection, skin necrosis and wound dehiscence are all possible adverse outcomes of use of barbed sutures, however proper training may help mitigate these risks.

Needle Types

The ideal surgical needle serves a dual role of being strong enough to provide direction for the suture while maintaining ductility, and sharp enough to penetrate without yielding control. Most surgical needles are crafted from a stainless-steel alloy and heat treated for reinforcement in tensile strength. The balance of strength and ductility is particularly important to cosmesis, as the incident of a needle breaking during suturing can cause significantly more trauma to the tissue and lead to an unsatisfactory cosmetic result.[4] The needle is often coated with silicon to help maintain sharpness during multiple passes through tissue. Though needle choice is often based on a surgeon's experience and personal choice, however there are factors that suggest certain needle characteristics are superior for certain situations.

Figure 4. Needle tip differentiation and common uses.

Needle Types (cross section)	**Uses**
 Blunt Tip	Fascia closures, friable tissues such as liver
 Cutting	Fibrous tissue and skin
 Reverse Cutting	Fibrous tissue and skin
 Taper Point	Subcutaneous, gastrointestinal or vascular tissue, muscle, tendons, ligaments, fibrous tissue
 Taper Cut	Fascia, pericardium, fibrotic vessels

A curved needle requires the use of a needle driver but tends to require less space for manipulation than a straight needle and therefore is typically preferred.[5] Use of the smallest possible needle length typically provides the best results, however a smaller curve length can require a larger space for manipulation. A three-eighths circle is an optimal selection for a superficial skin closure and can be appropriately applied in fascia or muscle as well (Figure 3). However, the three-eighths needle would require significant rotational manipulation of the hand and wrist to be easily used in a deep cavity. The five-eighths circle or half-circle are more appropriate choices for a deep cavity. The five-eighths is not often utilized in orthopedic surgery however has clinical utility in areas such as the oral cavity, urogenital tract or anus.[28]

The tip of a surgical needle is specifically designed to optimally penetrate a specific type of tissue, and there are several popular designs. Blunt tip needles are optimal in reducing risk of injury to surrounding tissues or the surgeon.

The blunt tip needle is sharp enough to penetrate fascia and muscle without posing a threat to skin. It is the ideal choice in fascia closures to prevent injury to visceral organs and may also be used in friable tissue such as the liver. The cutting needle has a characteristic triangular body shape (seen in cross section of needle) that forms a strong guide with increased resistance to bending (Figure 4). By definition, a cutting needle has at least two opposing cutting edges and a fine, sharp point and thus is a good choice for tough, fibrous tissues and skin. A cutting needle with three cutting edges can be conventional, when the third cutting edge is on the concave portion of the needle or reverse when the third cutting edge is along the convex angle. The reverse cutting needle provides increased strength for the sutures as the third cutting edge faces away from the incision, leaving more tissue between the suture and the incision that traditionally left by a conventional cutting needle.

A taper-point needle is defined as a very fine point that dilates into an oval or round shape, and when introduced to tissue does not truly cut, instead separates the tissues to allow the passage of the suture (Figure 4). The smaller diameter tapered needle is ideal for soft subcutaneous, gastrointestinal or vascular tissue, though larger diameter needles can be used on tougher tissues to gently separate muscle, tendons, ligaments, or fibrous tissue. The taper-cut needle combines the ideas of the cutting point and tapered point to allow for directed penetration with minimal tearing in fibrous tissue. The taper-cut is proficient in leaving tiny holes without cutting, and therefore are ideal for fascia, pericardium and fibrotic vessels.[4]

Cost Efficacy of Sutures in Orthopedic Surgery

While many factors contribute to the overall cost and reimbursement of a surgical procedure, one of the largest contributors is the duration of the surgery. Because of this, a suturing method that decreases closing time can have a major impact on the cost of the surgery while also increasing overall productivity.[29] In the past decade several studies have been conducted to investigate the impact of the use of barbed sutures versus traditional sutures on the duration of surgery. Chan et al[21] conducted a study in 2017 comparing the operation time and overall cost of total knee arthroplasties that used the traditional interrupted suture versus the continuous, knotless barbed sutures. Chan theorized this comparison is valid because once in the tissue the barbed suture acts mechanically similar to the simple interrupted suture. The study found that both arthrotomy and subcutaneous closure time were significantly shorter in the cases utilizing the barbed suture. The total wound closure time averaged 4.0 minutes faster with the barbed suture and continuous knotless suturing method. The bulk of the time reduction with use of the barbed suture lies in the self-anchoring nature of the suture eliminating the need for knotting. An additional cost reduction offered by the barbed suture is the ease in which one individual can perform solitary closures, contrasting with traditional interrupted sutures which typically requires a "third hand" from a second individual to hold the tension while reloading the needle.[24,30] Another study found that after controlling for a patient's BMI, size of incision and number of surgeons, barbed sutures were associated with significantly decreased closure times than traditional sutures in a total joint arthroplasty.[31] Smith performed a cost analysis to clarify that while the barbed suture may cost more than traditional sutures, the decrease in operating times was so significant that the overall operating cost was decreased by an average of 549.59 USD by simply using a barbed suture.[31] Furthermore, Zhang and colleagues found that use of the barbed suture can reduce closure time by an average of 3.56 minutes and lower operating cost by 290.72 USD.[32] These significant reductions in overall operative cost and improved efficacy should be considered in any orthopaedic surgical practice.

One limitation to the aforementioned studies is a lack of direct comparison between running barbed suture to a running standard suture in addition to the interrupted standard suture. The reduction in estimated closure time between the two sutures could potentially be due to the technique (running versus interrupted). However, one randomized control trial compared running barbed suture to running standard suture in dermal closures and found no significant difference in closure times.[24] The absence of a significant difference in closure times was thought to have been due to the fact that at the time of the study, the barbed sutures available were not long enough to stitch up the entire incision. Therefore, two barbed sutures were needed for the closures in the experimental group compared to one standard suture needed for the closures in the control group. Further, since both groups used the running technique, the lack of significant difference could be explained by the technique used. In this same study, there was no proven advantage over traditional suture in cosmesis or pain scores. However, it can be assumed the tensile strength of the barbed suture in preventing dehiscence is superior to that of a running standard suture. Further investigation is warranted.

The majority of the randomized control trials found during literature review regarded use of the barbed suture in total knee arthroplasty. Further data is needed to verify if the cost efficacy seen in total joint replacement operations is reflected similarly across other orthopedic surgeries. Additionally, further studies are needed to determine if there are differences in suture abscess formation, surgical site infections, or dehiscence rates between barbed and standard suture.

CONCLUSION

The choice of suture used in the operating room must be carefully considered by the surgeon as there is an array of choices. Sutures may be natural- or synthetic-derived, monofilament or multifilament, absorbable or nonabsorbable, or barbed structured. A monofilament suture is the preferred choice in an infected area as the lower surface area

theoretically allows for less adhesion of microbes. Antimicrobial coatings on multifilament sutures provide some abatement from infection, however their utilization is primarily grounded in non-infected wounds with a need for higher suture tensioning. With the exception of surgical stainless steel, any suture will eventually be broken down by the body, though a non-absorbable suture will maintain its tensile strength for a longer period of time than an absorbable one. Absorbable sutures minimize the need for post-operative wound care and shorter hospital stays. Multiple studies on barbed sutures have exhibited significant decreases in operation time and thus overall procedure cost. With these considerations in mind, surgeons should continue utilize their clinical judgement and experience to determine the best suture for each operative circumstance.

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