

Barbed sutures in total hip and knee arthroplasty: what is the evidence? A meta-analysis

Robert W. Borzio¹ · Robert Pivec¹ · Bhaveen H. Kapadia¹ · Julio J. Jauregui¹  · Aditya V. Maheshwari¹

Received: 11 September 2015 / Accepted: 3 November 2015 / Published online: 17 November 2015
© SICOT aisbl 2015

Abstract

Introduction Newer methods of wound closure such as bidirectional barbed sutures hold the potential to reduce closure time and thus overall operating room costs during total joint arthroplasty (TJA), including total hip arthroplasty (THA) and total knee arthroplasty (TKA). However, it is unclear whether these sutures have similar clinical outcomes or whether they place the patient at risk of developing wound complications that may outweigh the time-saving benefits of these sutures. **Methods** A systematic review of the literature was performed to identify all level I trials that reported the use of barbed suture during TJA. We analyzed the efficacy, safety, major and minor complications, and overall cost related to barbed sutures. **Results** Four studies met our criteria, and included 588 patients who were randomized either to barbed suture closure ($n=290$ TJAs, 268 TKAs, and 22 THAs) or to a matched conventional suture cohort ($n=298$ TJAs, 279 TKAs, and 19 THA). In terms of time savings with wound closure, the barbed suture was 6.3 minutes faster than the conventional

cohort ($p<0.05$). The odds for developing a minor complication were nearly identical (odds ratio [OR] 1.04, $p=0.95$) and for major complication was not significantly different (OR 2.94, $p=0.27$). The overall mean savings including both THA and TKA was USD 298 per case.

Conclusions In randomized controlled trials, barbed sutures are consistently associated with shorter wound closure time, which also corresponds to cost savings, even when the higher cost of these sutures is taken into account. There was no significant difference in the odds of experiencing either minor or major complications between patients in whom barbed sutures versus standard sutures were used for wound closure. Current evidence supports continued use of these sutures.

Level of Evidence: Level I

Keywords Barbed sutures · Total knee arthroplasty · Total hip arthroplasty · Wound closure · Meta analysis

Introduction

The number of total joint arthroplasty (TJA) procedures, including total hip arthroplasty (THA) and total knee arthroplasty (TKA), have consistently risen in recent years, and the need for this procedure is expected to continue to increase [1]. New healthcare policies, with lower reimbursement rates and fewer available resources, have focused on improving surgical efficiency and outcomes [2]. Hence, reduction in the time spent during wound closure may be an objective in efforts to reduce overall operative time and cost while increasing surgical productivity. In addition, shorter operative time has also been shown to decrease the rate of infection [3, 4].

Traditionally, wound closure after TJA has been performed with several layers of continuous and interrupted

✉ Aditya V. Maheshwari
adityavikramm@gmail.com

Robert W. Borzio
borziorw@gmail.com

Robert Pivec
robertpivec@yahoo.com

Bhaveen H. Kapadia
bhaveen.k@gmail.com

Julio J. Jauregui
juljau@gmail.com

¹ Department of Orthopaedic Surgery and Rehabilitation Medicine, SUNY Downstate Medical Center, 450 Clarkson Avenue, MSC 30, Brooklyn, NY 11203, USA

sutures using a variety of both absorbable and non-absorbable sutures and skin with non-absorbable suture, staples or 2-octyl cyanoacrylate (OCA) [5]. However, wound closure using these techniques may increase the time required [3]. Additionally, biomechanical studies have demonstrated that barbed sutures are stronger than interrupted braided sutures [6]. Despite the multiple potential benefits, Patel et al. reported that barbed sutures were associated with higher rates of complications than other closure methods such as staples (13.0 versus 3.9 %; $p=0.017$) [4].

Although multiple studies over the last decade have evaluated different possible alternatives for wound closure [7, 8], no study has assessed all available level I trials (defined as prospective randomized trials) [9] evaluating the effectiveness, risk of complications, and cost-saving capacity of barbed sutures in TKA and THA. Hence, the purpose of our study is to analyze the highest evidence-based (level I) studies in order to compare (1) rates of minor and major complication, (2) differences in operative time, and (3) cost reduction with the use of barbed sutures in TKA and THA.

Methods

Following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines, a query of PubMed, EMBASE and Ovid databases of relevant reports through June 2015 was performed [10] using the search strings "barbed AND suture," "wound AND barbed," "barbed AND total," and "self-locking AND arthroplasty," which yielded 594 studies. We then excluded studies that were (1) performed in animals, (2) non-English, or (3) single case reports. These exclusions left a total of 20 studies, which were carefully assessed for relevance. We then cross-referenced these studies and found two additional studies that were included, for a total of 22. After careful review, we found that 18 did not provide sufficient information, were focused on other types of procedures, were review studies, or had a lower level of evidence. Hence a total of four level I studies were included in our final review (see Fig. 1).

In all studies, we specifically focused on determining patient demographic characteristics, the specific type of procedure (TKA or THA), size of the incision, time savings, rate of closure, minor and major complications, and the overall cost savings. The complications were defined as minor (prominent suture, superficial infection, stich abscess, erythema, or other) or major (deep infections, pulmonary embolism, wound dehiscence, dehiscence of extensor mechanism) according to the definition for each individual study. In addition, we recorded any other possible difficulty described by any of the studies, such as needle sticks or suture breakage during closure. All data was inputted into an electronic spreadsheet, and

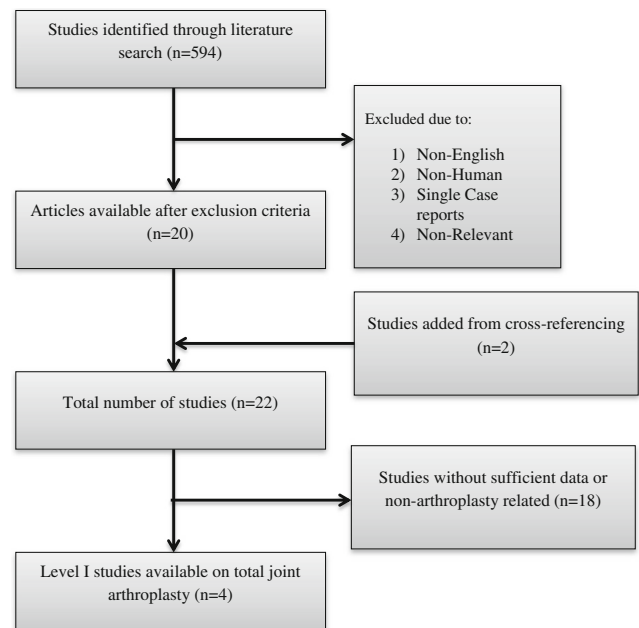


Fig. 1 Study flow chart of patients in this review

descriptive statistics were then performed for all of the previously compiled information. Utilizing a random effects model, we also calculated the odds ratio for developing a minor or major complication, which was performed with the aid of a statistical software (MedCalc Software bvba, Ostend, Belgium).

This study was performed with no external funding.

Results

A total of 588 patients were randomized to either barbed suture closure ($n=290$ TJAs, 268 TKAs, and 22 THAs) or a matched conventional suture cohort ($n=298$ TJAs, 279 TKAs, and 19 THAs). In the barbed cohort, 40 % (115) were men, with a mean age of 64 years (range of means, 59.2 to 68.1 years) and a mean body mass index (BMI) of 31.8 kg/m² (range of means, 30.1 to 33.7 kg/m²). In the randomized comparison cohort, 38 % (112) were men, with a mean age of 65 years (range of means, 63.0 to 68.1 years) and a mean BMI of 31.4 kg/m² (range of means, 30.1 to 33.0 kg/m²) (Table 1).

The mean length of incisions within the barbed cohort was 16.2 cm. Specifically, it was 16.4 cm for the knee and 16.2 cm for the hip. In the comparison cohort, the mean length of incisions was 15.9 cm (mean of 16.3 cm for TKA and 14.9 cm for THA), which was not significantly different from that of the barbed cohort ($p>0.05$). In terms of time savings during wound closure, the barbed suture was 6.3 minutes faster than the conventional closure (12 vs. 18.3 minutes, respectively). This was true for knee arthroplasties, with time savings of 4.3 minutes (10.1 vs. 14.4 min), and for hip arthroplasty, with time savings of 5.4 minutes (9.6 vs. 15.0 minutes) (Table 2).

Table 1 Demographic characteristics and type of suture

	Author, year	Fascia	Subcutaneous	Subcuticular	Knees, <i>N</i>	Hips, <i>N</i>	Joints, <i>N</i>	M/F	Mean BMI (kg/m ²)	Mean age (years)
Barbed cohort	Smith et al. 2014 [11]	#2 Quill SRS ^a	#0 Quill SRS ^a	2-0 Monoderm ^a	10	8	18	9/9	33.75	59.4
	Ting et al. 2012 [12]	#2 Polydioxanone	#0 Polydioxanone	2-0 Monoderm ^b	17	14	31	8/23	30.4	64.4
	Sah 2015 [13]	Quill ^b	Vicryl ^b	Monoderm ^b	50	0	50	21/29	30.1	68.1
	Gililland et al. 2012 [7]	#2 Quill SRS ^b	#0 Quill SRS ^b	NR	191	0	191	77/114	33	64
Comparison cohort	Smith et al. 2014 [11]	#1 Ethibond ^b	#0 Vicryl ^b	3-0 Monocryl ^b	8	8	16	6/10	30.1	64.25
	Ting et al. 2012 [12]	#1 Vicryl ^b	#0 Vicryl ^b	Dermabond ^b , Staples	18	11	29	8/21	32.2	63.5
	Sah 2015 [13]	#1 Vicryl TM pop-off ^b	2-0 Vicryl ^b	2-0/3-0 Monocryl ^b	50	0	50	21/29	30.1	68.1
	Gililland et al. 2012 [7]	#1 Ethibond ^b	2-0 Monocryl ^b	NR	203	0	203	77/126	33	63

NR not reported, *N* number, *M/F* male/female

^a SRS; Angiotech Pharmaceuticals, Inc., Vancouver, Canada

^b Ethicon Inc., Somerville, NJ, USA

There were no significant differences in rates of minor or major complication between the two cohorts (Table 3). In terms of minor complications, our random effects model demonstrated that the odds of developing a minor complication were nearly the same in both cohorts (odds ratio [OR] 1.04, 95 % confidence intervals [CI] 0.31–3.54, $p=0.95$; Fig. 2). Specifically, six cases of prominent sutures, seven superficial infections, five stitch abscesses, and two cases of skin erythema were observed within the barbed suture cohort. Similarly, the conventional closure cohort had two cases of prominent suture, four stitch abscesses, three cases of skin erythema, and four other unspecified minor complications. In terms of major

complications, there was no significant difference between cohorts (OR 2.94, 95 % CI 0.44–19.74, $p=0.27$; Fig. 3). The specific major complications in the barbed cohort were three deep infections and a pulmonary embolism; in the comparison cohort, only one patient developed a deep infection.

After accounting for the time savings, all studies reported cost savings with the use of barbed sutures. After all data were compiled for knee and hip arthroplasty, the total mean savings was US \$298 (please see Table 4). Specifically, of the studies that provided specific data for TKAs, the savings ranged from US \$58 to \$365, and the study providing specific data for THAs reported mean savings of US \$615. In terms of surgical

Table 2 Length of incision, time for closure, and closure rate

	Author, year	Incision length (cm), knee (type of approach)	Incision length (cm), hip (type of approach)	Incision length (cm)	Mean time for closure, knee	Mean time for closure, hip	Mean time for closure	Closure rate (cm/ min)
Barbed cohort	Smith et al. 2014 [11]	19 (medial parapatellar)	18.3 (posterolateral)	18.7	NR	NR	16.8	1.11
	Ting et al. 2012 [12]	14.6 (medial parapatellar)	14.1 (standard posterior)	14.4	9.2	9.6	9.4	1.53
	Sah 2015 [13]	NR (medial parapatellar)	NR	NR	11.4	NR	NR	NR
	Gililland et al. 2012 [7]	15.7 (medial parapatellar)	NR	15.7	9.8	n	9.8	1.60
Comparison cohort	Smith et al. 2014 [11]	17.7 (parapatellar)	15.6 (posterolateral)	16.7	NR	n	26.5	0.63
	Ting et al. 2012 [12]	14.6 (medial parapatellar)	14.1 (standard posterior)	14.4	12.7	15	13.9	1.04
	Sah 2015 [13]	NR (medial parapatellar)	NR	NR	16.1	NR	NR	NR
	Gililland et al. 2012 [7]	16.6 (medial parapatellar)	NR	16.6	14.4	n	14.4	1.15

Table 3 Complications

	Author, year	Minor	Prominent suture	Superficial infection	Stich abscess	Minor, other	Erythema	Major	Deep infections	Major, other
Barbed cohort	Smith et al. 2014 [11]	8	6	2	0	0	0	2	2	0
	Ting et al. 2012 [12]	2	0	0	0	0	2	0	0	0
	Sah 2015 [13]	0	0	0	0	0	0	0	0	0
	Gililland et al. 2012 [7]	2	0	5	5	0	0	0	1	1
Comparison cohort	Smith et al. 2014 [11]	2	1	1	0	0	0	0	0	0
	Ting et al. 2012 [12]	3	0	0	0	0	3	0	0	0
	Sah 2015 [13]	4	1	0	0	3	0	0	0	0
	Gililland et al. 2012 [7]	1	0	5	4	1	0	0	1	0

difficulties, 12 suture breaks were reported and one surgeon had a needle stick in the barbed closure cohort, while there were three suture breaks and five needle sticks in the conventional cohort.

Discussion

In light of new healthcare policies, cost and time savings while lowering or maintaining current complication rates is crucial. Hence, we attempted to analyze level I trials that have assessed the use of barbed sutures in the arthroplasty world for the highest possible evidence. We found no significant increase in complication rates, while all studies demonstrated the capacity for high cost and time savings. Similar studies have evaluated the effectiveness of these sutures in other spheres of the surgical field. Among these, a prospective porcine gastrointestinal trial demonstrated a 25 % decrease in surgical time while obtaining similar closure profile, adhesion formation, and histology scoring [14]. Other studies in the

obstetric-gynecologic and plastic surgery literature have also evaluated these sutures, finding either no difference or improved outcomes and faster surgical time [15, 16].

A recent meta-analysis by Meena et al. published in the *European Journal of Orthopedic Surgical Traumatology* evaluated the use of barbed sutures in the world of arthroplasty [17]. The authors included four level III retrospective studies [7, 8, 18, 19] and the level I study by Gililland et al. [20] Their primary outcome measure was superficial infection, and secondary outcome measures were deep infection, wound dehiscence, total operative time, closure time, and arthrofibrosis. As they included only TKA in their analysis, and did not account for cost or safety measures, we were unable to draw a meaningful conclusion. Hence, we believe that our study is necessary to better assess these sutures and to determine whether they can aid the adult reconstruction surgeon.

There were several limitations in our study. As with every review, we are limited to data available in the current

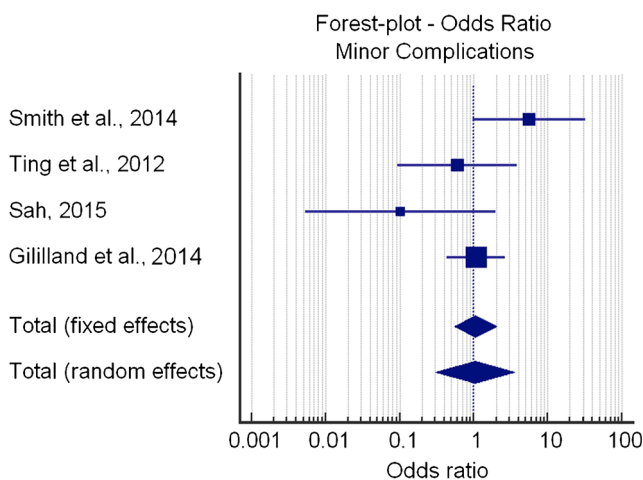


Fig. 2 Forest plot of level I studies comparing complications in patients with the use of directional barbed suture closure compared with traditional sutures. An odds ratio greater than 1 describes greater odds for minor complications with barbed sutures

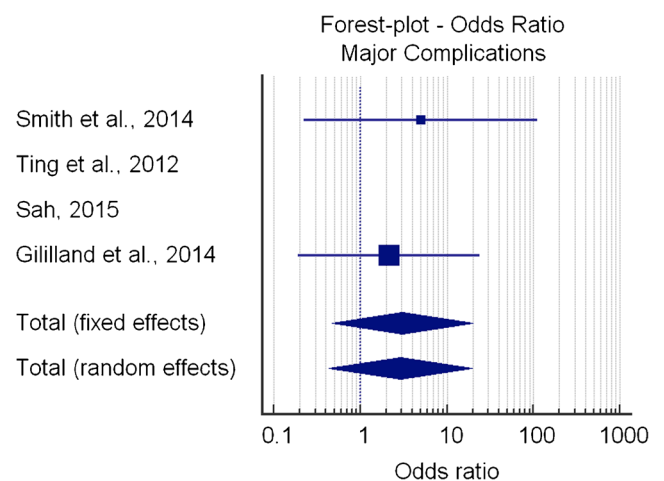


Fig. 3 Forest plot of level I studies comparing complications in patients with the use of directional barbed suture closure compared with traditional sutures. An odds ratio greater than 1 describes greater odds for major complications with barbed sutures. Note that the studies by Ting et al. and Sah had no major complications in either cohort

Table 4 Cost savings

Author, year	Cost savings, knee	Cost savings, hip	Cost savings
Smith et al. 2014 [11]	US \$549.6	US \$549.6	US \$549.6
Ting et al. 2012 [12]	US \$364.6	US \$614.7	US \$489.7
Sah 2015 [13]	US \$58.0	NR	US \$58.0
Gililland et al. 2012 [7]	US \$95.0	NR	US \$95.0

NR not reported

literature, therefore, the limitations of all evaluated trials are also our limitations. Additionally, non-level I studies were excluded, which may have excluded many high-quality case series; however, our inclusion criteria were chosen in order to include only studies with the best evidence. There are also different types of barbed sutures available, which may have affected homogeneity between studies. We classified complications based on the authors' subjective determination, and this can induce some bias. Also, various protocols for grading randomized controlled trials (level I) could be utilized, and there is no widespread agreement on the validity of this approach. Therefore, rejecting or accepting one versus another is controversial. Thus we have included all level I trials assessing the use of barbed sutures in TKA and THA.

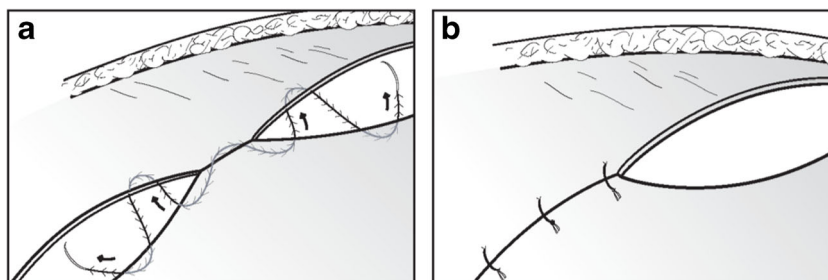
Among the multiple ways of closing the same type of wound, all studies stratified their information within two cohorts, a cohort utilizing a barbed suture and a comparison cohort without a barbed suture (Fig. 4). To illustrate these, we chose to describe the study by Smith et al. [11]. They used two cohorts undergoing different closure techniques following TJA. In the study cohort, running Quill (SRS; Angiotech Pharmaceuticals, Inc. Vancouver, Canada) for fascia, fat, subcutaneous and subcuticular layer with #2, #1, #0, 2–0 Monoderm was utilized, which was compared to #1 Ethibond (Ethicon Inc., Somerville, N J, USA) for fascia by running distally and interrupted proximally, running 0-Vicryl and interrupted 2–0 Vicryl for deep and superficial subcutaneous layers, and subcuticular layer with running 3–0 Monocryl (Ethicon Inc., Somerville, NJ, USA). The authors showed that after controlling for patient BMI, length of incision, and number of physicians closing the wound, 9.72 minutes was saved by utilizing barbed sutures.

Similarly, Gilliland et al. prospectively evaluated 411 TKAs randomized to barbed running suture (191 knees, Quill SRS; Angiotech Pharmaceuticals, Inc. Vancouver, Canada) or knotted interrupted suture (203 knees, Ethibond or Monocryl; Ethicon Inc., Somerville, NJ, USA; see Table 1) [20]. They found that closure time was significantly faster, by 4.6 minutes, with no difference in KSS (Knee Society Score) 6 weeks postoperatively, and with similar patient satisfaction and cosmesis.

Our meta-analysis demonstrated that barbed sutures did not significantly increase the odds of developing minor or major complications. However, other studies with lower levels of evidence (levels III and IV), which we did not include in this analysis, have demonstrated conflicting results. Of these, Patel et al. used absorbable barbed suture only for the subcuticular level, and showed a significantly higher minor and major complication rate compared to that with staples ($p=0.033$) [4]. Wright et al. described three cases of extensor mechanism failure that occurred with the use of bidirectional barbed sutures, and recommended avoiding this type of closure in morbidly obese, diabetic or rheumatoid patients undergoing TJA [21]. Campbell et al. found higher rates of infection and overall complications, and hence recommended avoiding this type of sutures in superficial closure [19].

Smith et al. combined their original prospective cohort of 34 patients with a retrospective cohort of 100 patients [11]. Although the differences in complication rates were not significant, they nonetheless prompted the discontinuation of the use of barbed sutures for closure, as their complication rate increased from 5.5 to 8.2 % for minor and 0 to 2 % for major complications ($p=0.45$ and 0.488, respectively).

Fig. 4 a, b Illustration of a fascial closure with a barbed and b conventional sutures



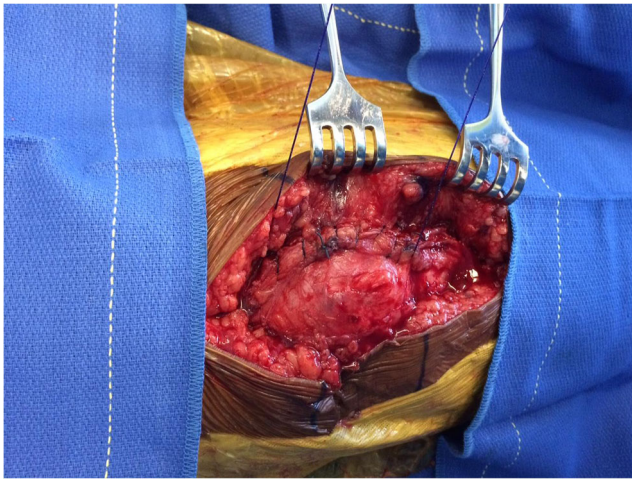


Fig. 5 Clinical intra-operative photograph of procedure utilizing barbed sutures, demonstrating closure of the deep arthrotomy in a patient undergoing total knee arthroplasty

Gilland et al. reported five needle sticks of surgical staff in the control group and only one stick in the barbed group, with no statistical difference between groups [20]. There was also no statistical difference in the rate of major or minor postoperative complications, including wound infection, and the authors found no correlation with cellulitis, dermal closure, ASA score, smoking, age, or BMI. Ting et al. showed a lower rate of wound-related complications that was not significant at three weeks or three months ($p > 0.05$) [12]. The Hollander wound score, patient-derived Likert, and VAS revealed no significant difference in wound outcomes or patient satisfaction. Sah reported a significantly lower number of suture handoffs between scrub technicians and surgeons with barbed sutures, with seven to nine sutures versus 14 to 16 passes with standard sutures, although there were no intra-operative clinical complications using either suture type [13]. The authors found no dehiscence or wound drainage in either group. There were three suture abscesses with traditional sutures and none with barbed sutures ($p = 0.24$). No antibiotics were used, and no surgical interventions were necessary in either group.

Although no study commented on the intra-operative difficulty of using these sutures, we have found in our experience with Quill sutures that they are difficult to use in tough scar tissue (as the needle is not cutting), and the tip bends easily when repeatedly held with needle driver, with the risk of tip breakage.

Conclusions

There is overall consensus in the literature regarding the time savings that can be extrapolated to total cost savings associated with the use of barbed sutures. However, the potential increase in complication rates described by some authors may dissuade surgeons from taking advantage of this apparent

cost benefit. In our evaluation of all level I trials, we found no significant increase in major complication rates, and minor complication rates were nearly equivalent between cohorts. Although the specific closure technique utilized is surgeon-dependent, when faster surgical time is a goal, the adult reconstruction surgeon could attempt to utilize this closure technique. Although larger cohort studies must be performed before a final conclusion can be made regarding whether major complication rates differ, current evidence supports the use of these sutures (see Fig. 5 for a clinical intra-operative photograph in a case utilizing barbed sutures).

References

1. Kurtz SM, Ong KL, Lau E, Bozic KJ (2014) Impact of the economic downturn on total joint replacement demand in the United States: updated projections to 2021. *J Bone Joint Surg Am* 96:624–630. doi:10.2106/JBJS.M.00285
2. Doran JP, Zabinski SJ (2015) Bundled payment initiatives for Medicare and non-Medicare total joint arthroplasty patients at a community hospital: bundles in the real world. *J Arthroplasty* 30:353–355. doi:10.1016/j.arth.2015.01.035
3. Peersman G, Laskin R, Davis J, Peterson MG, Richart T (2006) Prolonged operative time correlates with increased infection rate after total knee arthroplasty. *HSS J* 2:70–72. doi:10.1007/s11420-005-0130-2
4. Patel RM, Cayo M, Patel A, Albarillo M, Puri L (2012) Wound complications in joint arthroplasty: comparing traditional and modern methods of skin closure. *Orthopedics* 35:e641–e646. doi:10.3928/01477447-20120426-16
5. Khan RJ, Fick D, Yao F, Tang K, Hurworth M, Nivbrant B, Wood D (2006) A comparison of three methods of wound closure following arthroplasty: a prospective, randomised, controlled trial. *J Bone Joint Surg (Br)* 88:238–242. doi:10.1302/0301-620X.88B2.16923
6. Vakil JJ, O'Reilly MP, Sutter EG, Mears SC, Belkoff SM, Khanuja HS (2011) Knee arthrotomy repair with a continuous barbed suture: a biomechanical study. *J Arthroplasty* 26:710–713. doi:10.1016/j.arth.2010.07.003
7. Gililland JM, Anderson LA, Sun G, Erickson JA, Peters CL (2012) Perioperative closure-related complication rates and cost analysis of barbed suture for closure in TKA. *Clin Orthop Relat Res* 470:125–129. doi:10.1007/s11999-011-2104-7
8. Maheshwari AV, Naziri Q, Wong A, Burko I, Mont MA, Rasquinha VJ (2015) Barbed sutures in total knee arthroplasty: are these safe, efficacious, and cost-effective? *J Knee Surg* 28:151–156. doi:10.1055/s-0034-1373741
9. Marx RG, Wilson SM, Swiontkowski MF (2015) Updating the assignment of levels of evidence. *J Bone Joint Surg Am* 97:1–2. doi:10.2106/JBJS.N.01112
10. Stewart LA, Clarke M, Rovers M, Riley RD, Simmonds M, Stewart G, Tierney JF, Group P-ID (2015) Preferred reporting items for systematic review and meta-analyses of individual participant data: the PRISMA-IPD statement. *JAMA* 313:1657–1665. doi:10.1001/jama.2015.3656
11. Smith EL, DiSegna ST, Shukla PY, Matzkin EG (2014) Barbed versus traditional sutures: closure time, cost, and wound related outcomes in total joint arthroplasty. *J Arthroplasty* 29:283–287. doi:10.1016/j.arth.2013.05.031

12. Ting NT, Moric MM, Della Valle CJ, Levine BR (2012) Use of knotless suture for closure of total hip and knee arthroplasties: a prospective, randomized clinical trial. *J Arthroplasty* 27:1783–1788. doi:[10.1016/j.arth.2012.05.022](https://doi.org/10.1016/j.arth.2012.05.022)
13. Sah AP (2015) Is there an advantage to knotless barbed suture in TKA wound closure? A randomized trial in simultaneous bilateral TKAs. *Clin Orthop Relat Res* 473:2019–2027. doi:[10.1007/s11999-015-4157-5](https://doi.org/10.1007/s11999-015-4157-5)
14. Demyttenaere SV, Nau P, Henn M, Beck C, Zaruby J, Primavera M, Kirsch D, Miller J, Liu JJ, Bellizzi A, Melvin WS (2009) Barbed suture for gastrointestinal closure: a randomized control trial. *Surg Innov* 16:237–242. doi:[10.1177/1553350609342988](https://doi.org/10.1177/1553350609342988)
15. Naki MM, Api O, Acioglu HC, Ozkan S, Kars B, Unal O (2010) Comparative study of a barbed suture, poliglecaprone and stapler in Pfannenstiel incisions performed for benign gynecological procedures: a randomized trial. *Acta Obstet Gynecol Scand* 89:1473–1477. doi:[10.3109/00016349.2010.516815](https://doi.org/10.3109/00016349.2010.516815)
16. Rubin JP, Hunstad JP, Polynice A, Gusenoff JA, Schoeller T, Dunn R, Walgenbach KJ, Hansen JE (2014) A multicenter randomized controlled trial comparing absorbable barbed sutures versus conventional absorbable sutures for dermal closure in open surgical procedures. *Aesthet Surg J* 34:272–283. doi:[10.1177/1090820X13519264](https://doi.org/10.1177/1090820X13519264)
17. Meena S, Gangary S, Sharma P, Chowdhury B (2015) Barbed versus standard sutures in total knee arthroplasty: a meta-analysis. *Eur J Orthop Surg Traumatol* 25:1105–1110. doi:[10.1007/s00590-015-1644-z](https://doi.org/10.1007/s00590-015-1644-z)
18. Eickmann T, Quane E (2010) Total knee arthroplasty closure with barbed sutures. *J Knee Surg* 23:163–167
19. Campbell AL, Patrick DA Jr, Liabaud B, Geller JA (2014) Superficial wound closure complications with barbed sutures following knee arthroplasty. *J Arthroplasty* 29:966–969. doi:[10.1016/j.arth.2013.09.045](https://doi.org/10.1016/j.arth.2013.09.045)
20. Gililand JM, Anderson LA, Barney JK, Ross HL, Pelt CE, Peters CL (2014) Barbed versus standard sutures for closure in total knee arthroplasty: a multicenter prospective randomized trial. *J Arthroplasty* 29:135–138. doi:[10.1016/j.arth.2014.01.041](https://doi.org/10.1016/j.arth.2014.01.041)
21. Wright RC, Gillis CT, Yacoubian SV, Raven RB 3rd, Falkenstein Y, Yacoubian SV (2012) Extensor mechanism repair failure with use of bidirectional barbed suture in total knee arthroplasty. *J Arthroplasty* 27(1413):e1411–e1414. doi:[10.1016/j.arth.2011.08.013](https://doi.org/10.1016/j.arth.2011.08.013)