

Contents lists available at [SciVerse ScienceDirect](http://www.sciencedirect.com)

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Barbed Versus Traditional Sutures: Closure Time, Cost, and Wound Related Outcomes in Total Joint Arthroplasty

Eric L. Smith, MD ^a, Steven T. DiSegna, MS ^b, Pinak Y. Shukla, MD ^c, Elizabeth G. Matzkin, MD ^d

^a Tufts Medical Center, Department of Orthopaedic Surgery, Boston, Massachusetts

^b Tufts University School of Medicine, Boston, Massachusetts

^c Tufts Medical Center, Department of Orthopaedic Surgery, Boston, Massachusetts

^d Women's Musculoskeletal Health, Brigham and Women's Hospital, Department of Orthopedic Surgery, Boston, Massachusetts

ARTICLE INFO

Article history:

Received 31 July 2012

Accepted 30 May 2013

Available online xxxx

Keywords:

barbed suture

Quill suture

cost

hip arthroplasty

knee arthroplasty

ABSTRACT

The purpose of this study was to compare barbed sutures to traditional sutures in three domains: time, cost, and wound related outcomes in total knee arthroplasty (TKA) and total hip arthroplasty (THA). A total of 34 patients were enrolled in a prospective randomized controlled trial to assess time to wound closure and cost. In addition, a retrospective chart review of an additional 100 patients was conducted to further assess wound-related outcomes. On average, barbed sutures decreased time to wound closure by 9.72 min ($P < 0.05$) after controlling for length of incision, patient's BMI and number of physicians closing. Further, using barbed sutures saved an average of \$549.59 per case. However, increased frequency and severity of wound complications were associated with barbed sutures.

© 2013 Elsevier Inc. All rights reserved.

Suturing has essentially remained unchanged for decades. One innovation involving traditional methods of suturing was the invention of barbed sutures, first described by R.A. McKenzie in 1967 [1]. Within the last decade, barbed sutures became commercially available and have recently begun to gain popularity due to ease and speed of placement. However, scientific literature exploring their benefits and drawbacks is sparse, particularly in the field of orthopaedics.

In humans, barbed sutures have been investigated in a variety of procedures, yet such studies have displayed mixed results. Their use in robotic prostatectomy exhibited a decrease in suturing time [5]. In the realm of facial rejuvenation surgery, different findings exist specifically related to long term efficacy, patient satisfaction and morbidity [6–8]. Murtha et al demonstrated similar cosmetic outcomes, rates of infection, dehiscence and closure time comparing barbed sutures and traditional sutures when used in closing the dermal layer in non-emergent cesarean delivery surgeries [9]. In abdominoplasty, barbed sutures were shown to be safe and were associated with both a faster total surgery time [10] and a faster closing time [12]. Past work completed in animal models demonstrates equivalent efficacy, safety and strength when comparing barbed sutures to traditional sutures [2,3].

Within orthopaedics, one particular area in which barbed sutures have been extensively studied is flexor tendon repair. Many studies clearly show similar or greater strength achieved with barbed sutures compared to traditional suturing for this particular purpose [4,17–21]. One early observational study evaluating barbed sutures in knee and hip arthroplasties notes a faster time of placement and a theoretical cost reduction when using barbed sutures, but lacks standardization of suturing technique and lacks data describing exactly how much time or money is saved [14]. They report no change in complication or wound healing rates, but again provide no data to support this claim [14]. Another retrospective study evaluating barbed sutures in total knee arthroplasty showed a decrease in total surgical time when using barbed sutures, but comments solely on the suturing time [13]. It makes no comparison of cost between barbed and traditional suturing methods [13]. Lastly, a recent case report details three extensor mechanism failures after TKA using bidirectional barbed sutures to close the medial parapatellar arthrotomy [22]. Well designed studies providing prospective data evaluating barbed sutures are lacking in the current literature.

The purpose of this study was to prospectively investigate barbed sutures by comparing them to traditional sutures on three different levels; time to wound closure, cost, and rates of wound complications when used to close primary total knee arthroplasties (TKA) and primary total hip arthroplasties (THA). We hypothesized that using barbed sutures, specifically, the Quill Self-Retaining System (SRS; Angiotech Pharmaceuticals, Inc. Vancouver, Canada), would expedite the time to wound closure resulting in a decreased amount of time spent in the operating room. Further, we

The Conflict of Interest statement associated with this article can be found at <http://dx.doi.org/10.1016/j.arth.2013.05.031>.

Reprint requests: Eric L. Smith, MD, Tufts Medical Center, Department of Orthopaedic Surgery, 800 Washington Street, Box 306, Boston, MA 02111.

0883-5403/0000-0000\$36.00/0 – see front matter © 2013 Elsevier Inc. All rights reserved.
<http://dx.doi.org/10.1016/j.arth.2013.05.031>

Please cite this article as: Smith EL, et al, Barbed Versus Traditional Sutures: Closure Time, Cost, and Wound Related Outcomes in Total Joint Arthroplasty, *J Arthroplasty* (2013), <http://dx.doi.org/10.1016/j.arth.2013.05.031>

Table 1
Characteristics of the Study Population.

Procedure		Quill		Traditional	
		TKA	THA	TKA	THA
Total Number		10	8	8	8
Gender	Male	5	4	3	3
	Female	5	4	5	5
Age (Years)	Average	59.2	59.6	70.6	57.9
	Range	37-82	43-85	58-86	24-80
Length of Incision (cm)	Average	19.0	18.3	17.7	15.6
	Range	15-23	13-25	15-20	13-21
BMI	Average	33.7	33.8	30.1	30.1
	Range	25.5-42.7	21.3-48.9	22.7-44.4	24.4-39

Epidemiology of the two arms of the study.

hypothesized that there may be a cost reduction associated with barbed sutures secondary to their time saving capability. Lastly, we hypothesized that the rate of wound complications would be equivalent in the two groups.

Materials and Methods

Participant Recruitment

We performed a prospective, randomized controlled trial at our institution between August and October of 2010. The study design was approved by our institutional review board on July 21, 2010. A power analysis was performed to determine the number of participants necessary to detect a five minute difference between the two types of sutures. It was calculated that 34 patients would be necessary to establish significance, and therefore we recruited 34 patients for our prospective cohort. Recruitment occurred during preoperative visits with the one attending orthopaedic surgeon involved in the study. Patients meeting inclusion criteria were asked if they would like to be involved in the study and those who were interested signed a detailed informed consent form. Inclusion criteria included being scheduled to undergo a primary TKA or THA at our medical center with the attending surgeon involved in this study. Exclusion criteria included patients scheduled to undergo hip and knee revision arthroplasty. We did not exclude patients on the basis of age, race, gender, BMI or other comorbid conditions. In other words, the first consecutive 34 primary TKA and THA patients agreeable to be included in the study were included and no one was subsequently excluded for any reason. Details of the study population can be seen in Table 1.

Sealed envelopes in a random order were used to place study participants in either the barbed suture arm or in the traditional suture arm of the study. Patients were randomized in a one to one ratio. At the commencement of each arthroplasty, a random envelope was drawn which dictated the type of suture to be used, thus blinding the patients to the type of suture they received.

Table 2
Suture Type and Method of Placement THA.

Layer	Traditional Suture	Barbed Suture
Fascia	Distal interrupted and proximal running #1 Ethibond	Running #2 Quill
Fat	Running 0-Vicryl	Running #1 Quill
Subcutaneous	Interrupted 2.0 Vicryl	Running #0 Quill
Subcuticular	Running 3-0 Monocryl	Running 2-0 Quill Monoderm

Details of the suture type and method of placement for all THA.

Table 3
Suture Type and Method of Placement TKA.

Layer	Traditional Suture	Barbed Suture
Arthrotoomy	Interrupted #1 Ethibond	Running #2 Quill
Fat	Running 0-Vicryl	Running #1 Quill
Subcutaneous	Interrupted 2.0 Vicryl	Running #0 Quill
Subcuticular	Running 3-0 Monocryl	Running 2-0 Quill Monoderm

Details of the suture type and method of placement for all TKA.

Surgical Methods

The surgical methods were consistent throughout the entire study. We used the posterolateral approach for each THA and a median parapatellar approach for each TKA, regardless of suture type used during closure. Following all procedures, ABD's were used to cover the incision and soft dressings were applied. No acrylate glue or steri strips were used during this study. Details of the exact type of suture used and the method of placement can be found in Tables 2 and 3.

Suturing Methods

Traditional sutures were placed in the usual fashion throughout the study. Interrupted sutures were placed, tied and cut before moving on to the next knot. If space allowed, the attending and the resident surgeons would suture simultaneously when placing interrupted sutures. Running sutures were placed by first securing the suture to one end of the wound and running the suture in the usual fashion before securing it at the opposite end of the wound.

During closure with barbed suture, the suture was introduced in the center of the wound and the surgeons ran the suture towards opposite ends of the wound simultaneously. Each time barbed suture was used the attending and resident surgeons were suturing simultaneously. Upon reaching the end of the wound a few redundant throws were inserted back toward the center of the wound to secure the suture in place and the ends were cut. All suturing was completed by the same attending orthopaedic surgeon and the same fourth year resident surgeon throughout the entire study. Both had used the Quill suture for three months prior to the study to become comfortable using it and to correct for any learning curve that was necessary to overcome. A fat layer was used at the attending surgeon's discretion if the adipose layer was sufficiently thick requiring an additional suture layer to achieve tissue approximation.

Data Collection

At the conclusion of each arthroplasty the time from placement of the first stitch to the completion of wound closure was recorded using a stop watch. In addition, the time to close each individual layer of the wound was also recorded. Specifically, we recorded the time necessary to close the fascia, fat layer, subcutaneous layer, and subcuticular layers. The length of incision was measured after closure was completed and was used as a control during statistical analysis. The patient's height and weight were also recorded in order to calculate BMI, which was also used as a control during statistical analysis. Further, the quantity of each suture used was also recorded and used during the cost analysis. All data were recorded by a medical student or a nurse present in the operating room during closure.



Fig. 1. Magnified barbed suture showing the helical arrangement of the barbs. Source: http://trusted.md/feed/items/rlbates/2008/04/28/barbed_sutures#axzz15016wAcX.

Table 4
Time to Wound Closure.

Layer	Traditional		Quill		Time Difference (Min)	P Value
	Mean Time (Min)	Standard Deviation (Min)	Mean Time (Min)	Standard Deviation (Min)		
Fascia	8.56	2.394	5.06	0.998	3.50	$P < 0.001$
Fat	8.33	2.08	4.10	1.91	4.23	$P < 0.05$
Subcutaneous	8.56	2.63	4.72	1.49	3.84	$P < 0.001$
Subcuticular	7.81	2.54	4.72	1.74	3.09	$P < 0.001$
Total	26.50	6.83	16.78	3.28	9.72	$P < 0.001$

Table showing average time, SD, and P values for both Quill and traditional sutures associated with each layer of the wound.

Barbed Suture Specifics

The barbed suture used was the Quill Self-Retaining System, (SRS; Angiotech Pharmaceuticals, Inc. Vancouver, Canada) which is a knotless wound closure system equipped with tiny barbs on its surface. The barbs are arrayed helically around the suture and emanate in a bi-directional fashion beginning in the middle of the suture (Fig. 1). All Quill sutures used in this study were absorbable monofilament sutures.

Statistical Methods

To reduce within-group error variance and to eliminate confounders, analysis of covariance (ANCOVA) was conducted. General Linear Model (GLM) procedure in SPSS was conducted using method of suturing (barbed or traditional) as the fix factor, and BMI and length of incision, and number of physicians closing as covariates. Chi-square test was utilized to compare wound complication data.

Results

Time

Total time to wound closure and time to close each layer of the wound are detailed in Table 4. All layers were closed significantly faster using barbed sutures compared to traditional methods.

Cost

A detailed cost analysis comparing Quill sutures to traditional sutures is shown in Table 5. The average cost of Quill sutures was found to be \$91.93 greater than the average cost of traditional sutures per arthroplasty.

Further, the cost of operating room time at our institution is estimated to be \$66.00 per minute, including operating room charges

Table 5
Cost Analysis.

Type of Suture	Catalogue #	Price/Suture (\$)	Average Quantity of Suture/Arthroplasty	Avg. Total Cost/Arthroplasty (\$)	Avg. Total Cost Savings/Arthroplasty
Barbed				106.33	0
#2 Quill	RA 1065Q	30.84	1		
#1 Quill	RA 1059Q	28.27	0.61		
#0 Quill	RA 1067Q	29.55	1		
2-0 Quill Monoderm	YA 1024Q	28.27	1		
Traditional				14.40	91.93
#1 Ethibond	X865H	1.86	2.7		
0-Vicryl	VCP616H	1.9	0.2		
2-0 Vicryl	VCPB269H	2.35	2.8		
3-0 Monocryl	MCP316H	1.91	1.2		

Table showing cost analysis comparing barbed sutures to traditional sutures.

Table 6
Outcomes by Suture Type.

Suture	# Patients	# Poor Outcomes (%)		Outcomes
Traditional	36	Minor: 2 (5.5%)	Major: 0 (0%)	1 Prominent suture 1 Superficial infection
Barbed	98	Minor: 8 (8.2%)	Major: 2 (2.0%)	6 Superficial infections 2 Prominent suture 2 Deep wound infection
		$P = 0.45$	$P = 0.488$	

Table detailing adverse wound related outcomes broken down by suture type and major versus minor outcomes.

and anesthesiologist professional fees [11]. Therefore, because the Quill suture saves an average of 9.72 min per case as shown above, \$641.52 per case can be saved by using Quill sutures based on time savings alone.

Combining the greater cost of the Quill suture with its time saving capability, the average cost savings per arthroplasty are calculated as \$641.52–\$91.33. Therefore, analysis reveals an average savings of \$549.59 per arthroplasty when using Quill sutures.

Wound Related Outcomes

Another criterion used as a measure of comparison between barbed and traditional sutures was adverse wound outcomes. Outcomes were divided into major and minor, with major complications defined as those requiring further surgical intervention and minor complications requiring no further surgical intervention. Among the minor complications, prominent sutures are defined as retained sutures being expelled by the body through the skin. Superficial infections are defined as superficial cellulitis without infection deep to the fascia.

In the original cohort, there were three minor complications noted in the 18 patients in the Quill arm of the study (16.6%). All three patients experienced superficial wound infections. The only complication noted in the traditional arm of the study was one minor prominent suture (6.3%).

Our original power analysis was performed to detect a five minute difference in time between the two types of sutures and did not capture a difference in complications. However, over the next nine months while the same attending surgeon and the same fourth year resident continued to use the Quill suture when closing TKA's and THA's they observed an increased frequency of wound complications. Therefore, we performed a retrospective chart review of prospectively collected data to include the complications that occurred over those nine months. Specifically, we reviewed charts of the next 100 patients having TKA's or THA's by the same attending physician at our

Table 7
Outcomes by Operation.

Surgery	# Procedures	# Poor Outcomes (%)
THA	54	3 (5.6%)
TKA	80	9 (11.3%)
		$P = 0.257$

Table showing wound complications broken down by type of surgery.

institution. Within that cohort 80 patients received barbed sutures and five minor and two major complications were noted. The other 20 patients in that cohort received traditional sutures and only one minor complication was noted.

Combining these two cohorts we have 134 patients, 98 who received barbed sutures and 36 who received traditional sutures. In patients who received traditional sutures two (5.5%) minor and zero (0%) major complications were noted. In patients who received barbed sutures eight minor (8.2%) and two major (2%) complications were noted (Table 6). There is no statistical difference between Quill and traditional sutures when comparing the total complication rate ($P = 0.40$), major complications ($P = 0.45$) or minor complications ($P = 0.488$). This holds true even if prominent sutures are ignored as complications given their innocuous nature.

Table 7 shows a breakdown of complications based on type of surgery. There were three (5.5%) complications in THAs and nine (11.3%) complications in TKAs. Both major complications occurred in TKA's. There is no statistical difference in the overall complication rate between TKA and THA ($P = 0.257$). Table 8 further breaks down the complication by type of operation as well as type of suture used. Statistically, we do not have sufficient data to comment on the safety of barbed sutures in specific operations.

Treatment of Wound Complications

Prominent sutures were a universally innocuous complication in our cohort and were treated by removal with forceps and application of antibiotic ointment at a post-operative visit. Superficial infections were all successfully treated with oral antibiotics. Superficial dehiscence occurred in 8 patients receiving the Quill suture. These were successfully treated with removal of the Quill suture, oral antibiotics, and wound vac therapy (Figs. 2 and 3).

There were two major wound complications and both were closed with Quill suture. One underwent a TKA which was followed by full thickness skin necrosis and deep infection. The patient was treated initially with multiple debridements of devitalized tissue, poly exchange, extensive washout, wound VAC therapy and eventually medial gastrocnemius flap for skin defect during the first two months following the TKA. There were continued wound healing difficulties and over the next two months the gastrocnemius flap partially failed. Unfortunately, an above the knee amputation was performed for definitive management three months postoperatively.

The other major complication also occurred after a TKA. Two months post operatively the patient returned to the operating room for debridement of the entire 20 cm incision and removal of barbed suture secondary to superficial wound dehiscence and a foreign body reaction to the barbed suture. At that time there was no deep infection. Several weeks later the patient began experiencing fevers and a deep infection was discovered by joint aspiration. The patient

Table 8
Outcomes by Suture Type and Operation.

Suture	# Patients	# Poor Outcomes (%)
Traditional	TKA 19 THA 17	TKA 2 (10.5%) THA 0 (0%)
Barbed	TKA 61 THA 37	TKA 7 (11.5%) THA 3 (8.1%)

Table showing wound complications broken down by type of suture used and type of surgery.



Fig. 2. Image of one wound complication associated with barbed suture. Courtesy S. Zannikos.

returned to the operating room for removal of all components of the TKA, extensive washout and antibiotic spacer placement for treatment of a chronic, deep infection to the TKA. Two months later a successful revision arthroplasty was performed.

Discussion

Barbed sutures are becoming more popular in many areas of surgery because of ease and speed of placement. However, the literature concerning barbed sutures in the field of orthopaedics, particularly joint arthroplasty, is sparse and contains only retrospective cadaveric and observational studies [13–16,22]. The purpose of this study was to prospectively investigate barbed sutures by comparing them to traditional sutures in three domains; time to wound closure, cost, and rates of wound complications when used to close TKA's and THA's. This study represents the only randomized, prospective study evaluating the use of barbed suture in total joint arthroplasty.



Fig. 3. Image of same wound complication after 3 months of wound VAC therapy. Courtesy S. Zannikos.

After controlling for length of incision, patient's BMI and number of physicians closing, the Quill suture is 9.72 min faster than traditional methods of suturing when comparing mean total time to wound closure following TKA's and THA's (Table 4). This means that if three cases are done in one operating room in a single day, a total of 29.16 min are saved. This is a moderate amount of time and may leave enough time to perform another case that day, or simply allow the physician to tend to other professional obligations.

An interesting finding is that the Quill suture was significantly faster than a running Monocryl when closing the subcuticular layer. We believe that the method of placing the Quill suture, namely beginning in the center of the wound and running both proximally and distally simultaneously, explains why it is faster than even a running traditional suture when placed from proximal to distal. If two surgeons were to close the same wound at the same time with a running traditional suture we believe the time advantage would evaporate.

Another interesting point to consider is the safety profiles of Quill versus running traditional suture, given that they are both running sutures. We believe barbed sutures possess a theoretical advantage over running traditional sutures in the event of a suture rupture or failure. The barbs should theoretically resist a catastrophic failure of the entire length of the suture by holding the suture in place, even if one site breaks. If a running traditional suture fails nothing prevents the entire closure from failing due to the smooth nature of the stitch. In our clinical experience, the presence of barbs did not prevent wound dehiscence in some patients.

Another implication of the time saving nature of the Quill suture is the reduction in cost associated with its use. The cost analysis completed in Table 5 shows that the Quill suture costs an average of \$91.93 more per arthroplasty than traditional sutures. However, we must also consider the cost of using the operating room in our analysis. In 2005 Shippert showed how one minute of operating room time can cost \$66, including operating room fees and anesthesiology professional fees [11]. Therefore, because the Quill suture can save 9.72 min per case, \$641.52 can be saved per case simply by using barbed sutures. Combining the excess cost of the barbed suture, \$91.93 per arthroplasty, and the cost savings related to decreased operating room time, \$641.52, barbed sutures save an average of \$549.59 per arthroplasty. If a single operating room completes three cases each day, then the cost saved by using barbed sutures would be \$1648.77 each day. Saving time in the operating room has many benefits. Along with the cost savings, less time in the operating room decreases exposure to anesthesia which is safer for patients and helps control healthcare costs. These data show how barbed sutures can benefit the surgeon by saving time and thereby decreasing the cost of TKA's and THA's.

The last measure of comparison between these two types of sutures was poor wound related outcomes. We evaluated outcomes by combining our original prospective cohort of 34 patients with our added retrospective cohort of 100 patients. Tables 6, 7, and 8 show a breakdown of the complications. Although there is no significant difference in the complication rate between barbed and traditional sutures or between TKA and THA, we believe these findings are still worrisome. Both major complications occurred in the barbed suture group and both occurred after TKAs. While saving time and reducing costs can be beneficial, the most crucial aspect of any surgery is patient safety. Further, any cost savings accrued by decreasing time in the operating room are certainly negated if the treatment of serious wound complications is included in the cost calculation. These observations prompted the discontinuation of closing with barbed sutures by the senior surgeon involved.

Practicing physicians involved in this study speculate that one possible explanation for the higher rate of wound complications in the Quill arm is the presence of a stress riser at the barb, which weakens

the suture causing it to break. Further, as stated above, although the barbs would theoretically resist failure of the entire length of the suture, clinically this is still possible given that it is a running suture. An alternate explanation could be that the suture strangulates the vascular supply which inhibits proper healing of the tissue, again leading to necrosis and chronic wound infections.

These data are grossly generalizable due to the broad makeup of the study population. Each arm of the study included a relatively equal ratio of males to females, an equally wide range of ages, incision lengths, BMI, and ratio of TKA's to THA's.

In conclusion, barbed sutures are associated with a decreased time to wound closure following TKA's and THA's and the financial benefit associated with saving time in the operating room is significant. However, barbed sutures were also associated with increased frequency and severity of wound related complications. Some complications conveyed significant morbidity to patients and required additional procedures and months of wound therapy to heal. The poorest wound outcomes were associated with barbed sutures and their use was therefore discontinued by the attending surgeon involved.

References

- McKenzie AR. An experimental multiple barbed suture for the long flexor tendons of the palm and fingers. Preliminary report. *J Bone Joint Surg Br* 1967;49(3):440–7.
- Shikanov S, Wille M, Large M. Knotless closure of the collecting system and renal parenchyma with a novel barbed suture during laparoscopic porcine partial nephrectomy. *J Endourology* 2009;23:1157–60.
- Demyttenaere SV, Nau P, Henn M. Barbed suture for gastrointestinal closure: a randomized control trial. *Surg Innov* 2009;16:237–43.
- Parikh PM, Davison SP, Higgins JP. Barbed suture tenorrhaphy: an ex vivo biomechanical analysis. *Plast Reconstr Surg* 2009;124(5):1551–8.
- Moran ME, Marsh C, Perrotti M. Bidirectional-barbed suture knotless running anastomosis v classic Van Velthoven in a model system. *J Endourology* 2007;21:1175–7.
- Villa MT, White LE, Alam M, Yoo SS, Walton RL. Barbed sutures: a review of the literature. *Plast Reconstr Surg* 2008;121(3):102e–8e.
- Kaminer MS, Bogart M, Choi C, Wee SA. Long-term efficacy of anchored barbed sutures in the face and neck. *Dermatol Surg* 2008;34(8):1041–7.
- Rachel JD, Lack EB, Larson B. Incidence of complications and early recurrence in 29 patients after facial rejuvenation with barbed suture lifting. *Dermatol Surg* 2010;36(3):348–54.
- Murtha AP, Kaplan AL, Paglia MJ, Mills BB, Feldstein ML, Ruff GL. Evaluation of a novel technique for wound closure using a barbed suture. *Plast Reconstr Surg* 2006;117(6):1769–80.
- Rosen AD. Use of absorbable running barbed suture and progressive tension technique in abdominoplasty: a novel approach. *Plast Reconstr Surg* 2010;125(3):1024–7.
- Shippert RD. A study of time-dependent operating room fees and how to save \$100,000 by using time saving protocols. *Am J Cos Surg* 2005;22:25–34.
- Warner JP, Gutowski KA. Abdominoplasty with progressive tension closure using a barbed suture technique. *Aesthet Surg J* 2009;29(3):221–5.
- Eickmann T, Quane E. Total knee arthroplasty closure with barbed sutures. *J Knee Surg* 2010 Sep;23(3):163–7.
- Levine BR, Ting N, Della Valle CJ. Use of a barbed suture in the closure of hip and knee arthroplasty wounds. *Orthopedics* 2011;34(9):e473–5.
- Nett M, Avelar R, Sheehan M, Cushner F. Water-tight knee arthroscopy closure: comparison of a novel single bidirectional barbed self-retaining running suture versus conventional interrupted sutures. *J Knee Surg* 2011;24(1):55–9.
- Motta P, Errichiello C, Pontini I. Achilles tendon rupture. A new technique for easy surgical repair and immediate movement of the ankle and foot. *Am J Sports Med* 1997;25(2):172–6.
- Haddad R, Peltz TS, Walsh WR. Biomechanical evaluation of flexor tendon repair using barbed suture material: a comparative ex vivo study. *J Hand Surg Am* 2011;36(9):1565–6.
- Hirpara KM, Sullivan PJ, Oullivan ME. A new barbed device for repair of flexor tendons. *J Bone Joint Surg Br* 2010;92(8):1165–70 [PubMed].
- Marrero-Amadeo IC, Chauhan A, Warden SJ, Merrell GA. Flexor tendon repair with a knotless barbed suture: a comparative biomechanical study. *J Hand Surg Am* 2011;36(7):1204–8 [Epub 2011 Jun 12].
- McClellan WT, Schessler MJ, Ruch DS, Levin LS, Goldner RD. A knotless flexor tendon repair technique using a bidirectional barbed suture: an ex vivo comparison of three methods. *Plast Reconstr Surg* 2011;128(4):322e–7e.
- Trocchia AM, Aho HN, Sobol G. A re-exploration of the use of barbed sutures in flexor tendon repairs. *Orthopedics* 2009;32(10):1212.
- Wright RC, Gillis CT, Yacoubian SV, Raven RB, Falkinstein Y, Yacoubian SV. Extensor mechanism repair failure with use of bidirectional barbed suture in total knee arthroplasty. *JOA* 2012;27(7):1413e1–4.