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Managing Editor,
Journal of Arthroscopy and Joint Surgery,
B – 7/5 Safdarjung Enclave, New Delhi - 110029, India
Email: isksaaeducation@gmail.com

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An Early-stage Comparison of Functional Outcomes Following Robotic-assisted Versus Conventional Total Knee Arthroplasty: A Systematic Review and Meta-analysis

Philip M. Parel, Grigory A. Manyak[1], Jaime A. Carvajal[2], Thomas Abraham[3], Mamun Al Rashid[3]

Department of Orthopaedic Surgery, The George Washington University School of Medicine and Health Sciences, Washington, DC, [1]Department of Orthopaedic Surgery, Case Western Reserve University School of Medicine, Cleveland, OH, [2]Department of Orthopaedic Surgery, University of Miami Miller School of Medicine, Miami, [3]JFK Medical Center, West Palm Beach, FL, USA

Abstract

Introduction: Conventional total knee arthroplasty (cTKA) is used to relieve pain and restore knee function and stability. Robotic-assisted TKA (rTKA) was introduced to improve the placement of surgical implants, decrease postoperative complications, and improve implant longevity. To date, studies examining functional outcomes and patient-reported pain between rTKA and cTKA in the short-term postoperative period are limited, and a meta-analysis of such early-stage outcomes has yet to be accomplished. Our study aims to evaluate the differences in function, alignment, and pain between rTKA and cTKA within 6 months postoperatively through meta-analysis. **Materials and Methods:** A literature search of the PubMed and Cochrane electronic databases was performed in December 2021 with Medical Subject Headings and search terms limited to "knee replacement," "knee arthroplasty," and "robotic knee surgery." Subsequent analysis was conducted on all retrieved studies written in English. **Results:** Thirteen clinical studies were considered for systematic review, of which nine were included in meta-analysis. 1,336 cases of TKA were analyzed: RTKA ($n = 618$) and cTKA ($n = 718$). There were no significant differences between rTKA and cTKA in range of motion (mean difference,-0.08°; $P = 0.55$), functional score of the Knee Society Score (mean difference, 0.04; $P = 0.78$), oxford knee score (mean difference, −0.04; $P = 0.81$), and Functional score of the western ontario and mcmaster universities osteoarthritis index (WOMAC-F) (mean difference, −0.42; $P = 0.41$). There were no significant pain differences in Short Form Health Survey Bodily Pain (mean difference, −0.08; $P = 0.64$) and pain score of the WOMAC (WOMAC-P) (mean difference, −0.25; $P = 0.47$). However, rTKA subjects achieved more accurate mechanical axis alignment than cTKA subjects (mean difference, −0.50°; $P < 0.01$). **Conclusion:** Although limb alignment correction is more accurate in rTKA than cTKA, functional and pain metrics are comparable between the two procedures within 6 months' follow-up, suggesting no added clinical benefits for rTKA versus cTKA.

Keywords: Mechanical axis, meta-analysis, robotic, short-term, total knee arthroplasty

Introduction

Conventional total knee arthroplasty (cTKA) is one of the most common joint replacement procedures in the United States used to treat knee osteoarthritis; the native knee joint is replaced with an artificial prosthesis composed of metal alloys, high-grade plastics, and polymers.[1] The goal of this procedure is to restore knee function with a stable knee and a neutrally aligned lower limb.[2] Since 2012, there have been over 995,000 reported TKA procedures, and this number is projected to grow and exceed 1.2 million by 2025.[3,4] Despite its widespread use, patient satisfaction studies show that approximately 20% of patients who receive TKA are unsatisfied with the intervention due to poor longevity and failures of cTKA implants.[5]

The use of robotic-assisted TKA (rTKA) began to combat high complication rates, improve patient outcomes, and subsequently

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Address for correspondence: Mr. Philip M. Parel, The George Washington University School of Medicine and Health Sciences, 2300 I St NW, Washington, DC 20052, USA.
E-mail: pmparel2018@gmail.com

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promote patient satisfaction postsurgically.[6] Various robotic systems, such as the MAKO (Stryker Orthopaedics, Mahwah, NJ), CASPAR (URS Ortho, Rastatt, Germany), ROBODOC (Curexo Technology, Fremont, CA), and NAVIO (Smith and Nephew, Memphis, TN) confer patient-specific and three-dimensional preoperative planning capabilities that can be intraoperatively modified to account for soft-tissue balancing and alignment.[7] These systems allow surgeons to more accurately position knee implants with the potential to improve clinical outcomes, decrease revision rates, and achieve up to 98.8% implant survivorship, thus theoretically improving patient satisfaction.[2,8-10]

To date, most studies focus on long-term functional outcomes and patient satisfaction between rTKA and cTKA. These studies collect the data for up to 10 years during follow-up appointments and have shown no long-term, functional differences between rTKA and cTKA.[11] Further, recent evidence suggests that, despite the greater cost and surgical time associated with rTKA, early functional and quality of life differences may exist due to the greater accuracy of implant positioning, reduced soft-tissue injury, and reduced manipulation under anesthesia associated with rTKA.[12-14] However, clinical outcomes and patient satisfaction within 6 months postoperatively in rTKA and cTKA patients are understudied and are pertinent to dynamic patient populations eager to return to activity. These patient populations are experiencing a dramatically increased utilization of TKA, with some reports estimating a 20-fold increase in patients under 60 years of age in the past few decades alone.[15,16] Thus, surgical techniques that provide early clinical success are highly pertinent to this growing population.

Our study sought to examine whether rTKA leads to improved early-stage functional outcomes compared with cTKA using well-established metrics in the literature via meta-analysis. Specifically, we aimed to answer the following questions: (1) Do any preoperative functional, radiological, or patient-reported pain outcomes differences exist between patients who receive rTKA compared with traditional cTKA? (2) Does rTKA lead to more improved functional and radiological outcomes than cTKA within 6 months postoperatively? (3) Does rTKA lead to lower pain levels than cTKA within 6 months postoperatively? Given the lack of functional differences seen between rTKA and cTKA in long-term studies, we hypothesized that rTKA would lead to similar preoperative and postoperative characteristics compared with cTKA in the short-term. To the best of our knowledge, this is one of the first meta-analysis studies to report on early-stage rTKA and cTKA outcomes.

Materials and Methods

Search strategy and criteria

A multi-database systematic review and meta-analysis of the literature of the US National Library of Medicine (PubMed/MEDLINE) and Cochrane Database of Systematic Reviewers electronic databases were performed in December 2021 for the articles pertaining to functional, radiological, and pain outcomes in rTKA and cTKA. The specific Medical Subject Headings and search terms were limited to "knee replacement," "knee arthroplasty," and "robotic knee surgery." The authors collected and synthesized the data from previous clinical trials in which informed consent has already been obtained by the trial investigators in conformation to the Declaration of Helsinki. Subsequent analysis was conducted on all retrieved studies written in English.

Inclusion and exclusion criteria

The inclusion criteria for this meta-analysis were as follows: (1) Clinical studies, (2) studies comparing rTKA to cTKA in live human subjects, and (3) articles measuring the following functional, radiologic, or pain outcomes at follow-up periods of 1–6 months postoperatively:Range of motion (ROM), oxford knee score (OKS), the functional score of the Knee Society Score (KSS-F), the pain (WOMAC-P) and functional (WOMAC-F) scores of the Western Ontario and McMaster Universities Arthritis Index score, the Bodily Pain score of the Short Form Health Survey (SF-36), and mechanical axis alignment. The exclusion criteria were as follows: (1) studies using cadavers or animal subjects, (2) studies that were unpublished or published in a nonpeer reviewed journal, (3) studies not written in English, (4) studies that were unavailable as full texts, (5) abstracts, (6) case reports or series, (7) review articles, (8) letters to the editor, and (9) studies that did not analyze TKA. Two independent reviewers separately screened the databases using the titles and abstracts for relevance, and the full text was subsequently examined against the inclusion and exclusion criteria. Studies satisfying the inclusion and exclusion criteria were independently reviewed by all authors. If disagreement between the reviewers occurred, discrepancies between the two authors were resolved through discussion. After initial screening, 13 studies were considered for eligibility, of which four studies were excluded for failing to meet the inclusion and exclusion criteria for measuring undesired outcomes or did not have the appropriate follow-up period [Figure 1].

Data extraction

The data extracted by the two reviewers from the selected studies included study design, year of publication, number of patients undergoing rTKA and cTKA, respectively, and the mean and standard deviations (SD) for the functional, radiological, and patient-reported pain outcomes of the intervention. The functional outcomes were measured by the OKS, KSS-F, WOMAC-F, and ROM. The analyzed radiological outcome included the mechanical axis alignment of the joint. Patient-reported pain outcomes included the SF-36 and WOMAC-P. Further, to evaluate risk, the American Society of Anesthesiologist (ASA) scoring system was used as a metric. When SDs were unavailable, the values were imputed from the appropriate *P* values in accordance with the Cochrane Handbook for Systematic Reviews of Interventions.[17] The Level of Evidence in the included studies was determined using the Oxford Center for Evidence-Based Medicine Levels of Evidence.[18]

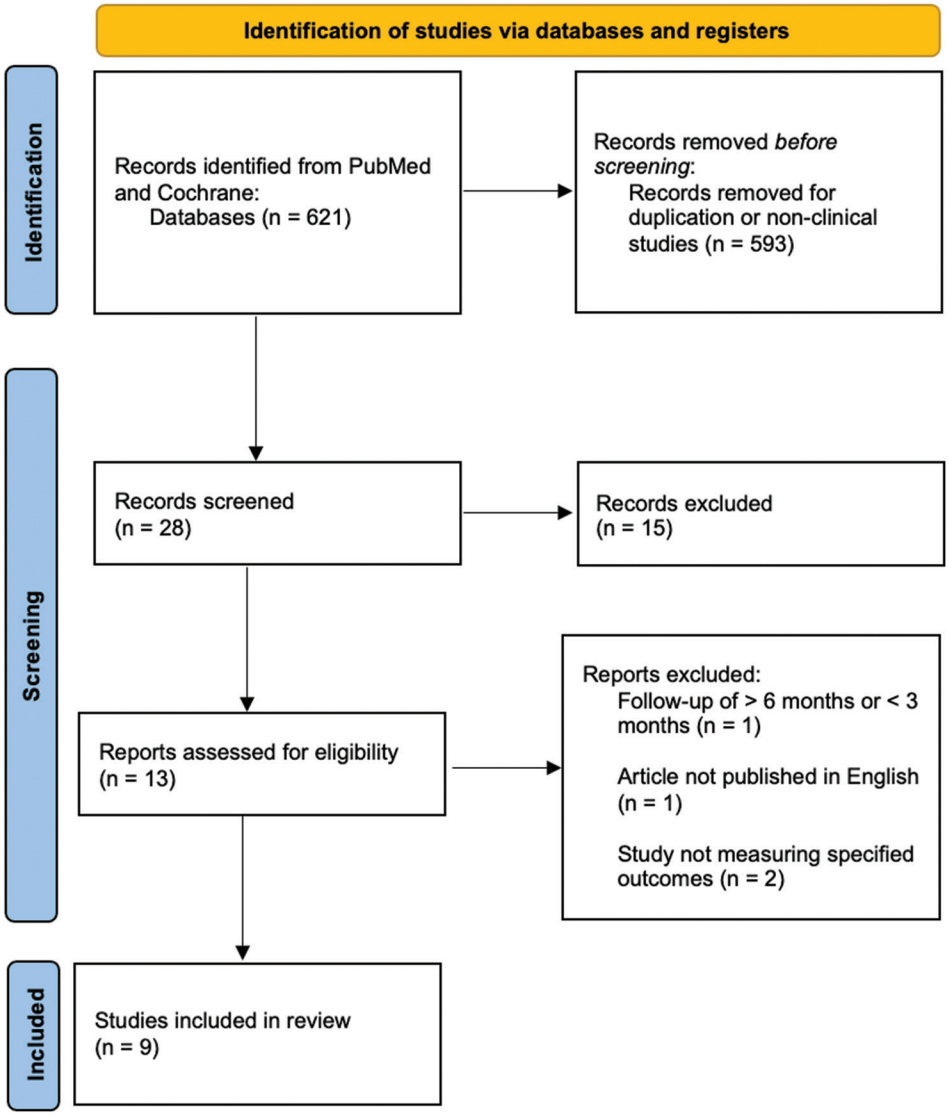

Figure 1: The PRISMA flow diagram. PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses

Statistical analysis of data

Study bias was minimized by using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the methodological quality of the included studies was quantified using the modified Coleman Methodology Score, which ranges from 0 to 100 with higher scores indicating the absence of biases and confounding factors.[19,20] The final score was categorized as excellent (85–100 points), good (70–84 points), fair (50–69 points), or poor (<50 points). Publication bias was evaluated using the Egger's regression test and minimized by adhering to the PRISMA guidelines. StataCorp LLC: College Station, Texas, USA was used for all statistical analysis and figure production based on the guidelines provided in the Cochrane Handbook for Systematic Reviews of Interventions.[17] The random-effects model with a 95% confidence interval (CI) was used in the meta-analysis to account for any differences in the rTKA treatment effect between the studies when heterogeneity was greater than 50% and a fixed-effects model was used when the heterogeneity was <50%. A two-tailed $P = 0.05$ was considered statistically significant. The I^2 statistic was used to determine study heterogeneity. A small effect of heterogeneity was defined as 0% <I^2 <40%, a moderate effect of heterogeneity was defined as 30% <I^2 <60%, and a substantial heterogeneity was defined as 50% <I^2 <90%.[21] If 75% <I^2 <100%, then heterogeneity was concluded to have an extremely high effect on the variance, and thus, any perceived differences between rTKA and cTKA outcomes were more likely to be due to heterogeneity between the studies rather than a true effect.[21]

Results

Search results and demographics

Nine clinical studies were included in the meta-analysis, of which three were randomized-controlled trials with Level of

Evidence I and six were nonrandomized prospective cohort or retrospective cohort clinical studies with Level of Evidence II and III [Table 1].[6,12,22-28] All included studies had fair-good methodological quality as assessed by the modified Coleman Methodology Score. Using the Egger test, no publication bias was detected in studies reporting of ROM and KSS ($P > 0.05$). Extracted values used in the meta-analysis are displayed in Tables 2 and 3.

There were a total of 1,336 cases of TKA: RTKA ($n = 618$) and cTKA ($n = 718$). Follow-up periods ranged from 6 weeks to 6 months. rTKA and cTKA groups were matched for age, sex, and body-mass index. Further, three studies reported no notable differences in the ASA scores.[23,27,28] Most of the patients in these studies had mild (ASA 2) or moderate (ASA 3) systematic disease.

In the rTKA subjects, one study relied on the NAVIO system, three studies utilized the ROBODOC system, five studies used the MAKO system for surgical assistance. Preoperative and postoperative ROM were measured in six studies, KSS-F was measured in five studies, and two studies measured SF-36 Bodily Pain, OKS, mechanical axis alignment, WOMAC-P, and WOMAC-F.

Were there any preoperative functional, radiological, or pain differences in robotic-assisted total knee arthroplasty and conventional total knee arthroplasty?

There were no significant functional differences between rTKA and cTKA in ROM (mean difference, −0.04°; 95% CI, −0.21°–0.14°; $P = 0.70$), KSS-F (mean difference, 0.06; 95% CI, −0.08–0.20; $P = 0.41$), or WOMAC-F (mean difference, 0.05; 95% CI, −0.21–0.32; $P = 0.69$). There was no significant pain difference in SF-36 bodily pain (mean difference, 0.33; 95% CI, −0.02–0.69; $P = 0.07$) or WOMAC-P (mean difference, 0.04; 95% CI, −0.22–0.30; $P = 0.76$). There were no significant radiological differences in mechanical axis alignment (mean difference, −0.10°; 95% CI −0.46° to 0.25°, $P = 0.57$). However, the rTKA subjects had significantly lower OKS (mean difference, −0.44; 95% CI, −0.80–0.08; $P = 0.02$) than cTKA subjects. Low heterogeneity was observed for all preoperative outcomes.

Were there any postoperative functional, radiological, or pain differences in robotic-assisted total knee arthroplasty and conventional total knee arthroplasty?

There were no significant differences between rTKA and cTKA in ROM (mean difference, −0.08°; 95% CI, −0.35°–0.19°; $P = 0.55$), KSS-F (mean difference, 0.04; 95% CI, −0.24–0.33; $P = 0.78$), OKS (mean difference, −0.04; 95% CI, −0.40–0.31; $P = 0.81$), and WOMAC-F (mean difference, −0.42; 95% CI, −1.43–0.59; $P = 0.41$). There were no significant pain differences in SF-36 bodily pain (mean difference, −0.08; 95% CI, −0.44–0.27; $P = 0.64$) and WOMAC-P (mean difference, −0.25; 95% CI, −0.92–0.43; $P = 0.47$) [Figures 2-4]. However, rTKA subjects achieved more accurate mechanical axis alignment than cTKA subjects (mean difference, −0.50°; 95% CI, −0.86° to −0.14°, $P < 0.01$). ROM ($I^2 = 66.9\%$), KSS-F ($I^2 = 60.7\%$), WOMAC-P ($I^2 = 75.3\%$), and WOMAC-F ($I^2 = 88.2\%$) all exhibited substantial heterogeneity.

The three RCTs were separately analyzed to account for the substantial heterogeneity in ROM and KSS-F. Sub-group analysis revealed no significant differences between rTKA and cTKA in ROM (mean difference, −0.31°; 95% CI, −0.62°–0.00°; $P = 0.051$) or KSS-F (mean difference, 0.05; 95% CI, −0.30–0.40; $P = 0.78$) and heterogeneity was low for both ROM ($I^2 = 11.5\%$) and KSS-F ($I^2 = 0\%$). Moreover, rTKA subjects sustained more accurate mechanical axis alignment than cTKA subjects (mean difference, −0.50°; 95% CI, −0.86° to − 0.14°; $P < 0.01$).

Discussion

In this meta-analysis of 9 studies, totaling 1336 knees, we examined short-term differences in functional outcomes and patient-reported pain in patients undergoing either rTKA or cTKA. Our study found comparable functional outcomes– as measured by ROM, OKS, KSS-F, and WOMAC-F– and similar patient-reported pain levels – as measured by SF-36 Bodily Pain score and WOMAC-P – between patients receiving rTKA or cTKA within 6 months postoperatively, thus validating our hypothesis. Mechanical axis limb alignment, however, was

Table 1: Descriptive data of studies used in meta-analysis[a]

Study	Follow-up period	Type of study	Robotic system	Level of evidence	Modified Coleman methodology score
Held *et al*. (2021)	3 months	Retrospective cohort	NAVIO	III	50
Khlopas *et al*. (2020)	3 months	Prospective cohort	MAKO	II	63
Marchand *et al*. (2017)	6 months	Retrospective cohort	MAKO	III	52
Naziri *et al*. (2019)	90 days	Retrospective cohort	MAKO	III	50
Samuel *et al*. (2021)	90 days	Retrospective cohort	MAKO	III	51
Smith *et al*. (2021)	6 weeks	Prospective cohort	MAKO	II	60
Liow *et al*. (2016)	6 months	RCT	ROBODOC	I	69
Song *et al*. (2011)	6 months	RCT	ROBODOC	I	66
Liow *et al*. (2014)	6 months	RCT	ROBODOC	I	69

[a]Level of evidence was determined using the Oxford Centre for Evidence-Based Medicine Levels of Evidence. RCT: Randomized control trial

Table 2: Preoperative outcome variables extracted for meta-analysis

Study	Mean±SD	
	rTKA	cTKA
ROM		
Naziri *et al*. (2019)	117.5±6.0	118.5±6.0
Samuel *et al*. (2021)	-	-
Held *et al*. (2021)	112±0.01	112±0.01
Liow *et al*. (2014)	121±17.4	119.8±17.9
Song *et al*. (2011)	120±16	123±14.3
Liow *et al*. (2011)	121±17.4	119.8±17.9
KSS		
Held *et al*. (2021)	52.6±20.3	50.6±20.3
Khlopas *et al*. (2020)	44.7±20.0	46±20.0
Smith *et al*. (2021)	44±21.5	43±21.5
Liow *et al*. (2014)	55.9±16.9	51±20.4
Liow *et al*. (2016)	55.4±16.9	51±20.4
Mechanical axis alignment		
Liow *et al*. (2014)	8.8±4.6	8.6±6.3
Song *et al*. (2011)	9.1±5.9	10.9±8.6
OKS		
Liow *et al*. (2014)	34.3±7.8	37.4±8.7
Liow *et al*. (2016)	33.6±7.8	38.2±9.5
SF-36		
Liow *et al*. (2014)	33.4±16.6	28±15.4
Liow *et al*. (2016)	33.4±16.6	28±15.4
WOMAC-P		
Marchand *et al*. (2017)	-	-
Held *et al*. (2021)	47.4±23.0	46.4±23.0
WOMAC-F		
Marchand *et al*. (2017)	-	-
Held *et al*. (2017)	47.4±20.8	46.3±20.8

TKA: Total knee arthroplasty, rTKA: Robotic-assisted TKA, cTKA: Conventional TKA, SD: Standard deviation, ROM: Range of motion, KSS: Knee Society Score, OKS: Oxford Knee Score, SF-6: Short Form Health Survey

Table 3: Postoperative outcome variables extracted for meta-analysis

Study	Mean±SD	
	rTKA	cTKA
ROM		
Naziri *et al*. (2019)	121.3±28.6	109.8±28.6
Samuel *et al*. (2021)	117.8±10.2	120.3±9.9
Held *et al*. (2021)	118±11.1	116±11.1
Liow *et al*. (2014)	116±17.8	122.4±10.7
Song *et al*. (2011)	129±13.8	129±12.8
Liow *et al*. (2011)	114.1±20.1	122.4±10.7
KSS		
Held *et al*. (2021)	59.3±23.7	65.1±23.7
Khlopas *et al*. (2020)	65.5 (-)	67.2 (-)
Smith *et al*. (2021)	63±15.9	58±15.9
Liow *et al*. (2014)	71.3±18.5	70±15.6
Liow *et al*. (2016)	70.5±20.30	70±15.6
Mechanical axis alignment		
Liow *et al*. (2014)	1.3±0.9	1.8±1.2
Song *et al*. (2011)	0.2±1.6	1.2±2.1
OKS		
Liow *et al*. (2014)	18.8±5.7	19.6±6.8
Liow *et al*. (2016)	19.9±7.9	19.6±6.8
SF-36		
Liow *et al*. (2014)	65±27.1	64.8±25.4
Liow *et al*. (2016)	60±28.5	64.8±25.4
WOMAC-P		
Marchand *et al*. (2017)	3.0±3.0	5.0±3.0
Held *et al*. (2021)	47.4±23.0	46.4±23.0
WOMAC-F		
Marchand *et al*. (2017)	4.0±5.0	9.0±5.0
Held *et al*. (2021)	74.7±52.1	71.9±52.1

TKA: Total knee arthroplasty, rTKA: Robotic-assisted TKA, cTKA: Conventional TKA, SD: Standard deviation, ROM: Range of motion, KSS: Knee Society Score, OKS: Oxford Knee Score, SF-6: Short Form Health Survey

more accurately restored in the short-term for patients who underwent rTKA versus cTKA.

Recent trends throughout the last decade have shown a 56% increase in TKA procedures nationwide, and future projections estimate the number of TKA procedures will increase by 143% by 2050.[4,29] Further, clinical trends have shown a dramatic increase in TKA popularity in younger populations, which is predicted to continue increasing in the coming years.[15] While cTKA is a highly successful procedure, the rate of poor outcomes ranges from 7% to 20% and is due to pain, infection, stiffness, and poor function postoperatively.[30] Revision TKA is conducted after failed cTKA and is a more technically demanding procedure with greater complication rates, costs, and poorer outcomes when compared with cTKA.[31] Indeed, along with the rise in incident TKA procedures, these revision TKA procedure rates are projected to increase by 78%–182% as well.[32]

Prior meta-analysis studies examined the long-term (>10 years) and mid-term (3–10 years) functional, radiological, and pain comparisons between these two procedures and have concluded no added benefit of rTKA over cTKA. In a mid-term follow-up of 273 knees, there were no functional differences between rTKA and cTKA as assessed by WOMAC (95% CI: 3.45–0.19, $P = 0.08$).[33] Moreover, in a long-term follow-up study of 163 knees, there were no ROM (95% CI: 1.7–5.2, $P = 0.637$) nor patient-reported satisfaction differences as measured by SF-36 (95% CI; 3.3–8.7, $P = 0.539$).[34] These studies, however, failed to evaluate short-term, clinically relevant differences, which would be particularly beneficial to younger, dynamic patient populations eager to return to routine activity. To the best of our knowledge, Bouché *et al*. is the only published meta-analysis to have attempted to fill this chronology by examining WOMAC, KSS, and alignment differences at 6 months postoperatively; however, this analysis

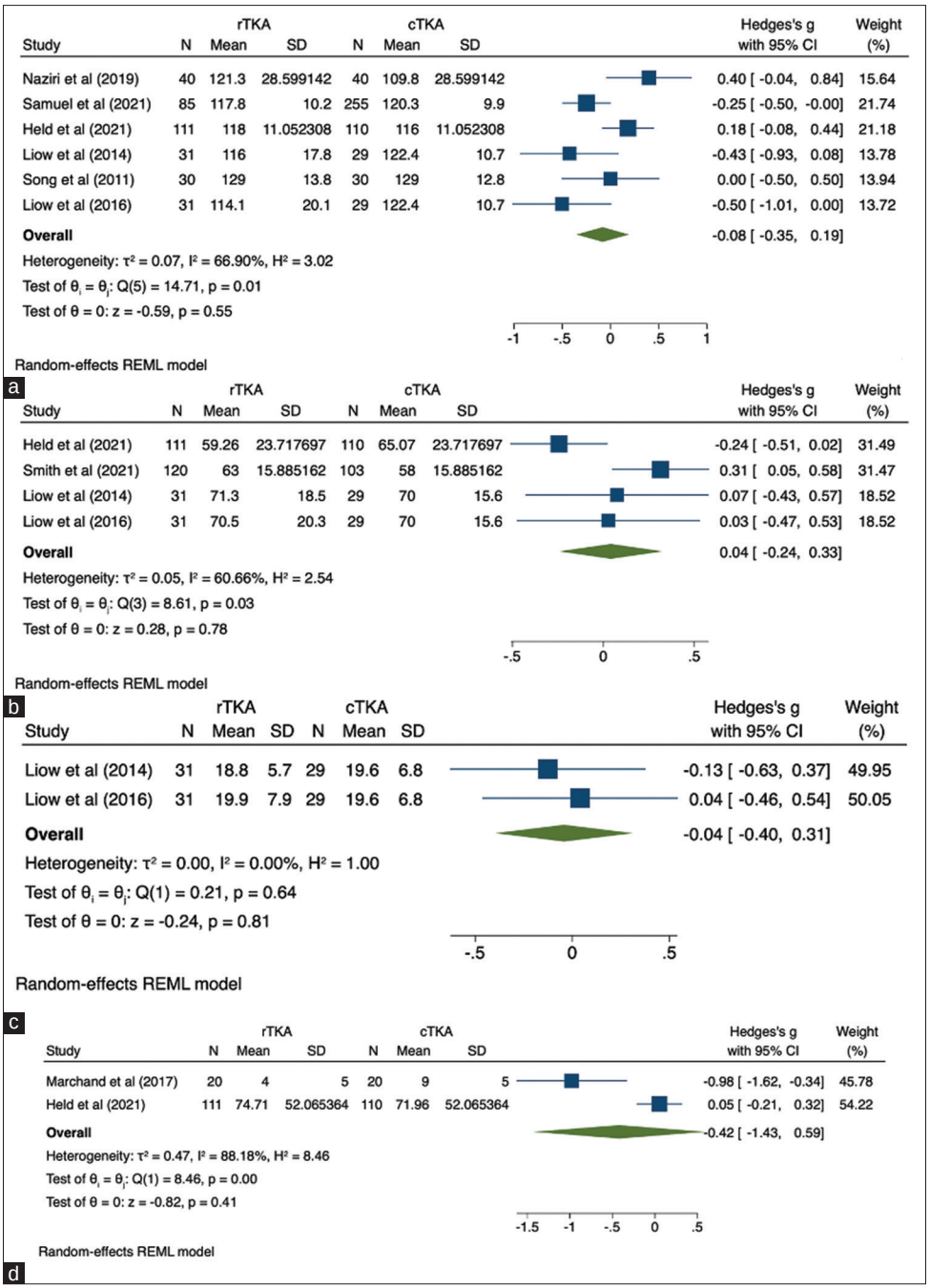

Figure 2: Forest plot for postoperative ROM (a), KSS-F (b), OKS (c), and WOMAC-F (d) between rTKA and cTKA in selected studies. ROM: Range of motion; KSS-F: Functional score of the Knee Society Score; OKS: Oxford knee score; WOMAC-F: Functional Score of the Western Ontario and McMaster Universities Osteoarthritis Index; rTKA: Robotic-assisted total knee arthroplasty; cTKA: Conventional total knee arthroplasty

only succeeded synthesizing two studies utilizing the robotic systems.[35]

Our study suggests that rTKA may not be superior to cTKA in functional outcomes. However, we found improved, short-term, mechanical axis alignment in rTKA compared to cTKA, which contrasts long-term study findings that showed no alignment differences between these two methods.[11] Of interest, restoration of neutral mechanical alignment is one of the key criteria of successful TKA.[36] Neutral alignment of the knee reduces mechanical and shear stresses on the prosthesis interface, which is essential for the long-term survivability of the joint implant.[37] Given that prior studies found no differences in long-term implant survivorship, however, the additional 0.5° of accuracy in rTKA may not be of clinical significance. Indeed, literature suggests that postoperative alignment of the lower limb should be within 3° of the neutral mechanical axis, so the additional 0.5°

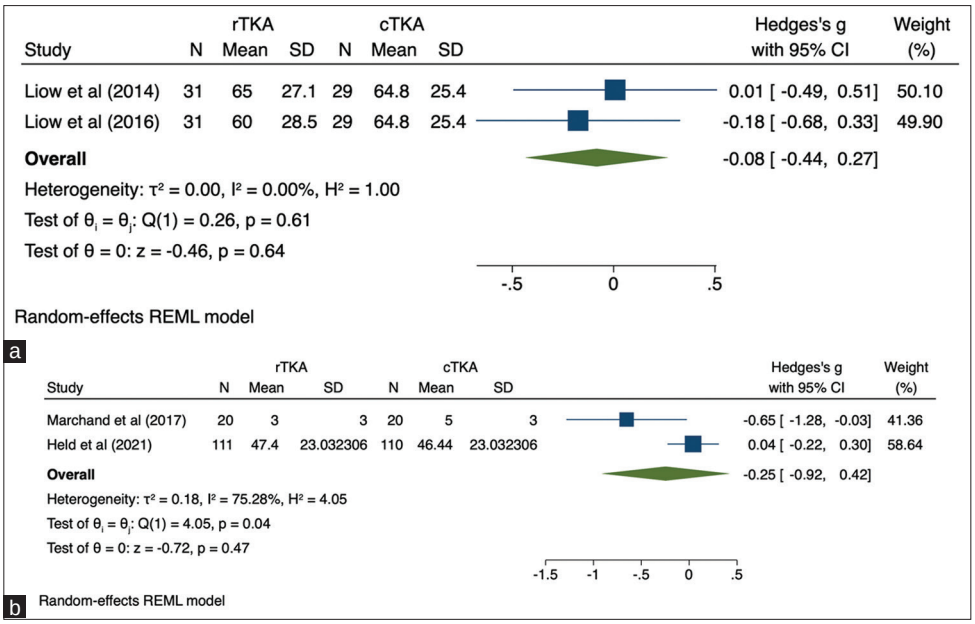

Figure 3: Forest plot for postoperative SF-36 (a) and WOMAC-P (b) between rTKA and cTKA in selected studies. SF-36: Bodily Pain score of the Short Form Health Survey; WOMAC-P: Pain Score of the Western Ontario and McMaster Universities Osteoarthritis Index; rTKA: Robotic-assisted total knee arthroplasty; cTKA: Conventional total knee arthroplasty

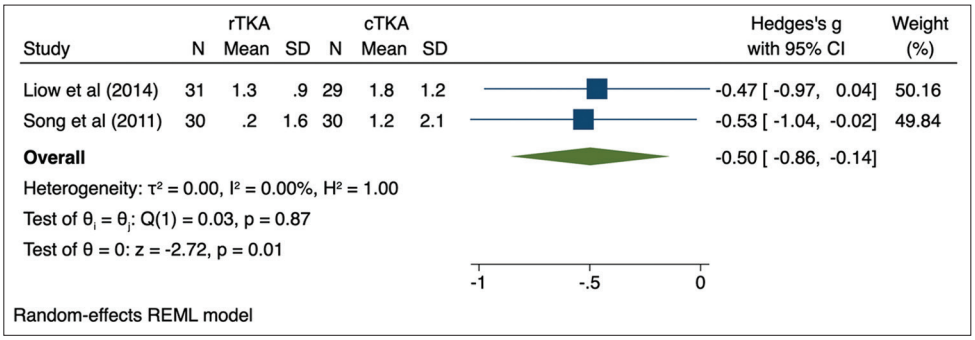

Figure 4: Forest plot for postoperative mechanical axis alignment between rTKA and cTKA in selected studies. rTKA: Robotic-assisted total knee arthroplasty; cTKA: Conventional total knee arthroplasty

of accuracy between rTKA and cTKA may only provide subclinical benefit.[38]

Further, in accordance with the negligible long-term pain differences noted in other studies in the literature, short-term pain differences between the two procedures are also absent. Thus, rTKA is unlikely to curb the predicted increase in revision and dissatisfaction rates in the coming years. In fact, rTKA is not without drawbacks. rTKA is 10% more expensive than cTKA and has an increased surgical time, despite having only comparable long-term functional outcomes to cTKA.[10,39] Further, as demonstrated in this meta-analysis, rTKA has equivalent short-term functional outcomes to cTKA as well. Recently, Chin *et al*. conducted similar meta-analyses and found no long-term ROM differences, which suggests that any flexion differences between rTKA and cTKA may only exist within the first 6 months.[33] Thus, until robotic surgery demonstrates improved early-stage functional outcomes, cTKA remains as a cost-effective and commensurate alternative to patients receiving this treatment.[10]

This study has some limitations that require consideration including variance in follow-up periods between 6 weeks or 6 months and the inclusion of both RCT and non-RCT studies. Ideally, multicenter RCTs with consistent follow-up periods would provide more definitive, early-stage evidence of differences between the two TKA methodologies. However, only three RCTs exist in the literature that report on early outcomes, and thus, an RCT-only meta-analysis in early outcomes is currently not yet feasible. Related, the finding of a significant difference in mechanical axis alignment between rTKA and cTKA is associated with only a subset of two

studies due to the limited availability of current literature on short-term alignment. As rTKA becomes more widespread, future meta-analyses will benefit from incorporating additional RCTs that measure early-stage alignment to further validate the present results. In addition, surgical techniques may have differed between studies, which could have contributed to variance in results. Song *et al*., for example, specified the retention of the cruciate ligament, whereas Liow *et al*. did not.[6,12] Furthermore, in addition to following PRISMA guidelines, we quantified publication bias using the Egger test; however, this analysis requires a minimum of 5-6 studies to be appropriately powered to detect publication bias.[40] Due to the nature of our research question and the paucity in the current literature on short-term outcomes in rTKA versus cTKA, the publication bias associated with ROM and KSS were only able to be assessed. For all other outcomes, publication bias was not quantifiable. However, prior studies demonstrate that adherence to PRISMA guidelines improves the reporting quality of meta-analyses and provides substantial transparency in the selection process of studies in the systematic review, thus minimizing the publication bias for the outcomes for which publication bias was un-assessable.[41] Finally, all the studies included in our analysis were based on a limited selection of robotic systems: The ROBODOC, NAVIO, and MAKO. We were unable to assess the study variables in other currently used robotic systems. Future directions would include a multi-center comparative analysis of functional, radiological, and patient-reported outcomes between rTKA and cTKA over a larger patient population and with different robotic systems to generalize results and substantiate the findings of our study. Moreover, future studies may benefit from a comparative meta-analysis examining functional outcomes between the various robotic technologies. Finally, studies on the clinical benefit of rTKA in the context of other surgical approaches may provide a more holistic outlook on the benefit of rTKA for patients with knee osteoarthritis, and larger prospective studies are required to substantiate such findings in the present study.

This systematic review and meta-analysis of the literature found that functional outcomes and patient-reported pain levels are comparable in both rTKA and cTKA within 6 months postoperatively. Our study suggests that rTKA may not provide a short-term clinical benefit apart from improved alignment, which may not necessarily translate to long-term alignment improvements as noted in the previously published literature. Thus, our study suggests that although short-term limb alignment is more accurate in rTKA than cTKA, the comparable functional and pain metrics in conjunction with lack of improvement in mechanical alignment in the long-term suggest no added clinical benefits for rTKA versus cTKA.

Data availability

Data extracted from included studies can be provided, upon reasonable written request, to the corresponding author.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Review Article

Total Elbow Arthroplasty: An Update on Surgical Techniques and Approaches

Zachary Tyler Skipper, Senthilvelan Rajagopalan[1], Srinivas B. S. Kambhampati[2], Bhavya Chand Manne[3], Srinath Kamineni[4]

Mississippi Sports Medicine and Orthopaedic Surgery Center, Jackson, MS, [4]Department of Orthopaedic Surgery and Sports Medicine, University of Kentucky, Lexington, KY, USA, [1]Department of Shoulder and Upper Limb Surgery, MIOT International, Chennai, Tamil Nadu, [2]Sri Dhaatri Orthopaedic, Maternity and Gynaecology Center, Vijayawada, [3]Department of Orthopaedics, VIRRD Hospital, Dwaraka Tirumala, Andhra Pradesh, India

Abstract

Total elbow arthroplasty (TEA) has significantly evolved over the last few decades and is used to treat advanced elbow arthritis (rheumatoid, primary, and posttraumatic), trauma sequelae, and acute unreconstructable fractures. TEA design varies between linked, unlinked, and convertible types. Long-term complications including infection, aseptic loosening, instability, and periprosthetic fractures continue to be significant. The current evidence for TEA is summarized in this article, which includes surgical approaches, designs of elbow replacements, outcomes, and surgical tips based on the previous literature.

Keywords: Approaches, elbow arthritis, surgical technique, total elbow replacement

Introduction

The elbow is important for daily activities, notably getting hand to mouth/head for eating, face cleaning, grooming, and reaching areas for personal hygiene. Pathologies that lead to elbow dysfunction, either pain and/or stiffness, which cannot be treated predictably with other methods, are considered for elbow arthroplasty. Alternatives to elbow replacement surgery include resection arthroplasty, interposition arthroplasty, and arthrodesis.

Excision arthroplasty, which involves the resection of the distal humerus and proximal ulna, was first documented in 1780. This technique had instability issues, limiting its functional usage. Interposition arthroplasty involves the interposition of a biologic structure, for example, dermis, fascia, or tendon, to provide pain relief and also address some of the instability issues of resection arthroplasty. Although the literature demonstrates that interposition improves stability, it provides less dependable pain mitigation than resection arthroplasty.[1]

Robineau first attempted to replace the elbow joint with metal and rubber in 1925, and in 1941, Boerema used a hinged nonanatomical total elbow prosthesis. Venable published a case report in 1952 in which a custom anatomical prosthesis had a 15-month follow-up with an excellent outcome, which sparked the development of other elbow arthroplasty designs.[2] Multiple designs emerged, including rigid-linked, semi-rigid designs coupled with pins, linkable, and unlinked designs. The designs had varying degrees of constraint, and each had its own set of advantages and disadvantages.[3]

In the early 1970s, the most common indication for total elbow arthroplasty (TEA) was advanced rheumatoid arthritis (RA). However, due to advances in the medical treatment of RA patients with disease-modifying antirheumatic medications (DMARDs), the number of TEAs conducted for RA has declined significantly. TEA has also shown to be an effective treatment for primary osteoarthritis, posttraumatic arthritis, and some types of recalcitrant elbow instability. More recently, TEA has been advocated for acute complex unreconstructable intra-articular distal humerus fractures in the elderly,[4] with encouraging early and mid-term results.

Address for correspondence: Dr. Senthilvelan Rajagopalan, Department of Shoulder and Upper Limb Surgery, MIOT International, Chennai, Tamil Nadu, India.
E-mail: velansenthil78@gmail.com

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However, long-term outcomes, complications, and revision rates are pending.

Indications

The indications of TER are Inflammatory arthritis (RA), primary osteoarthritis, posttraumatic arthritis, low demand, elderly patients >70 years with complex intra-articular fractures [Figure 1], chronic instability/history of resection arthroplasty with limited functionality or ankylosed elbow joint.

Contraindications

Active infection or Charcot joints: Caution should be exercised while recommending TEA to patients under 65 who are relatively active. Patients who have already had olecranon osteotomy may be a relative contraindication for TEA in view of the altered proximal ulna anatomy. After TEA, patients are usually advised not to lift more than 2lb repetitively, or 10 lb as a single event.

Types of Implants

A constraint is a biomechanically defined term, but it most often describes the resistance to instability or dislocation.

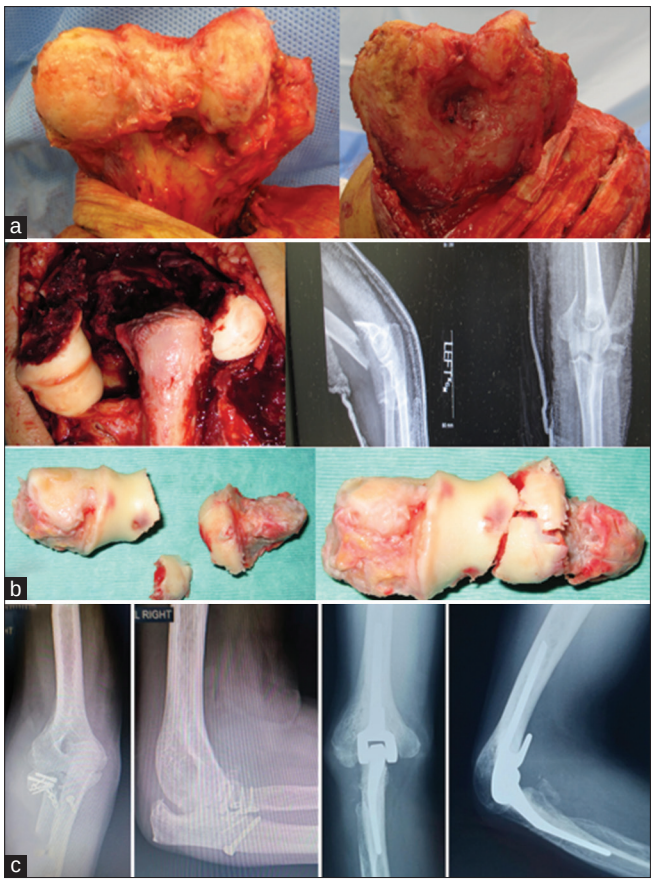


Figure 1: Some of indications of TEA are (a) Rheumatoid arthritis, (b) Unreconstructable distal humerus fractures in the elderly, (c) posttraumatic sequelae

The words, "constrained" and "nonconstrained" implants, are commonly used but are confusing and should be considered obsolete descriptive terminologies.

The term constraint should be described as a spectrum, e.g. low constraint to high constraint, instead of unconstrained and constrained. A more intuitive anatomical description of the physical connection between components is unlinked and linked prosthesis.[5]

Unlinked designs can have low constraint (Sorbie, Pritchard, Kudo, Ewald) or high constraint (Souter-Strathclyde) by design, and require competent ligamentous support and adequate bone quality. In addition, soft-tissue balancing is paramount to achieve a successful outcome in these designs. The linked (Sloppy Hinge – Coonrad-Morrey) "semi-constrained" design, with a moderate constraint and firm end point at the limit of the 7° laxity, has the best-published results of all designs and is the most widely used. In this design, the humeral component has an anterior flange intended to resist posterior and rotational forces. The "semi-constrained" hinge permits a small degree of varus–valgus laxity which reduces bone–cement interface stresses.[6] While this implant has the best overall published results, conversely the highest loosening rates have been reported in linked/"high-constraint" designs (Rigid Hinge-Dee) due to the rigidity and no out-of-plane laxity. The different types of Total Elbow replacements, designs and constraint level is elaborated in Table 1.

Preoperative Planning

(1) Hematological workup to exclude infection, poor diabetic control, acceptable baseline metabolic parameters, as well as routine preoperative indices

(2) Imaging should include plain radiographs, elbow anteroposterior and lateral views, to assess bone/canal size, shape, and curvature. Computed tomography (CT) scans can be helpful in some difficult cases of abnormal anatomy, malunions, congenital deformities, etc., although not routinely of value [Figure 2]. Magnetic resonance imaging scans are not routinely useful but may provide additional information in patients with previous arthrodesis, chronic instability, previous ulna nerve transposition, etc.

Patient Positioning

TEA can be carried out in the lateral or supine position. Arm tourniquet is usually used, but sometimes, it may limit proximal access if the incision needs to be extended proximally. The supine position allows for full-arm ROM intraoperatively. A pillow or rolled-up towel is placed on the chest to support and keep the elbow flexed at 90° [Figure 3]. This position requires an assistant to hold the arm across the chest of the patient during surgery, and adequate caution must be taken not to disturb the endotracheal tube.

In the lateral decubitus position, an arm positioner or bolster is used. The arm cannot be freely moved intraoperatively in this

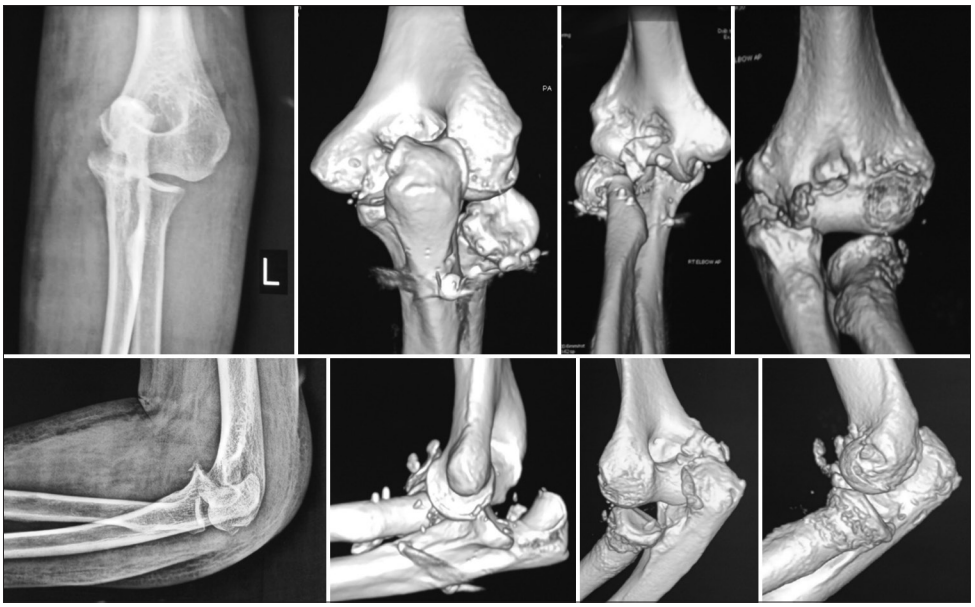


Figure 2: X-ray and CT 3D reconstruction images of chronic dislocated Elbow. CT: Computed tomography

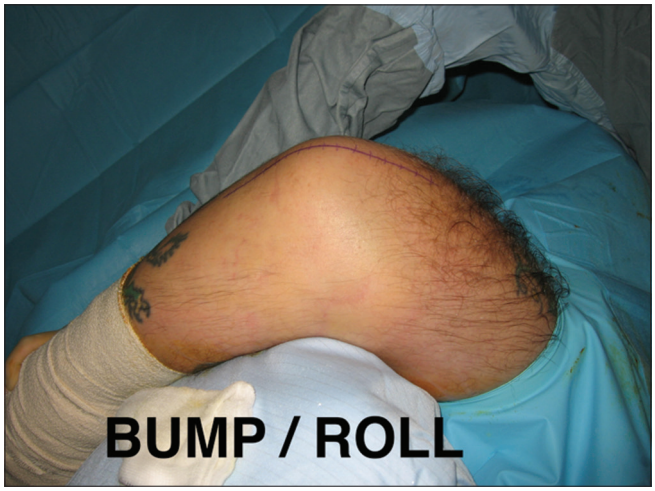


Figure 3: Bump or roll is placed under the elbow to keep it at 90° during surgery

position but provides a more stable position to operate. Patients can also be operated in the prone position over a bolster. Like the lateral position, this position does limit extremes of flexion but provides a stable position for the patient to be operated on.

Surgical Approaches

All approaches used in TEA use posterior longitudinal skin incision either medial or lateral to the tip of the olecranon to prevent wound issues. All approaches [Figure 4] are summarized in Supplementary [Table 1]. Some of the approaches are described below.

Triceps-splitting approaches

Campbell posterior triceps-splitting approach

In the Campbell posterior triceps-splitting approach,[7] a 15-cm incision is made 10 cm proximal and 5 cm distal to elbow. The triceps is split in the middle, anconeus reflected laterally, and flexor carpi ulnaris (FCU) reflected medially. Collateral ligaments are released if needed. The ulnar nerve is identified and protected. After implantation, triceps is repaired to the ulna using bone tunnels. This approach is rarely used for TEA since the triceps is completely taken down. However, it is used in revision surgery for elbows that have undergone multiple operations.

Van Gorder triceps-splitting and triceps-reflection approach

In this approach,[7] a standard posterior lateral para-midline incision is used. The ulnar nerve is identified mobilized, and full-thickness skin flaps are lifted. A distally based triceps flap is made measuring 10 cm long by 2–3 cm wide. The flap at the olecranon is wide distally and progresses to a point proximally, to allow for V-Y progression if necessary. The distal olecranon attachment must be preserved.

In addition, a sufficient amount of tendon on all sides must remain intact to allow tendon-to-tendon closure and healing during closure. To retain the reflected tendon distally, a tendon flap is lifted off the muscle, and the underlying triceps is split in line. A gauze can be wrapped around the tendon flap to keep it moist. The olecranon fossa is cleared, the MCL posterior band is released, and a medial and lateral window is used to expose the epicondyles.

This approach serves mainly as a revision TEA approach. The distal aspect of triceps tendon is dissected in a way to retain its insertion onto the olecranon, but the muscular components are reflected in continuity with the flexor and extensor muscles, off the ulna.

Triceps-sparing approaches

Para-olecranon triceps-sparing approach

In this approach,[8] a medial full-thickness fasciocutaneous flap is created around the medial epicondyle. The ulnar nerve

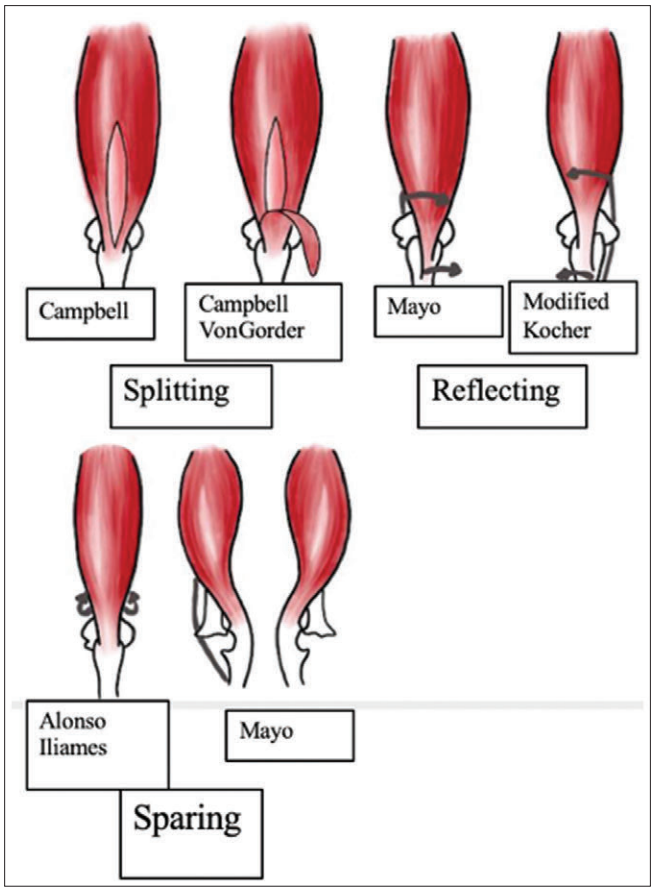


Figure 4: Schematic diagram elaborating different approaches to TEA

is freed, the medial intermuscular septum is released, and an anterior subcutaneous transposition is performed.

A smaller lateral full-thickness skin flap is created, which exposes the central triceps tendon and lateral border. The Boyd interval is developed along the lateral subcutaneous ulna border, leaving a cuff of forearm fascia for subsequent repair. The triceps tendon is split centrally and interval is extended by releasing around the lateral aspect of olecranon.

The lateral aspect of the triceps tendon, the common extensor origin, the humeral insertion of the lateral collateral ligament, and the joint capsule are then reflected subperiosteally off the lateral epicondyle and the LCL is tagged for repair.

Along with the common flexor origin, the anterior and posterior joint capsules and the MCL are subperiosteally elevated from the medial epicondyle. Once the distal humerus is circumferentially released, the elbow can be dislocated.

Triple-window surgical approach-hybrid exposure

The triple-window approach[9] avoids detaching the medial and lateral muscular triceps extensions, which would otherwise have to be repaired, thereby converting a contra tile element into noncontractile scar.

A midline posterior skin incision curves laterally around the olecranon tip. Three windows are created, medial, lateral, and central, in that order. After mobilization and protection of the ulnar nerve, the medial window is created, which involves dissection of the interval between the triceps and flexor pronator mass, into the pronator teres, as the ulna nerve is released into the forearm. Thereafter, the triceps is released from the posterior humerus. The medial epicondyle is freed from the flexor-pronator mass origin. The anterior surface of the humerus is released from brachialis and anterior capsule with n periosteal elevator. This provides complete medial access to the medial epicondyle, olecranon, and humerus, with the ulnar nerve mobile and protected.

The lateral window is created by incising the fascia over the lateral margin of triceps, and released proximally and distally over the origin of the proximal extensor mass insertion. The distal lateral border of the triceps is exposed and the incision is carried distally into the Kocher (ECU – Anconeus) interval. Sharp dissection of the LCL, extensor mass, and anterior capsule is carried out. The humerus can now be disarticulated and delivered through lateral window for humeral bone preparation.

The central window is made by making a split in the central triceps tendon and carried down to midline olecranon. The triceps tendon footprint is elevated from the olecranon without disturbing the medial and lateral muscular attachments. Through the posterior window, the ulna is readily accessible. The ulna can now be prepared, through the prepared humeral yolk/columns, in line with the shaft for easier orientation of the component insertion.

Triceps-reflection approaches

Bryan-Morrey approach

A 10–15-cm posterior incision is centered medially to the tip of the olecranon, and large subcutaneous full-thickness medial and lateral skin flaps are developed. The triceps medial border is elevated, and the ulnar nerve is identified, protected, and transposed anteriorly. The whole triceps insertion on the ulna is released. Once the flexor and extensor masses, capsule, and medial and lateral collateral ligaments have been released, the triceps is translocated over the lateral epicondyle. The joint can be dislocated and the articular surfaces are accessible.[10]

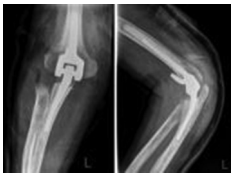
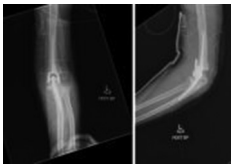
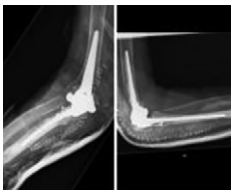
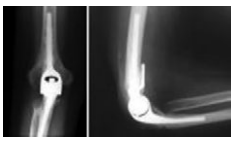
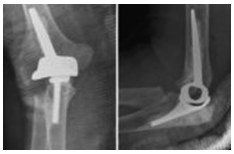
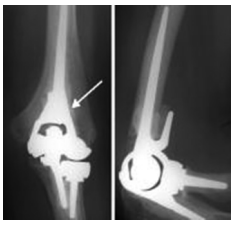
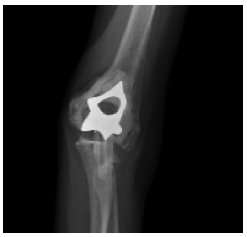
The triceps insertion is repaired with sutures through bone tunnels onto the ulna after implantation. The osteo-anconeus method entails cutting an osteoperiosteal flap off the ulna and removing a wafer of bone from the olecranon, which is subsequently reconstructed with bone tunnels, permitting bone-to-bone healing.

Triceps-on approach

The posterior skin incision is made slightly medial to the medial aspect of the olecranon tip.[11,12] The incision is deepened to the triceps fascia and medial subcutaneous tissue is undermined so that ulnar nerve can be dissected and transposed anteriorly.

Subperiosteal elevation of the FCU is done off the medial aspect ulna, and MCL is released. Subsequently, the medial side of the humerus is exposed, leaving the triceps insertion

Table 1: Total elbow replacement, features, and description

Type of prosthesis	Description	Constraint	Features	Picture
Coonrad/ Morrey total elbow	The prosthesis is made of titanium Ti–6Al–4V alloy and is a cemented prosthesis Coonrad/Morrey total elbow has a 12 years survival of 92.4% Zimmer	The connection of the components is linked, but semi-constrained	Anterior flange in distal humeral component	
Nexel total elbow	Made of titanium Ti–6Al–4V alloy and is cemented The survivorship rate without revision is 75% at 45 months[36] Zimmer	Constrained with thicker polyethylene bearing, compared with the Coonrad/ Morrey total elbow	Edge loading is reduced with the design. Joint reaction forces are distributed and in effect stress in joint is reduced	
GSB III Elbow Prosthesis	Titanium alloy, cemented 10 years survival rate of 0.8 (95% CI 0.74–0.85)[37] Zimmer	Component connection between humeral stem and the ulna component is "plug-in," nonconstrained	No anterior humeral flange	
Discovery Elbow System	Is made of CoCrMo or titanium alloy, and humeral, ulnar components are cemented 5 years survival rate was 88% and 79% at 10–14 years[38] Biomet	Constrained	Anterior Flange in distal humeral component	
Kudo type-5 prosthesis	Ulnar component is narrow and straight The survival rate analysis in RA showed 87.8% after five years and 70.7% after ten years[39] Stryker Howmedica Osteonics	Nonconstrained, unlinked prosthesis	Does not require cement for fixation	
Latitude elbow	Cemented Cobalt–chrome prosthesis Radial prosthesis can be done along with this prosthesis Survival analysis showed a survival rate of 82% at 10 years after surgery[40] Tornier	The components can be constrained, or nonconstrained unlinked or linked	Medial and lateral fins on the humeral stem resist rotation Concave barrel-shaped trochlea resists varus–valgus stress	
Souter–Strathclyde total elbow	Humeral component - Vitallium T Ulnar component-Ultra-high molecular weight polyethylene 12 years survivorship of 87% in patients with rheumatoid arthritis[41] Stryker Howmedica Osteonics	Cemented unlinked Prosthesis Partially constrained	The humeral component is very short Flanges into medial epicondyle and capitellum	

Images and content of Table courtesy: Oflazoglu K, Koenrades N, Somford MP, van den Bekerom MP. Recognizing the elbow prosthesis on conventional radiographs. Strategies Trauma Limb Reconstr 2016;11:161-8. RA: Rheumatoid arthritis, CI: Confidence interval

intact. The ulnohumeral joint and the distal humerus can be exposed by pronating the forearm. Anterior capsule elevation exposes the distal anterior humerus.

The LCL is then released from the lateral distal humerus. As triceps is not fully released manipulating the joint may feel tight, but this is addressed by periosteal dissection of the proximal triceps or distal FCU. This approach can be challenging for ulna visualization, especially in larger patients.

Surgery-Technical Tips

During surgery, the ulnar nerve is identified, released, isolated with a vessel loop, and transposed anteriorly if needed. It is

important not to hang any instrument from the ulnar nerve vessel loop as it may cause traction injury. When making bone cuts in the distal humerus, it should be made sure that stress risers are not created with the saw. The epicondyles, if fractured, can influence implant placement and implant longevity.

When the olecranon fossa is present, standard humeral insertion can be performed. This is the landmark for the seating point of the base of the anterior flange of the Coonrad-Morrey/Discovery/Latitude humeral component, and if the olecranon fossa is not present, an extended flange may be needed.

A wedge-shaped cancellous bone graft is prepared for placement behind the humeral flange as it provides for rotational stability once incorporated [Figure 5]. The bone graft is placed behind the flange on insertion, and the implant can be completely seated and coupled. The posterior flat surface of the distal humerus is used as a reference for component orientation. The component is inserted until the flange is completely engaged with the anterior cortex.

For ulnar canal preparation, the olecranon tip is removed, and the canal is entered at the base of the coronoid. The entry point is then enlarged toward the coronoid with a burr for easier component entry. During canal preparation, the broaches must be parallel to the subcutaneous border of the ulna to ensure the insertion track is parallel to the intramedullary canal. The tip of the coronoid is removed to avoid terminal flexion impingement. For the ulnar component, the component is inserted such that the implant is perpendicular to the olecranon's flat dorsal surface, thereby avoiding component malrotation.[13]

For triceps reattachment, the triceps should be repaired using a nonabsorbable suture in a running locking (Krackow) fashion. Care should be taken not to capture abundant triceps muscle fibers in the stitch. The triceps tendon is reattached to the flat surface of the olecranon process, and not the tip. The sutures should be passed through bone tunnels that begin at the periphery of the olecranon. During triceps reattachment, the elbow should be at 30°–45° of flexion when tying the knots to ensure appropriate tensioning.[13]

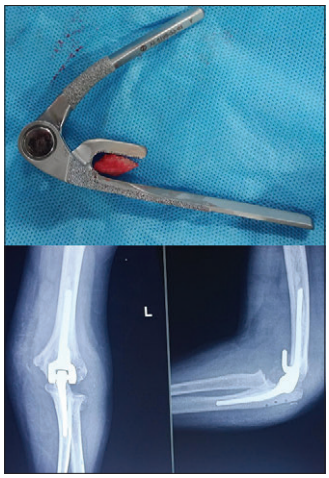


Figure 5: Wedge-shaped graft is kept in the anterior flange to provide rotational stability

Caution should be exercised in reapproximating the triceps to the flexor and extensor masses so as not to overtighten the repair and restrict motion. The knots tied directly over superficial areas on the ulna can cause pain, and hence it is better to place them under the anconeus.

Postoperatively, for compliant patients, on day 2, gentle active antigravity flexion and passive gravity-assisted extension exercises can begin. Greater than 90° elbow flexion is attempted after 5 weeks allowing sufficient time for the triceps to heal.

Outcomes

Successful TEA, whether linked or unlinked, restores function, relieves pain, and consistently improves elbow motion. RA patients with advanced disease have shown the longest survivorship with TEA. Some results have shown up to a 90% survival rate at 10 years for RA TEA. Individuals with inflammatory arthritides have much higher TEA survival rates compared to patients with trauma-related causes. Several studies reporting on TEA in RA with more than 10 years of follow-up with "semi-constrained" and "nonconstrained" TEA have shown that more than 85% of patients have satisfactory or outstanding functional results.[14] The overall mean weighted survival rate after 11.1 years was 79.2% in the systematic review by Welsink *et al*.,[15] and after 12.9 years for RA, it was 72.6%. The mean flexion and extension were 129° and 30°, respectively. The average Mayo Elbow Performance Score was 80.5–94.1[15] and the overall complication rate was between 11% and 38%. The outcomes of 461 TEAs using the semi-constrained Coonrad-Morrey prosthesis were reported by Sanchez-Sotelo *et al*. in patients with RA. At the final follow-up, 89% of elbows did not need revision.[16]

Functional demands are greater for patients with primary osteoarthritis than for those with inflammatory arthritis and so TEA should be used as a last resort option in these patients. Arthroscopic debridement and other joint-preserving procedures should be prioritized over prosthetic joint replacement. In a study of 18 TEAs for primary osteoarthritis with a 9-year follow-up, the self-reported discomfort decreased significantly, but 50% of patients had issues, and many patients experienced mechanical implant failure.[17]

Although most TEAs for posttraumatic arthritis had satisfactory outcomes at long-term follow-up, the rate of sequelae, particularly aseptic loosening and infection, is higher than for RA.[18]

In elderly patients with osteoporotic distal humerus fractures, TEA has recently become a reliable option.[19] Although TEA can restore function, Perretta *et al*.[20] reported that trauma-related TEA was four times more likely than TEA in RA to require component revision. In another study by Barco

et al.,[21] there was a 52% complication rate, with 18% of elbows requiring revision surgery or resection arthroplasty.

Complications

The rate of complications associated with TEA has been reported between 14% and 80%.[6] The most common cause for failure in a "constrained" linked implant is aseptic loosening[22] [Figure 6]. Periprosthetic fractures can occur in patients with osteoporotic bone if there is a stem-canal size mismatch or stem-canal curvature mismatch.[23] Infection is a serious complication and may require serial irrigation and debridement, antibiotic bead placement, IV antibiotics, or single, two-stage, or multi-stage revision surgery. The incidence of periprosthetic infections in TEA ranges from 1% to 12.5%.[24] Other notable complications are instability, triceps avulsion, triceps insufficiency, and bushing wear.[23] Stiffness can occur following TEA due to overlengthened implantation, overtensioned triceps reattachment, and overly tight triceps closure to the flexor-extensor musculature. The incidence of triceps insufficiency is between 0.4% and 2.4% and varies with triceps sparing versus reflection approaches.[25]

Impingement-related pain after TEA can either be caused by impingement of the radial head on the humeral component, coronoid on the humeral component, or olecranon process on the posterior humerus. Other possible complications are delayed wound healing, hematomas, fracture blisters, posterior skin necrosis, and ulnar nerve neuropathy or injury.

Discussion

Some of the current issues with elbow arthroplasty include aseptic loosening, triceps dysfunction, ulnar nerve positioning after arthroplasty, controversy regarding radial head replacement, management of loose implants, computer-assisted components versus standard implantation techniques, metal allergies, and ligament repair after TEA.

Early designs with rigid hinged devices had an unacceptably high rate of aseptic loosening due to the amount of stress the constraint placed on the bone–cement interface. Contemporary designs of "nonconstrained" or "semi-constrained" implants have improved success and reduced loosening rates.[26] Unlinked, nonhinged designs require soft-tissue balancing for stability, consisting of the collateral ligaments as primary stabilizers, and the posterior capsule and muscles as secondary stabilizers. Instability and dislocation of the prosthesis are significant complications for unlinked implants. The importance of static (MCL, LCL, and anterior capsule) and dynamic stabilizers cannot be overstressed and require diligent repair or reconstruction to provide the required soft-tissue stability.[27]

The linked "semi-constrained" design, Coonrad-Morrey (Zimmer), allows 7°–10° of varus–valgus laxity and axial rotation with a central axis pin, which is cylindrical. However, aseptic loosening and bushing wear are important complications with this design.[28]

The "semi-constrained," condylar-bearing designs (Discovery by DJO, Nexel by Zimmer, and Latitude by Tornier) allow for a broader contact of the articular surfaces between cobalt-chrome and UHMWPE. This avoids edge loading and a consequent focal polyethylene wear. A convertible design allows surgeons to choose between a linked and unlinked prosthesis, thereby accounting for implant instability or collateral ligament insufficiency observed intraoperatively.[28]

Surgical approaches can be categorized as triceps-off and triceps-on and directly influence the procedure with respect to triceps insufficiency with the former and component rotation with the latter. The rate of triceps insufficiency is between 0.4% and 2.4% with the various approaches that involve detaching and reattaching the triceps.[28]

It is still unclear whether the ulnar nerve has to be routinely transposed. Ulnar nerve transposition was reported in 31% of the studies in a systematic review.[29] Ulnar nerve complications were reported in 2% of transposition patients and 3.2% with *in situ* decompression. The bilaterotricipital and para-olecranon approaches typically avoid transposition, and hence, risk to the ulnar nerve is mitigated. In essence, ulnar nerve transposition versus decompression is partially linked to the selected exposure.[30]

Most elbow arthroplasties do not include a radiocapitellar arthroplasty, but some historical designs like the Ewald and Sorbie-Questor, and a currently available design, Latitude (Tornier), provide this option. The radiocapitellar joint

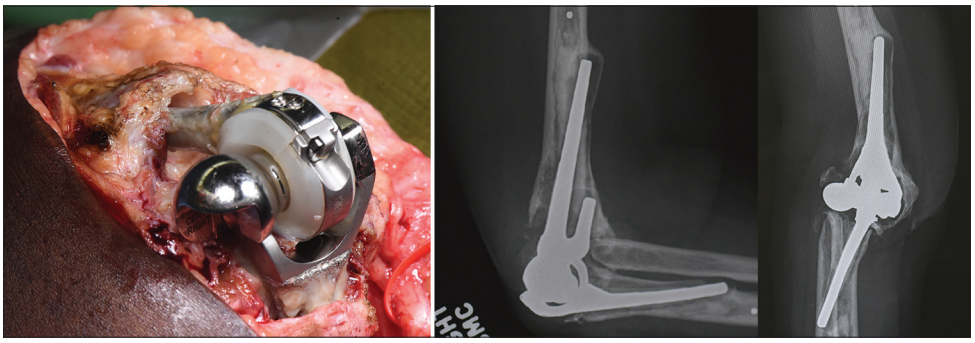


Figure 6: Aseptic loosening

supports >50% of the axial load from the forearm in certain positions in the native elbow, so there could be a theoretical advantage to an arthroplasty with a radiocapitellum portion for load sharing.[31] In the Australian joint arthroplasty registry study, out of the 1220 TEA performed, 43 (4%) had the radial head replaced with the Latitude prosthesis. No statistical difference in revision rate was observed when the radial head replacement.[32]

Aseptic loosening is one of the most common complications of TEA and there are many different options for the associated bone loss, including cancellous autograft, impaction grafting, allograft-prosthesis composite, or cortical strut allograft.[33]

Allergic responses to TEA are uncommonly reported but can lead to pain, swelling, inflammation, and decreased range of motion leading to impairment in implant function. Such symptoms can mimic infection and the most common allergens include nickel, cobalt, and chromium.[34]

The TEA has evolved over the past few decades with respect to design, surgical technique, and indications. The most common indication used to be for the arthritic rheumatoid elbow but is now reserved for patients with advanced disease refractory to disease-modifying antirheumatic medications. The use of TEA has increased for acute trauma with data demonstrating good outcomes and decreased reoperation rates in the elderly with complex intra-articular distal humerus fractures, compared to ORIF.[35] The use of TEA is a viable option for multiple types of elbow pathologies in elderly patients, but the overall complication rate has continued to remain relatively high compared to other joint arthroplasties. The need for further research exists, but due to the overall low volume of TEAs in general, large-scale prospective randomized control trials have been difficult to perform.

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Conflicts of interest

There are no conflicts of interest.

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Review Article

Hill–Sachs Lesions Revisited

Rajesh Itha, Abhishek Vaish, Raju Vaishya

Department of Orthopaedics and Joint Replacement Surgery, Indraprastha Apollo Hospital, New Delhi, India

Abstract

Background: The anterior shoulder instability is often associated with a bony defect in the humeral head which is known as a Hill–Sachs lesion that is caused by compression fracture. It causes significant disability, particularly in younger patients, due to recurrent shoulder instability. The severity of the instability, the extent of the defect, and the concomitant pathology of the capsule, labrum, and glenoid influence the treatment. **Purpose and Methods:** The purpose of this review paper is to provide up-to-date details of the clinical evaluation, current diagnostic tools, and treatment modalities. We shall also discuss the lacunae in the treatment guidelines, and suggest the treatment algorithm. We reviewed several articles in the literature (PubMed, Scopus, and Google Scholar) on this topic, especially the mechanism of injury, diagnosis, and treatment methods to produce a review article. **Conclusion:** There are multiple methods for diagnosing the Hill–Sachs lesion, but there is no commonly accepted technique for quantifying it. A thorough evaluation is mandatory to verify the associated pathology that can modify the treatment protocols. An algorithm has been proposed for the management of Hill–Sachs defects.

Keywords: Arthroplasty, dislocation, glenoid, Hill–Sachs, instability, shoulder

Introduction

The Hill–Sachs lesion is a defect in the postero-supero-lateral part of the humeral head. It is a compression fracture of the head of the humerus accompanying anterior instability and recurrent dislocation of the shoulder. This entity was first characterized as a "line of condensation" on a radiograph by two radiologists – Hill and Sachs in 1940.[1] The true incidence is unclear, but it has been reported to occur in 40%–90% of all anterior shoulder dislocation cases, and it could be as high as 90%–100% in cases of recurrent anterior instability.[2,3] It is caused by the impingement of the postero-supero-lateral segment of the humeral head against the anterior margin of the glenoid during an anterior shoulder dislocation.

It can be present as an isolated lesion or in association with a glenoid bone loss, in which case it is referred to as a bipolar lesion.[4] As the size and orientation of each lesion vary, each presentation should be treated uniquely.

Several classification and grading systems have been proposed, but these cannot guide the treatment, particularly with the larger defects. Calandra's classification is a commonly used classification to grade the Hill–Sachs lesions [Table 1] which is based on the depth of the lesion measured by arthroscopy [Figure 1a and b].[4,5] Rowe *et al*. classified the Hill–Sachs lesions into mild, moderate, and severe types based on axillary radiographs.[6] Franceschi *et al*. proposed their grading system based on arthroscopic findings.[7] The other classification systems include Hall *et al*.,[8] Richards *et al*.,[9] and Flatow and Warner.[10]

Diagnosis

The diagnosis is most obvious from the clinical history and local examination and it is confirmed with imaging.

History and physical examination

There is often a history of a traumatic event that resulted in the dislocation of the shoulder, with an abduction and external rotation deformity of the shoulder. An inquiry is to be made regarding the degree of discomfort, mechanical symptoms such as crepitus, clicking, and catching, details of dislocation such as the frequency of dislocation, provocative position

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Address for correspondence: Dr. Rajesh Itha, Department of Orthopaedics and Joint Replacement Surgery, Indraprastha Apollo Hospital, Sarita Vihar, New Delhi - 110 076, India.
E-mail: dr.rajesh.itha@gmail.com

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causing recurrent dislocation, instability with daily activities, and treatments received. It is critical to evaluate risk factors for recurrence, such as convulsions, a tendency to fall, or involvement in activities that necessitate external rotation and abduction.[11] Assessment should be made for instability, laxity, and concomitant soft tissue injuries. The apprehension test is a classic test to determine the instability in the glenohumeral joint.[4] Some special tests like shift and load tests are used to assess the status of the glenoid rim by moving the humeral head anterior.[11]

Imaging

Radiographic assessment in the form of plain radiographs, computed tomography (CT) scan, and magnetic resonance imaging (MRI) are helpful in the diagnosis and assessing humeral and glenoid bone defects.

Plain radiographs

Routine radiographic views (anteroposterior or AP, lateral, and axillary) may indicate or visualize the defect. Special views (modified West Point axillary and Stryker notch views) may be used to demonstrate Hill–Sachs lesions in inconclusive cases.[8] The special views are more accurate than basic views to demonstrate the defect but are difficult to obtain because of patient limitations or discomfort.[12] The better imaging modalities for diagnosing a Hill–Sachs defect are CT and MRI, as about 60% of the defects can be overlooked by the plain radiographs.[13]

Computed Tomography Scan

The bone loss associated with Hill–Sachs lesions can be assessed using CT scan with three-dimensional (3D) reconstruction, which is regarded as the gold standard.[14] The morphology of the defect may be fully appreciated using 3D-CT, which is especially helpful when planning the surgery beforehand. After digitally subtracting the humeral head, it is also possible to measure the bone loss of glenoid, with accuracy. The improved conceptualization makes 3D-CT superior to two-dimensional imaging as it gives more consistent and reproducible measurements of osseous defects.[15]

Table 1: Calandara's classification

Grading	Arthroscopic finding
I	Cartilage lesion alone
II	Extension of the lesion into the subchondral bone
III	A large bone defect

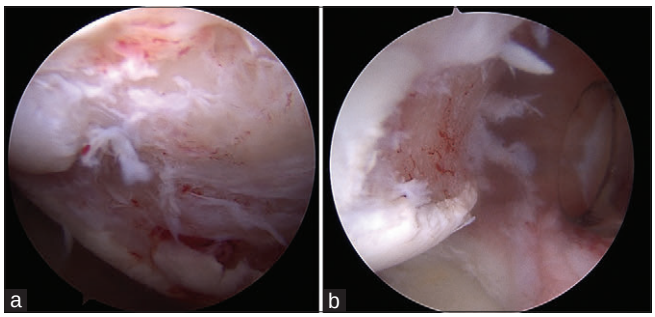

Figure 1: (a) End-on arthroscopic view of a Hill–Sachs lesion of the right shoulder (when viewed from a posterolateral portal), (b) Arthroscopic view of a Hill–Sachs lesion of the right shoulder (when seen from an anterosuperior portal)

Magnetic resonance imaging

It is a preferable technique for evaluation of the soft tissue architecture of patients with anterior shoulder instability [Figure 2].[16] 3D-MR evaluates the bony defects of the humeral head and the glenoid more accurately than the conventional MRI, with a full set of slices.[17] The 3D osseous reconstructions prepared by 3D-CT and 3D-MR are comparable, but the advantage of 3D-MR over 3D-CT is the lack of radiation and simultaneous provision of information about soft tissue anatomy.[18]

Ultrasonography

This technique can be used to assess the size of the Hill–Sachs lesion. In an intraoperative analysis, Cicak *et al*. noted that ultrasound imaging is 100% specific and 96% sensitive for determining the size of the Hill–Sachs lesions with a success rate of 97% success rate.[19]

It is challenging to correctly determine the morphology of the Hill–Sachs lesion and the coexisting glenoid bone loss without modern imaging techniques.[20] Despite the substantial advancements in imaging technology, more research is still required to establish the most appropriate imaging method for measuring bony defects.[4]

Types of Hill–Sachs Lesions

At present, there is no consensus on the definition of the size of the lesions. However, lesions that involve <25% of the articular surface are regarded as minor, whereas lesions that involve over 25% of the articular surface are considered significant.[21,22]

Engaging versus nonengaging lesions

Burkhart and de Beer have first presented the concept of the

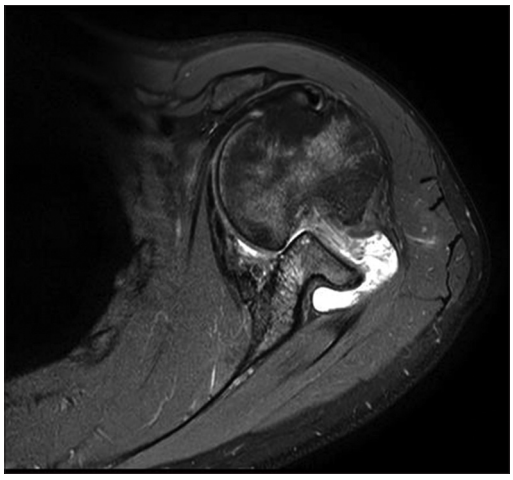

Figure 2: An engaging Hill–Sachs lesion, as seen on T2-weighted MRI image, in a case of chronically locked anterior shoulder dislocation

nonengaging and engaging lesions.[23] Nonengaging lesions move diagonally over the anterior glenoid and maintain constant contact between the lesion and the articular surface, thus avoiding the anterior glenoid. Engaging lesions orient parallel to the anterior glenoid which results in the engagement with glenoid corner.

On-track versus off-track lesions (glenoid track concept)

Yamamoto *et al*. have introduced the concept of "glenoid track."[23] It refers to a contact zone between the humeral head's posterior articular edge and the glenoid, when the shoulder moves in different extents of abduction, extension, and external rotation.[24] The terms "nonengaging" and "engaging" lesions are confusing and thus mostly misused. To avoid such type of confusion, a new terminology "on-track lesion" and "off-track lesion" was proposed by Di Giacomo G *et al*.[24] An on-track lesion is one that remains on the glenoid track, does not engage with the glenoid, and is not associated with dislocation. The lesion is termed to be off-track when it exits the glenoid track and is prone to engagement and ultimately dislocation [Figure 3].

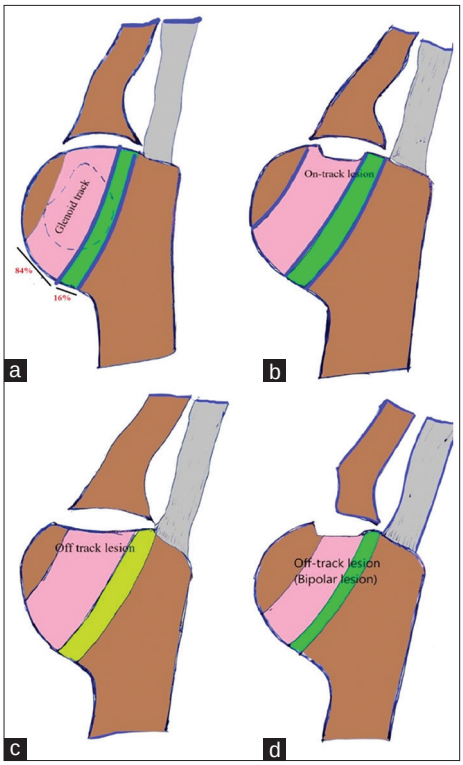

Figure 3: Glenoid track concept, on-track and off-track lesions, (a) The "glenoid track" refers to the area of contact between the glenoid surface and the humeral head in the abduction-external rotation position. It comprises nearly 84% of the glenoid transverse diameter (in the picture it is depicted in pink color), while the glenoid reminder (16%) contacts the medial border of the rotator cuff footprint (in the picture, it is depicted in green color), (b) On-track lesion: the Hill–Sachs lesion stays within the glenoid track and is not engaging, (c) Off-track lesion: the Hill–Sachs lesion goes medially beyond the glenoid track, and also the Hill–Sachs lesion is engaging, (d) Off-track lesion (bipolar lesions): The glenoid track of the humeral head is narrowed by the bony defect of the glenoid rim. Hill–Sachs lesion extends medially beyond the glenoid track, and thus, the Hill–Sachs lesion is engaging

Clinical Significance of Hill–Sachs Lesions

The engagement of the lesion might be considered a stronger predictor of recurrent instability or failure of surgical procedures rather than the results of the studies based solely on the size.[25] The posture of the arm during the first episode of the dislocation and the angle of the Hill–Sachs lesion are also predictors of engagement and recurrence. The greater the angle, the greater the degree of engagement and, as a result, the greater the shoulder instability and vice versa.[26] Various clinical studies showed that the on-track and off-track lesion concepts can reliably predict the need for glenoid surgery.[27,28] The presence of concomitant glenoid bone lesions, as well as a Hill–Sachs lesion engagement with the glenoid, amplifies the clinical significance of a minor Hill–Sachs lesion.[4] A solitary Hill–Sachs lesion may raise the risk of a bipolar lesion by 2.5–11 times.[29] The concurrent large glenoid defects can cause more instability than with small glenoid defects.[30]

Management

Nonsurgical management

Nonsurgical management is offered to patients with insignificant lesions which cover <20% articular surface and/or the on-track lesions. Routinely, a trial of nonsurgical management can be offered to first-time dislocators without any significant bone loss. A few months of focused physical therapy is required.[4] Numerous studies found high failure rates with the nonsurgical approach. Patients who are poor surgical candidates (elderly aged and medical issues) with significant lesions are the ideal candidates for nonsurgical methods.[11]

Surgical management

The surgery is indicated for the Hill–Sachs lesions, based on the symptoms of instability and the clinical significance of the bony defect [Table 2]. The factors to be considered are the size of the lesion, engagement, and associated other injuries such as a bipolar lesion.

Soft tissue procedures

Glenohumeral capsular shift

It is mentioned here for the historical importance. The anterior capsule is tightened to minimize the lateral rotation and forward translation.[31] Even though it may increase the shoulder

Table 2: Surgical indications for Hill Sachs lesions

Absolute
Fracture of the humeral head with displacement or dislocation and concurrent Hill–Sachs lesion
Lesions which cover>30% of the articular surface in chronic dislocation or recurrent shoulder dislocation
Relative
Lesions which cover>20%–35% of the articular surface with features of engagement on clinical assessment
Lesions which cover>10%–25% of the articular surface with incongruity of the head of the humerus with glenoid fossa following an arthroscopic instability repair

stability significantly, loss of lateral rotation is troublesome for young individuals. As it deals with the soft tissue only, it cannot address the large lesions or off-track lesions.

Remplissage

The French surgeons, Purchase *et al*., first described the term remplissage, which means filling.[32] In this technique, the tendon of infraspinatus muscle, along with a portion of greater tuberosity, is used to fill the humeral head defect [Figure 4a and b]. The principle behind this procedure is that the intra-articular defect is converted into an extra-articular one, with the soft tissue coverage, which prevents the engagement of the lesion.[32,33] It is indicated in large Hill–Sachs lesions with concurrent glenoid bone deficiencies of <20%–25%. If there is more than 25% glenoid bone loss, Itoi recommends a Latarjet procedure to restore the glenoid track, and if the Hill–Sachs lesion is still off-track after the Latarjet surgery, remplissage should be added.[27] Connolly first described it as an open procedure in 1972.[34] Wolf *et al*. first described arthroscopic remplissage, which involves capsulodesis of the posterior capsule, tenodesis of the infraspinatus, and soft tissue fixation to the defect.[35] Later, various modifications have been proposed.[33,36] The advantages of this procedure include minimally invasive, concurrent other procedures, and avoiding the need for a bone graft. The disadvantages include limitation of the movements during throwing[37] and reduction of lateral rotation.[38]

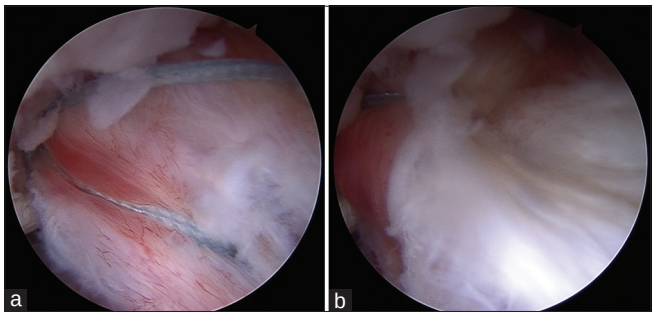

Figure 4: (a) Arthroscopic remplissage procedure-posterior capsule and infraspinatus being fixed to the Hill–Sachs lesion, (b) Arthroscopic picture demonstrating fill of a bony defect after remplissage

Bony procedures

Bone augmentation

Glenoid bone augmentation is recommended for patients who have large Hill–Sachs lesions and recurrent anterior shoulder dislocation. These bony augmentation methods include Latarjet's procedure (coracoid transfer) or iliac crest bone grafting.[11,39,40] Allografts (from femoral head and distal tibia) have also been tried. These techniques do not directly address the humeral head defects, but they do extend the arc of the glenoid, which prevents the Hill–Sachs defect from engaging and eventually shoulder dislocation during normal movements.

The techniques of augmentation of the humeral head are used to treat both isolated significant Hill–Sachs lesions and bipolar lesions by using various types of size-matched bone plugs. These bone plugs include autograft harvested from the iliac crest, allograft (fresh or frozen), or synthetic such as metal or polyethylene.[4] Rarely, restoration of the anatomy along with the soft tissue procedures may be required in large humeral head defects without associated glenoid loss. The principle behind these procedures is that the arc of the humeral head is increased which ultimately prevents engagement and instability. Both sizes matched bone grafts and the entire humeral head replacement with allograft showed good results.[41,42]

Humeroplasty

Disimpaction or humeroplasty can be done for lesions which are acute in duration (<3 weeks), and cover <40% of the articular surface of the humeral head.[43] In this technique, the compression fracture is elevated and the space is filled with

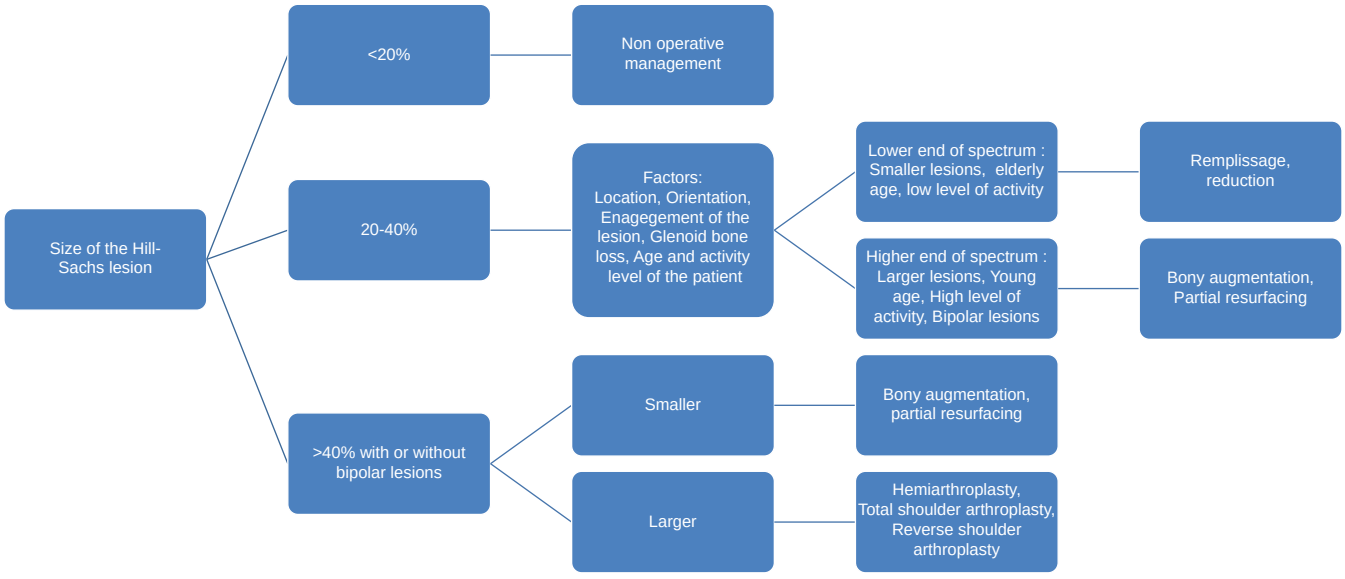

Figure 5: Proposed treatment algorithm for the treatment of Hill–Sachs lesion

the bone graft so that the geometry of the humeral head is restored without internal fixation.[44,45] The principle behind this method is to increase the articular arc so that engagement and instability can be prevented.[4] Various techniques are available for this procedure.[44-47]

Weber osteotomy

It was used to be indicated for large engaging lesions. The osteotomy of the proximal humerus is done at the surgical neck and then the humeral head is retroverted relative to the humeral shaft that prevent the engagement of the lesion.[48] It is associated with various complications such as nonunion, delayed union, overcorrection, iatrogenic fracture, and posttraumatic arthritis making it an outdated procedure.[49]

Arthroplasty

Partial humeral head resurfacing arthroplasty

Partial resurfacing of the humeral head defects is done using a cobalt-chrome implant. The advantages of this procedure include the risks and complications associated with autografts and allografts such as the donor site morbidity, early resorption of the graft, need for implant removal, and disease transmission.[50] The drawbacks include the risk of insufficient implant fixation to the humeral head and a mismatch in the geometry of the defect and implant, which may necessitate subsequent reaming and resurfacing of the healthy cartilage of the humerus.[50]

Hemiarthroplasty

Hemiarthroplasty is recommended for older patients with lesions affecting more than 40% of the humeral head cartilage, as well as for younger individuals with chronic lesions and severe cartilage loss. The amount of retroversion needs to be increased by 10°–15°. If there is any residual instability or glenoid articular pathology after hemiarthroplasty, it must be treated with soft tissue procedures, glenoid-sided bone grafting, or total shoulder arthroplasty.[51]

Total shoulder arthroplasty

It is recommended to patients with the glenoid-sided articular wear in fixed anterior shoulder dislocations and recurrent instability with instability arthropathy due to the pathology itself or treatment errors.[52-54]

Reverse shoulder arthroplasty

Reverse shoulder arthroplasty is indicated in patients with locked anterior shoulder dislocations, instability arthropathy following surgical procedures, and rotator cuff tears with associated defects of the glenoid bone. It has the advantage of fewer complication rates compared to anatomic shoulder arthroplasty.[55]

Treatment algorithm

We propose a treatment protocol for the management of the Hill–Sachs lesion based on the data found in the literature [Figure 5]. Smaller lesions (20%) can be handled nonsurgically, however, larger lesions (>20%) necessitate surgical methods such as remplissage, bone grafting, or arthroplasty.

Conclusion

The Hill–Sachs lesions are very common with recurrent shoulder dislocations. There has been increasing knowledge on the diagnostic modalities and the methods for the assessment of the bony lesion, but still, there is no consensus technique for quantifying the defect. The concept of glenoid tracking avoids the confusion between the on-track and off-track lesions, and that of bipolar lesions makes the previously insignificant lesions into significant lesions. There are several techniques available to manage anterior instability. The optimal technique to be chosen depends on the size of the Hill–Sachs lesion and concurrent lesions. The coexisting humeral, as well as the glenoid defects, should be addressed simultaneously, otherwise there may be residual instability and recurrence. Sometimes, a combination of techniques is required. The role of primary shoulder arthroplasty and reverse shoulder arthroplasty requires further research and long-term outcomes.

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Authors' contribution

RI: Conceptualization, writing, revision, and final approval; RV: Conceptualization, revision, and final approval; AV: Literature search, revision, and final approval.

Ethical approval

Not required, being a narrative review and not involving any patient's data or identity.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

The Obturator Externus as Surgical Landmark for the Direct Anterior Approach and Its Role in LLD after Total Hip Replacement

Lieven Vermuyten, Ronald Driesen, Hans Welters, Kristoff Corten
Department of Orthopedic Surgery, ZOL, Genk, Belgium

Abstract

Purpose: The purpose of this study was to asses the usefulness of the obturator externus tendon (OE) as landmark and the correlation of the femoral stem position in relation to the OE and its effect on postoperative leg length difference (LLD) after direct anterior approach-total hip replacement (DAA-THR). **Patients and Methods:** A retrospective radiographic analysis of 85 patients undergoing THR was performed. Postoperative leg length was determined using the center of femoral rotation to tear drop line and lesser trochanter method. Relative distance of the femoral component to the insertion of the OE was determined (OE-SH). The intraclass correlation coefficient (ICC) was performed for intra- and inter-reliability ratings. Regression analysis was performed. Discriminant analysis was performed to define a possible critical cutoff of OE-SH with regard to defining groups based on LLD. Risk analysis with regard to OE-SH ><6 mm and difference in distance between teardrop and lesser trochanter before and after implantation of THR (ΔTDLT) ><5 or 10 mm was performed. **Results:** Seventeen cases (21%) had lengthening (ΔTDLT) >5 mm and 7 cases (8%) had ΔTDLT >10 mm, with a mean ΔTDLT of 1.61 ± 4.92 mm SD. ICC values for intra- and interobserver reliability were rated as excellent. Regression analysis showed a clear correlation between ΔTDLT and OE-SH (ΔTDLT = −1.076 + 0.60176*OE-SH). Risk analysis showed a relative risk (RR) of 11.20 (confidence interval [CI] 3.52–35.60, power 1) for 5 mm ΔTDLT when OE-SH >6 mm and a RR 14.4 (CI 1.83–113.54, power 0.86) for 10 mm ΔTDLT when OE-SH >6 mm. **Conclusion:** OE-SH is a reliable measurement and a reliable predictor of LLD after THR. The radiographic cutoffs of OE-SH correlate well with the average size of the OE tendon, further underlining its clinical value in DAA THR. Intraoperative significant OE-SH warrants a critical review and correlation to preoperative planning.

Keywords: Direct anterior approach, external obturator, leg length inequality, total hip replacement

Introduction

The goals of total hip replacement (THR) are to relieve pain, improve joint mobility, and maximize activity.

Accurate implant positioning and restoration of the native hip biomechanics are essential to reduce complications such as leg length difference (LLD) which is one of the main causes of patient dissatisfaction and malpractice claims after primary THR[1] and has been associated with nerve palsy, residual hip pain, instability, and abnormal gait.[2-4]

Pre- and intraoperative surgical landmarks help translate the preoperative planning into a reproducible, reliable surgical technique and predictable outcome.[5,6] Landmarks for femoral stem depth are limited in the direct anterior approach (DAA) THR. The obturator externus (OE) with its readily available anatomy during femoral broaching has the potential to fill this gap. This is more relevant as leg lengthening after THR occurs mostly on the femoral component.[7,8] The OE has recently been described as a reliable pre- and intra-operative surgical landmark for specific restoration of biomechanics in DAA THR.[9-11] Its consistent anatomy and radiographic appearance have been documented, but clinical implications have not yet been studied.

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Address for correspondence: Mr. Lieven Vermuyten, Department of Orthopedic Surgery, ZOL, Genk, Belgium.
E-mail: lieven.vermuyten@uzleuven.be

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Based on our clinical practice, we predict the OE to be a reliable surgical landmark for femoral component placement with regard to postoperative LLD.

To assess its usefulness, the link between OE to femoral shoulder distance and postoperative LLD was studied. We predict that most LLD will be from femoral lengthening, and that an increased distance between the femoral component and OE is linked with LLD and an increased distance is a significant risk factor for clinically relevant LLD. We expect the OE-SH to be a reproducible and reliable measurement. We also expect to see most of the LLD to originate on the femoral side. We expect there to be a significant correlation between postoperative LLD and the OE-SH.

Patients and Methods

Study design and setting

This study was designed as a retrospective radiographical analysis of longitudinally maintained data of patients who underwent THR through a DAA at a single high-volume center. All cases were operated by the senior author, who is a dedicated hip surgeon with ample experience and volume.

Ethical approval

The study was approved by the local ethical committee.

Patients

Patients were enrolled in the study after inclusion criteria were met. Cases between January and March of 2019 were available for radiographical analysis.

A total of 140 cases were analyzed of which 55 cases (39%) were excluded for further analysis due to the following reasons: bilateral THR (35 cases [25%/64%]), history of fracture or previous operations on either side (5 cases [4%/9%]) or due to poor X-ray quality not meeting quality criteria[12] (15 cases [11%/27%]). The residual 85 cases were radiographically analyzed at 1 year postoperatively. The 85 cases encompass 34 (40%) females and 51 males (60%) with a mean age of 70.4 years overall.

Radiographic analysis

Postoperative X-rays were assessed by two observers and the centre of femoral rotation to tear drop line and lesser trochanter (CFR-TD-LT) method[13] [Figure 1 for example and description] was used to asses postoperative leg length difference (LLD) and the distribution of acetabular and femoral leg length difference.

The measurement between these two additional lines is the overall LLD (C + E/D + F).

Besides leg length, the distance between the OE and GT and GT and shoulder of the femoral component was measured. The relative distance of the shoulder of the stem to the OE (OE-SH) will be deducted from these measurements (B-A). The insertion point of the OE was determined as the angle made between the vertical line of the trochanteric fossa and the oblique intertrochanteric crest. Magnification was corrected by the documented size of the metal head.

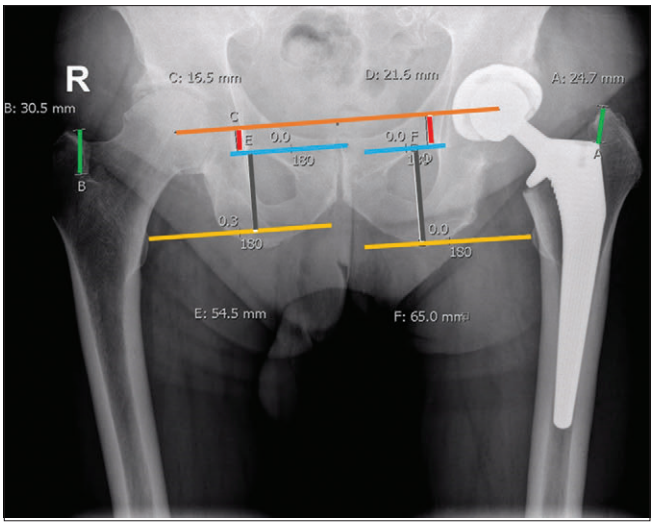

Figure 1: The CFR-T-LT method: Firstly, the CFR is determined. An initial reference line is drawn between the CFR of both hips (orange line). Two further lines are drawn parallel to this. The first at the level of the most inferior part of the acetabular teardrop (blue lines) to give measurement C/D (red lines), which corresponds to any inequality (D-C) due to the position of the cup (ΔCFR-TL). The second is at the level of the lesser trochanter (yellow line) to give measurement E/F (gray lines), which corresponds to inequality (F-E) due to position of the stem (ΔTD-LT). The measurement between these two additional lines is the overall LLD (C + E/D + F). The distance between the OE and GT and GT and shoulder of the femoral component was measured. The relative distance of the shoulder of the stem to the OE (OE-SH) was deducted from these measurements (B-A). The insertion point of the OE was determined as the angle made between the vertical line of the trochanteric fossa and the oblique intertrochanteric crest. Magnification was corrected by the documented size of the metal head. CFR-T-LT: Center of femoral rotation to tear drop line and lesser trochanter, OE: Obturator externus

All measurements were performed by two independent observers to determine inter observer reliability. For intra-rater reliability, the first author performed a second set of measurements with a minimum of 2-week interval between measurements.

X-rays were only used if the two observers found the trochanteric fossa to be clearly visible on the preoperative X-rays. The reason for this being exorotation of the operative leg not in keeping with standard X-ray protocol.[12] To objectify this, the thickness of the lesser trochanter (TLT) method as described by Yamamura *et al*.[14] was used to exclude overly excessive external femoral rotation (x >5 mm).

Further radiographic exclusion criteria were as follows: teardrop not visible (n = 2), lesser trochanter not visible or too wide as per above (n = 9), and Tönnis grade >2 in the contralateral hip (n = 4). The combination of the above led to the exclusion of 15 patients.

The Agfa Healthcare Enterprise imaging™ program was used for processing images and measurement (Agfa HealthCare NV B-2640 Mortsel - Belgium).

Data and statistical analysis

Excel™ (Microsoft, USA) was used for anonymization and processing of patient data and performed measurements.

All data were entered into the Statistical Package for the Social Sciences™ (Version 25.0, SPSS, IBM Corp, Armonk, NY, USA) and the following statistical analyses were made:

- For intra- and interobserver reliability, an intraclass coefficient (ICC) was used[15,16]
- For intra-rater reliability, an ICC with two-way mixed model with absolute agreement definition is used
- For interobserver reliability, an ICC with two-way mixed model for single measures with each measurement being performed by the same measurers was performed as we wanted the ICC to reflect the correlation between any given single measurement between the two observers instead of the average measures, which gives the correlation between the whole series of measurements.

We defined the outcome of ICC according to the paper of McGraw and Wong.[17]

An *ad hoc* power analysis was performed for determination of adequate study size of the patient population.

A regression analysis after plotting OE-SH against difference in TDLT (ΔTDLT) was performed. Furthermore, a discriminant analysis (DA) was used to investigate whether a certain cutoff value of OE-SH could be defined which correlates with postoperative leg length (ΔTDLT) being > or <5 or 10 mm.

A risk analysis (relative risk [RR], odds ratio) was performed to investigate the risk of ΔTDLT >5 mm, >10 mm given an OE-SH being < or >6 mm. Power analysis was performed.

A statistical significance of $P < 0.05$ was used for all performed statistics.

Theory

We expect the OE-SH to be a reproducible and reliable measurement.

We also expect to see most of the LLD to originate on the femoral side.

We expect there to be a significant correlation between postoperative LLD and the OE-SH.

Results

Descriptive

Overall LLD

The mean overall LLD was 4.97 mm ± 4.93 SD, reflecting a variation of lengthening.

There were 41 (48%) cases where total LLD was more than 5 mm. Of these, the deformity was femoral in 17 cases (41.46%), acetabular in 18 cases (51.22%) and combined in origin in 1 case (2.44%). In 5 cases (12.20%), it was a combination below the threshold of both components that caused total LLD to become more than 5 mm.

Femoral or acetabular contribution was considered relevant if half of the average lengthening in that group (4.29 mm) was caused by a component.

In 14 (16%) cases, total LLD was more than 10 mm. Of these, the deformity was femoral in 9 cases (64%) and acetabular in 5 cases (36%) with the same cutoffs applied.

ΔTDLT

Patients with difference in TDLT (ΔTDLT) were analyzed. The mean ΔTDLT was 1.61 mm ± 4.92 mm SD. Of these patients, there were 17 cases (21%) with a Δ TDLT of more than 5 mm and 7 cases (8%) with Δ TDLT of more than 10 mm. Of the cases with a Δ TDLT >5 mm, the mean ΔTDLT measured 8.58 ± 3.21 mm SD For Δ TDLT >10 mm the mean measured 11.94 ± 2.15 mm SD.

In the 17 cases with Δ TDLT >5 mm, the average change in center of rotation (ΔCFR-TL) was 0.44 ± 1.49 mm SD. In the 7 cases with Δ TDLT >10 mm, the average change in centre of rotation (ΔCFR-TL) was 0.41 ± 0.99 mm SD.

Distribution of males versus females with ΔTDLT >5 mm was 7 versus 10. In the group with Δ TDLT >10 mm, the distribution male versus female patients was 1 versus 6.

Obturator externus-SH

Average distance measured between shoulder of the femoral stem and OE (OE-SH) was 4.48 ± 3.29 mm SD. The number of cases in OE-SH >3 mm or >6 mm was 56 (66%) and 26 (31%).

In the group where OE-SH was >6 mm, there were 15 (58%) patients with a delta TDLT >5 mm and 11 (42%) with delta TDLT <5 mm.

In the group of patients with delta TDLT >5 mm, there were 15 (83%) cases with an OE-SH >6 mm and 3 cases (17%) with an OE-SH smaller than 6 mm.

In the group of patients with delta TDLT >10 mm, all 7 cases (100%) had an OE-SH >6 mm.

We found an OE-SH distance >6 mm in 12 cases (14%) with a nonsignificant LLD (<5 mm). In these cases, there is no acetabular proximalization that was corrected by leaving the femoral stem proud nor is there in any of these cases a significant femoral lengthening compensated for with a smaller femoral head.

Reliability and reproducibility

Intrarater reliability

All ICC values indicated excellent intraobserver reliability [Table 1].

Interrater reliability

All ICC values indicated excellent intraobserver reliability [Table 2].

Statistical analysis

Regression analysis

ΔTDLT values were plotted out against values of OE-SH and a regression analysis was performed [Figure 2]. A normal distribution of OE-SH values was noted. A regression coefficient of 0.602 was noted ($P < 0.0001$) throughout the observed range of OE-SH. The expected average Δ TDLT in the function of OE-SH can be defined as Δ TDLT = −1.076 + 0.60176*OE-SH.

Discriminant analysis

DA is a multivariate technique used to separate two or more groups of observations (individuals) based on variables measured on each experimental unit (sample) and find the contribution of each variable in separating the groups. DA was performed to analyze a possible predictive value to divide patients in a ΔTDLT < or >5 mm group depending on their OE-SH value. For a ΔTDLT dichotomy based on 5 mm, there were 68 patients with ΔTDLT <5 mm and 17 patients with ΔTDLT ≥5 mm. The correlating cutoff for OE-SH was defined as 5.67 mm to divide between these two groups. Based on this cutoff, we get the following classifications:

There are 26 patients with OE-SH >5.67 mm, and 14 of these have Δ TDLT ≥5 mm. In other words, the cutoff of 5.67 mm for OE-SH incorrectly classifies 12 patients with ΔTDLT <5 mm (17.65%) as ΔTDLT >5 mm. There are 59 patients with OE-SH <5.67 mm, and 56 of these have ΔTDLT <5 mm. The cutoff of 5.67 mm for OE-SH misclassifies 3 patients with ΔTDLT ≥5 mm (17.65%) as ΔTDLT <5 mm. The overall misclassification rate is 17.65% [Table 3].

For a ΔTDLT dichotomy based on 10 mm, there were 78 patients with ΔTDLT <10 mm and 7 patients with Δ TDLT ≥10 mm. The correlating cutoff for OE-SH was defined as 5.99 mm to divide between these two groups. Based on this cutoff, we get the following classifications. There are 25 patients with OE-SH >5.99 mm, and 6 of these have ΔTDLT >10 mm. In other words, the cut-off of 5.99 mm for OE-SH incorrectly classifies 19 (24.36%) patients with ΔTDLT <10 mm as Δ TDLT ≥10 mm. There are 60 patients with OE-SH <5.99 mm, and 59 of these have ΔTDLT <10 mm, 1 (14.29%) is misclassified as ΔTDLT ≥10 mm. The overall misclassification rate is 19.32% [Table 4].

Table 1: Results of Intrarater reliability using ICC

	TD-LT pre	TD-LT post	TD-CR pre	TD-CR post	GT-OE pre	GT-SH post
ICC value	0.99	0.99	0.99	0.99	0.99	0.99
95% CI	0.89-0.99	0.90-0.99	0.81-0.99	0.75-0.99	0.74-0.99	0.78-0.99

Results of Intrarater reliability using ICC. ICC: Intraclass correlation coefficient, TD-LT: Tear drop line and lesser trochanter, OE: Obturator externus, CI: Confidence interval, TD-CR:Tear drop to centre of rotation, GT: Greater trochanter, SH: Shoulder of femoral stem

Table 2: Results of Interrater reliability using ICC

	TD-LT pre	TD-LT post	TD-CR pre	TD-CR post	GT-OE pre	GT-SH post
ICC value	0.99	0.99	0.99	0.99	0.99	0.99
95% CI	0.97-0.99	0.92-0.99	0.91-0.99	0.78-0.99	0.72-0.99	0.92-0.99

Results of interrater reliability using ICC. ICC: Intraclass correlation coefficient, TD-LT: Tear drop line and lesser trochanter, OE: Obturator externus, CI: Confidence interval, TD-CR: Tear drop to centre of rotation, GT: Greater trochanter, SH: Shoulder of femoral stem

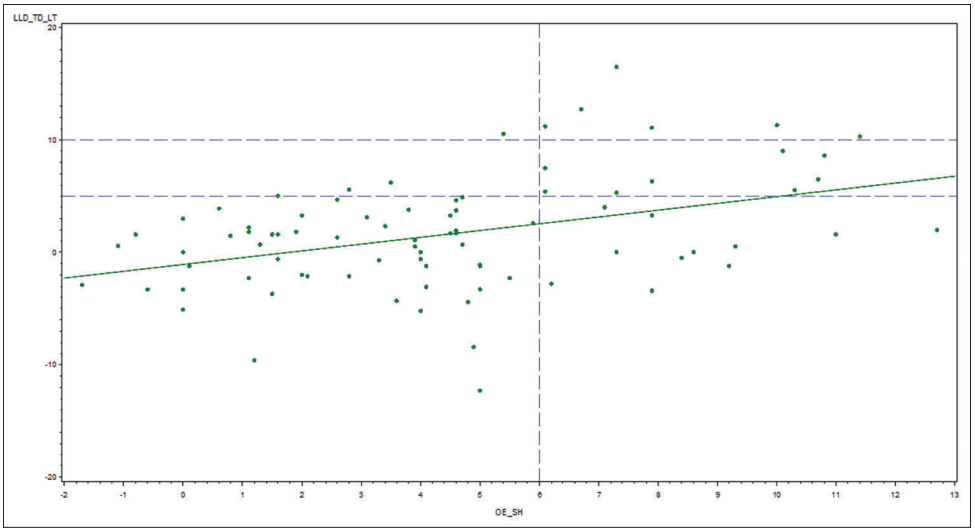

Figure 2: Plotted regression analysis of LLD and OE-SH. The blue lines are the proposed cutoffs of OE-SH < or >6 mm and ΔTDLT < or >5- or 10-mm. Majority of the patients fall below both cutoffs (lower left quadrant). OE: Obturator externus

Risk analysis

Risk analysis was performed to predict the risk of a larger ΔTDLT (>or <5 mm or > or <10 mm) given a certain OE-SH (>or <6 mm).

The following probabilities and definitions were defined: P_0 is the probability (risk) of a ΔTDLT >10 mm in the group of patients with OE-SH <6 mm. P_1 is the probability (risk) of a ΔTDLT >10 m in the group of patients with OE-SH >6 mm.

Table 3: Discriminant analysis for Δ TDLT dichotomy based on 5 mm

ΔTDLT dichotomy based on 5 mm	ΔTDLT ≥5 mm	ΔTDLT <5 mm	Total OE-SH
OE-SH ≥5.67 mm#	14	12	26
Percentage	16.47	14.12	30.59
Correct/misclassification %	83.35	17.65	
OE-SH <5.67 mm#	3	56	59
Percentage	3.53	65.88	69.41
Correct/misclassification %	17.65	82.35	
Total#	17	68	85
Percentage	20.00	80.00	100.00

#cutoff value determined by discrimant analysis. Discriminant analysis for ΔTDLT dichotomy based on 5 mm. ΔTDLT: Difference in distance between teardrop and lesser trochanter before and after implantation of total hip replacement, OE: Obturator externus, SH: Shoulder of femoral stem

Table 4: Discriminant analysis for Δ TDLT dichotomy based on 10 mm

ΔTDLT dichotomy based on 10 mm	ΔTDLT ≥10 mm	ΔTDLT <10 mm	Total OE-SH
OE-SH ≥5.99 mm#	6	19	25
Percentage	7.06	22.35	29.41
Correct/misclassification %	85.71	24.36	
OE-SH <5.99 mm#	1	59	60
Percentage	1.18	69.41	70.59
Correct/misclassification %	14.29	75.64	
Total#	7	78	85
Percentage	8.24	91.76	100.00

#cutoff value determined by discrimant analysis. Discriminant analysis for ΔTDLT dichotomy based on 10 mm. ΔTDLT: Difference in distance between teardrop and lesser trochanter before and after implantation of total hip replacement, OE: Obturator externus, SH: Shoulder of femoral stem

Difference in risk = P_2-P_1. RR = P_2/P_1. Odds ratio = $[P_2/(1-P_2)]/[P_1/(1-P_1)]$.

In order to see whether the risks differ, the following must be applied: the confidence interval (CI) for difference in risk cannot contain 0. The CI for RR and odds ratio cannot contain 1. Power analysis was performed for each of these parameters [Table 5].

Discussion

Optimizing THA outcomes is a continuous strife and preventing significant LLD is a major challenge as it is the most frequent complication causing dissatisfaction and even litigation.[1] To achieve this goal, reliable landmarks are needed to guide the surgeon in planning, execution, and evaluation of the performed procedure. This has stimulated interest in the OE as a possible candidate for this role. After Rüdiger *et al*.[11] studied its consistency on radiographs by correlating CT scans and conventional X-rays, they found the OE insertion consistent in width (6.4 mm) and location, in the so-called "piriformis" fossa, which can be reliably found on a plain X-ray by following the intersection of the line formed by the vertical wall of the trochanteric fossa and a more oblique line formed by the intertrochanteric crest. Elaborating on this idea, the group of Vles *et al*.[9,10] studied the role of the OE in templating and its intraoperative reliability and were able to confirm the OE's role to play as the most important landmark for femoral component placement in the DAA THR.

The aim of this study was to investigate the correlation between the position of the femoral stem in relation to the OE and its correlation to a significant LLD. Classically, a LLD of more than 10 mm was deemed significant,[18] but more recent investigations suggest clinically relevant gait alterations starting from a 5 mm LLD.[19]

To investigate this correlation, we retrospectively analyzed 85 postoperative X-rays from THR performed through the DAA by a senior surgeon. We investigated the LLD present in this population and found it to be 20% for LLD >5 mm and 8% for an LLD >10 mm. This is lower than other reports in the literature, where figures vary from LLD >10 mm being between 14 and 20%.[19,20] The group of Love[21] even reported an 18% incidence of LLD >15 mm after THR. The fact that the senior authors institution is a high-volume center and the fact that

Table 5: Results of risk analysis performed

OE-SH	ΔTDLT	Ref proportion (p1) (%)	Difference in risk (CI)	Relative risk (CI)	OR (CI)
Cutoff 6 mm	Cutoff 5 mm	5	51% (31-71)	11.2 (3.5-35.6)	24.2 (5.9-98.5)
Cutoff 6 mm	Cutoff 10 mm	1.7	22% (6-39)	14.4 (1.8-113.5)	18.6 (2.1-164.7)
OE-SH	**ΔTDLT**	**Power**	**Difference in risk**	**Relative risk**	**OR**
Cutoff 6 mm	Cutoff 5 mm	Power	1.00	1.00	1.00
Cutoff 6 mm	Cutoff 10 mm	Power	0.86	0.86	0.90

Results of risk analysis performed. ΔTDLT: Difference in distance between teardrop and lesser trochanter before and after implantation of total hip replacement, OR: Odds ratio, CI: Confidence interval

other groups performed the THR in a posterolateral fashion, where LLD is not as easily verifiable intraoperatively, may play a role in this finding.[20]

Distribution of males versus females with ΔTDLT >5 seemed equally distributed (7/10), but in the group with ΔTDLT >10 mm the distribution shifted more toward female patients (1/6). This may well be an underlying gender difference as pointed out by Warnock *et al*.[21] who postulated that due to smaller femurs and shorter distance between femoral rotation centre (FCR) and the LT in females, surgeons are more conservative toward the neck cut and therefore female patients are more at risk for femoral lengthening. Adequate power to perform a logistic regression analysis to examine the link of lengthening and gender was not obtained in this study and therefore it was not performed as it also was beyond the scope of this radiographic study.

We not only analyzed radiographical LLD but more importantly we also investigated radiographic apparent leg length difference through the CFR-TD-LT method as described by McWilliams *et al*.[13] which was defined as the length difference between the teardrop line and the lesser trochanter (ΔTDLT). We assumed that the lengthening would be mostly on the femoral side. All cases with Δ TDLT >5 mm only showed an average change in FCR <0.5 mm. The same finding applied for the 7 cases with ΔTDLT >10 mm. These findings further highlight the importance of the femoral component in LLD as was suggested in other studies.[7,8]

Furthermore, we investigated the link between femoral stem positioning relative to the OE insertion and LLD in our population. One of the problems encountered in elaborating a link between the two values was the fact that the obturator fossa is occluded in most postoperative X-rays leading to a significant loss of available patients to be examined in other studies.[10] Hence, we used an new method of indirectly measuring the distance between the stem and the OE (OE-SH) by use of the GT which is an commonly used reference and is described as a reliable radiographic landmark.[22-24]

DA was performed to analyze a possible predictive value to divide patients in a ΔTDLT > or <5 or 10 mm group depending on their OE-SH value, suggesting a critical value of OE-SH to be respected before risk of LLD increases significantly. This resulted in a discriminating value of 5.99 mm and 5.24 mm for a ΔTDLT of 5 and 10 mm, respectively. These values are close to the average width of the OE tendon of 6.4 mm as observed by Rüdiger *et al*. and Vles *et al*.,[9,11] further confirming the OE's clinical relevance as the OE-SH increasing above 6 mm correlates strongly to an increased risk of significant LLD as shown in the risk analysis performed in this study. An important finding even more so due to the fact that the low amount of lengthened patients in this group did not stop it from being a significant and adequately powered finding.

This is the first study we know of to correlate postoperative femoral stem position relative to the OE and studies its implication on LLD after DAA THR. The method and findings in this study can be readily incorporated in daily practice and allow means to investigate unexpected LLD after THR. The radiographic method mitigates postoperative obscurance of the trochanteric fossa and allows for further studies in this field. Our large group being operated on by a single surgeon in a high-volume center aids in lowering variation and making the results from this study more reliable.

As with any retrospective radiographic study, there are certain limitations.

Firstly, there is an inherent observer error in radiographic studies. This was mitigated as much as possible, and high ICC for inter as well as intraobserver reliability showed the measurements to be reproducible and reliable. A gap of minimal 2 weeks between measurements was maintained.

Secondly, as this was beyond the scope of our study, no clinical correlation was made with current findings. The impact on outcome by LLD has been studied copiously however,[1,2,8,19,25-28] and the LLD in itself is just a parameter in the whole set of parameters restoring the normal hip biomechanics.

The high (13%) number of patients without a significant LLD having a high (>6 mm) OE-SH distance underlines the fact that leg length is not solely dependent on stem depth and a significant compensation can happen on the acetabular side and/or from the femoral head. Also, intended OE-SH distance due to patient anatomy (coxa vara-valga) might contribute to this group. This needs to be elaborated on in further prospective research which takes the preoperative templating into account. Nevertheless, a strong connection was found indicating that regardless of the above the OE-SH is an important parameter in LLD after THR.

Other considerations need to be made. Firstly, the assumption that proximal femoral anatomy was symmetrical could make interpretation of results less reliable. The same applies for hip flexion, which can impact the measurements used in this study. Spinal deformity is a contributing factor to LLD and was excluded when present as described above. The nonoperative side is rarely unaffected and this could interfere with the interpretation of LLD. The latter was counteracted by excluding Tönnis > grade 2 hips from analysis.

Due to the scope of this paper, other causes of LLD were not investigated. For example, diaphyseal-metaphyseal mismatch may lead to suboptimal femoral sizing, thus impacting placement relative to the OE. The role of certain parameters as the canal flare index on LLD have been reported in other papers[29,30] but are not routinely used in LLD research. The rol of parameters as the canal flare index, the level and plane of the femoral neck cut on LLD are subjects for further research in THR.[31]

Conclusion

- OE-SH is a reliable measurement and a reliable predictor of LLD after THR
- The radiographic cutoffs of OE-SH correlate well with the average size of the OE tendon, further underlining its clinical value in DAA THR
- Intraoperative significant OE-SH warrants a critical review and correlation to preoperative planning
- The radiographical method described in this article allows for further objective quantification of the OE as a surgical landmark for DAA in a prospective fashion.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Which Hemostatic Agent Works Best in Reducing Blood Loss in Total Knee Arthroplasty? - A Retrospective Study in University Clinical Hospital Mostar

Maki Grle, Damir Franjic, Robert Karlovic, Mladen Mandic, Jerko Prlic
Department of Orthopedics, University Clinical Hospital Mostar, Mostar, Bosnia and Herzegovina

Abstract

Context: Total knee arthroplasty (TKA) is one of the most performed orthopedic surgeries worldwide. It is accompanied by high blood loss during and after the surgery. **Aims:** The study aims to determine if hydrogen peroxide (H_2O_2) is superior to tranexamic acid (TXA) in reducing blood loss during TKA. **Subjects and Methods:** This research's total number of participants was 101. Participants were divided into three groups based on the hemostatic agent they received: TXA, H_2O_2, and control. Postoperative blood loss was measured by taking a blood sample on the operation day, the 1st day, 7th day postoperatively, and on discharge from the hospital. The participants were compared according to blood loss during the timeline, amount of blood transfusions, loss in drains, and patella resurfacing. **Statistical Analysis Used:** Frequencies of nominal variables were analyzed using the Chi-square test. All continuous data were expressed as mean ± standard deviation. Distribution was normal so the significance of continuous variables was analyzed using one-way analysis of variance test. **Results:** Patients' general characteristics, hospital stay, and preoperative hemoglobin (Hb) were similar among the groups. The TXA group had significantly lower Hb loss on the 1st ($P = 0.019$) and 7th ($P = 0.035$) postoperative day. The TXA group had the lower number of indicated transfusions ($P = 0.001$). Drainage blood loss was lowest in the TXA group ($P < 0.014$). Differences in the volume of lost blood, resurfaced patella, and blood group among the groups were not statistically significant. **Conclusions:** TXA proved to be more efficient than H_2O_2 in reducing blood loss, the need for transfusions, and drain blood loss in TKA.

Keywords: Blood loss, blood transfusions, hydrogen peroxide, total knee arthroplasty, tranexamic acid

Introduction

Total knee arthroplasty (TKA) is one of the most performed orthopedic surgeries worldwide.[1] It is cost-efficient and provides great outcomes in degenerative osteoarthritis. Surgery is accompanied by a high risk of infection and significant blood loss which can be up to 1800 ml.[2,3] Nowadays, TKA is mostly done bloodless using a tourniquet during surgery, resulting in minor intraoperative blood loss and significant postoperative blood loss.[4] As a result of that, topical hemostatic agents such as tranexamic acid (TXA) and 3% hydrogen peroxide (H_2O_2) are introduced.[5] The hypothesis of this research was that H_2O_2 is more effective than TXA in reducing postoperative blood loss during TKA.

Subjects and Methods

This retrospective study included a total of 121 patients who underwent TKA on the orthopedics ward at University Clinical Hospital Mostar (UCHM). Surgeries were performed between January 1, 2018 and December 31, 2021.

This research was approved by the Institutional Ethics Committee at UCHM. All procedures followed were in accordance with the ethical standards laid down in the 1975 Declaration of Helsinki and its later amendments.

The study included all patients who were diagnosed with primary end-stage knee osteoarthritis (Kellgren–Lawrence

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Address for correspondence: Dr. Maki Grle, Department of Orthopedics, University Clinical Hospital Mostar, Kralja Tvrtka bb, 88000 Mostar, Bosnia and Herzegovina.
E-mail: grlemaki@gmail.com

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Grades 3–4). Patients with secondary osteoarthritis, a history of thromboembolic disease, a history of bleeding, bleeding disorders, and patients receiving lifetime warfarin therapy were excluded from the study.

All surgeries were performed by the same surgeon. Preoperative hemoglobin (Hb) was measured in the 3-week preoperative patient preparation period. The patients received general endotracheal or spinal anesthesia. A dose of 1 g cefazoline was administered intravenously before the surgery. In every TKA, a midline skin incision and a medial parapatellar approach were used. Every patient had the tourniquet applied to the upper thigh and after exsanguination; it was inflated to 300 mmHg. Minor bleeding throughout the surgery was electrocauterized. All the patients were implanted with Multigen Plus knee (LimaCorporate S. p. A, Villanova, San Daniele del Friuli, Italy). After cementing, topical hemostatic agents were administered, and briefly, after that, the tourniquet was deflated until the end of surgery. In each group, patients received vacuum drainage for 48 h.

The participants were divided into two study groups and a control. In the first group, H_2O_2 was packed in the surgical wound after endoprosthesis cementing, and in the second group, TXA was used perioperatively. The control group received only the vacuum drainage. There were 43 patients in the H_2O_2 group. After cementing endoprosthesis, gauzes were soaked in 100 ml of 3% H_2O_2, which was directly packed onto the surgical wound, bandaged, and left for 2 min to act. Consequently, the tourniquet was released and the major bleeding vessels were cauterized.

The TXA group received 1 g of TXA in an intravenous infusion 30 min before the surgery. After the tourniquet was deflated, the major bleeding vessels were cauterized and 1 g of TXA was injected topically into the surrounding tissue. After the joint, capsule was sutured 1 g of TXA was injected intraarticularly.

The blood samples were taken in the afternoon on the day of surgery, the 1st postoperative day, and the 7th day after the surgery.

The blood loss was calculated using the Hb balance method. Initially, an estimate of a total blood volume (BV) in ml using Nadler's formula was made, whereby the average BV per demographic adult male was 75 mL/kg and for adult females 65 mL/kg. Initial hemoglobin before the surgery was marked Hb_i (g/L). Hemoglobin measured after the surgery was marked Hb_e (g/L). The total volume of blood transfusions was marked Hb_t (g). Generally, 1 U of the banked blood contains 52 ± 5.4 g of Hb. After everything was added to the equation, the total Hb loss in grams was calculated. Putting that into another equation, the total volume of blood loss (in ml) was measured.

$$Hb_{loss\ total} = BV \times (Hb_i - Hb_e) \times 0.001 + Hb_t$$

$$V_{loss\ total} = 1000 \times Hb_{loss\ total}/Hb_i$$

The transfusion protocol in our clinic was based on Hb levels. The threshold was set to 90 g/L. Despite that, in rare cases, transfusion could be indicated by the clinical decision.

Nominal data were presented using frequency and percentage. Frequencies of nominal variables were analyzed using the Chi-square test. All continuous data were expressed as mean ± standard deviation. The data distribution for continuous variables was determined using the Kolmogorov–Smirnov test. Distribution was normal so the statistical significance of continuous variables between groups was analyzed using the one-way analysis of variance test with the Bonferroni *post hoc* analysis. Results were analyzed using the SPSS version 26.0 (SPSS, Chicago, IL, USA) and the computer program Excel (Microsoft Office Excel 2019). All tests were two-tailed and the $P < 0.05$ were considered statistically significant.

Results

There was no difference in the patient mean age, gender distribution, body weight, hospital stay, or preoperative Hb between study groups. According to Table 1, there was no significant difference among groups [Table 1]. Twenty patients were excluded from the study due to missing data.

The Hb drop compared before surgery and on the discharge from the hospital was 22.8 ± 11.7, 26.8 ± 13.8, and 26.6 ± 13.1 g/L ($P = 0.384$) for TXA, H_2O_2, and suction, respectively. Serum Hb loss on the day of operation, the 1st postoperative day, and on day 7 are shown in Table 2. A comparison of the Hb drop during the timeline between the three groups is displayed in Chart 1.

The volume of lost blood based on the equation was 425 ± 276, 515 ± 252, and 510 ± 271 ml ($P = 0.317$) for TXA, H_2O_2, and suction, respectively. Postoperative drainage blood loss was lower in the TXA group compared to the other two groups [Chart 2].

Table 1: Patient's general characteristics among groups

	TXA ($n=31$)	H_2O_2 ($n=43$)	Suction ($n=27$)	*P*
Age (years)	66±8	69±6	66±8	0.143
Male, *n* (%)	9 (29)	14 (32.6)	7 (25.9)	0.856
Female, *n* (%)	22 (71)	29 (67.4)	20 (74.1)	
Body weight (kg)	90.3±14.3	86.9±12.2	90±15.6	0.505
Hospital days	13.6±5.5	12.8±5	13.8±5.9	0.702
Mean preoperative Hb (g/L)	136±10	136±13	135±16	0.915

Hb: Hemoglobin, TXA: Tranexamic acid, H_2O_2: Hydrogen peroxide

Table 2: Hemoglobin loss after surgery, on the 1st and the 7th postoperative day

	TXA	H_2O_2	Suction	*P*
Day of operation	19.2±14.4	21.9±10.7	22.3±14.4	0.583*
First postoperative day	26.4±11.8	34.7±10.6	31.3±7.8	0.019†
Seven days postoperative	22.9±12.1	30.3±13.5	28.2±13.8	0.035†

*One-way ANOVA, †With Bonferroni *post hoc* correction.
TXA: Tranexamic acid, H_2O_2: Hydrogen peroxide

There was no difference in the average number of transfusions received by a single patient among the groups with the maximum number of five transfusions per patient in each group. Apart from that, there were significantly fewer patients that received transfusions in the TXA group [Table 3].

Patella resurfacing (P = 0.746) and blood group (P = 0.132) did not have a significant impact on blood loss. Almost 12% of patients had Hb levels below the transfusion threshold set by our ward, but 56% of patients received a transfusion.

Discussion

Based on our results, we can reject our hypothesis that H_2O_2 wash is more efficient than TXA in blood loss reduction during TKA arthroplasty. The TXA proved to be the best hemostatic agent for peri- and postoperative blood loss management during TKA. It was superior in reducing Hb drop, blood loss in drains, and the need for blood transfusions.

TKA brings various benefits to the patients along with its complications, whereas blood loss is considered one of the most common and most important. Patients with high blood loss have increased functional ability impairment, longer hospital stays, and increased morbidity and mortality.[2,6] Therefore, surgeons are coming up with new ideas to address this issue and achieve better results. In recent years, TXA has gained significant popularity among orthopedic surgeons as a method of blood loss management.[7]

Table 3: Transfusions distribution among the groups

	TXA (n=31), n (%)	H_2O_2 (n=43), n (%)	Suction (n=27)	P
Received transfusion				
Yes	9 (15.8)	29 (50.9)	19 (33.3)	<0.001†
No	22 (50)	14 (31.8)	8 (18.2)	
Average transfusions per patient (maximum)	2.8 (5)	2.3 (5)	2.3 (5)	0.337*

*One-way ANOVA, †Chi-square. TXA: Tranexamic acid, H_2O_2: Hydrogen peroxide

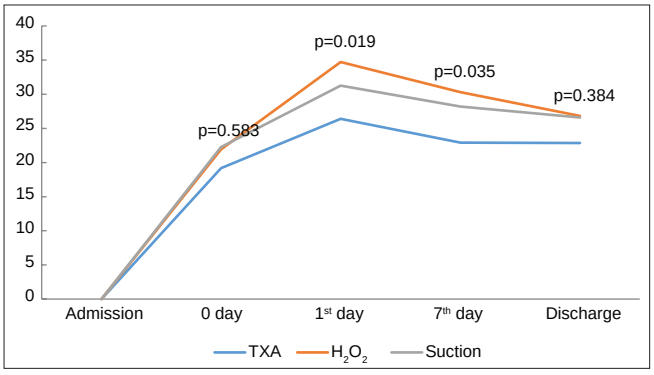

Chart 1: Hemoglobin loss during timeline (g/L). Analyzed using one-way ANOVA with Bonferroni *post hoc* correction. ANOVA: Analysis of variance

The TXA group showed a significant decrease in blood loss during the postoperative period. On the operation day, the difference was not big but in the coming days, it became apparent that TXA surpassed two other groups. Our observations are consistent with other research questioning TXA in blood loss management.[8]

BV lost during TKA was calculated using the formula. There was no significant difference, but the TXA group had the lowest BV loss. Similarly, blood loss in drains was significantly lower in the TXA compared to the latter. Tille *et al*. in Dresden and Dorji *et al*. in India got the same results in their articles.[9,10] Usage of drains is still controversial among orthopedic surgeons. Research in 2020 by Goyal found no difference in blood loss with or without drainage. They concluded that draining is a matter of the surgeon's personal choice.[11] We agree with them and we think that it should be up to the surgeon.

Alternatively, H_2O_2 was used for decades as a hemostatic and antiseptic agent in joint arthroplasty, especially in total hip replacement. Its widespread use is due to its availability, low cost, antimicrobial properties, hemostatic effect, and drying bone surface before cementation.[12] Even though it has a lot of benefits, it is pushed out of use in recent years because there are more effective ways of achieving hemostasis without the risks that come with H_2O_2. Our research along with many others confirms the significant efficiency of TXA over H_2O_2 in hemostasis.[5,13,14] Addressed complications of H_2O_2 are associated with aseptic loosening of the prosthesis, bone cell toxicity, and increased risk of gas embolization which overcomes its benefits.[5,15,16]

Our research group found a significant decrease in recorded blood transfusions given in the TXA group, compared to the H_2O_2 and suction only. Tille *et al*. and Singh Sidhu *et al*. also found that intra-articular application of TXA reduced the need for allogeneic blood transfusions.[9,17] However, in our research, we applied TXA intraarticularly and intravenously. The same research was conducted in India with similar results.[10] Since the meta-analysis conducted by Franchini *et al*. found no risk

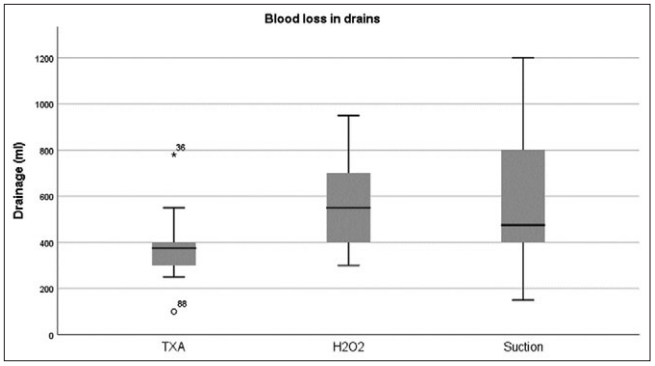

Chart 2: Drainage blood loss among groups analyzed using one-way ANOVA (P < 0.014). Drainage was 377 ± 155, 574 ± 179, and 561 ± 260 ml for TXA, H_2O_2, and suction, respectively. ANOVA: Analysis of variance, TXA: Tranexamic acid, H_2O_2: Hydrogen peroxide

of thromboembolic incidents in the intravenous administration of TXA, we support a combined approach.[18] Combined administration is also supported by Oremus *et al*. because local application creates high drug concentration at the site of clot formation inside the joint, and at the same time, induces microvascular hemostasis in the affected area. On the other hand, the intravenous route delivers medication into tissues even before the first incision is made.[5,14] Hence, the combined approach uses the benefits of both routes without increased risk of complications.

Research conducted by Qiang Lu in 2018 found that allogenic blood transfusions increase hospital stay with increased postoperative complications.[19] Conversely, in our research, there was no difference in the hospital stay between the three groups. We concluded that it could be due to the population with a low number of blood–borne viral diseases and good transfusion center control.

Based on our results, we found out that there were a lot of unnecessary indicated transfusions. The transfusion threshold for orthopedic surgery patients set by the American Association of Blood Banks is 80 g/L.[20] Practice on our ward was threshold set to 90 g/L. We found that even with an increased threshold only 12% of patients fulfilled the criteria, despite that 56% received a blood transfusion. Our results opened our eyes and made us revise our transfusion criteria. We want to point out the problem of unnecessary transfusions so every clinic should revise and supervise their transfusions.

In our research, we examined blood groups in their susceptibility to hemorrhage. Our results showed no difference between groups. Similar to our research, Komatsu *et al*. found that the blood group is not associated with higher intraoperative bleeding.[21] On the other hand, researches conducted worldwide suggested contrary results. One conducted by Mehic *et al*. found that blood group O has lower levels of von Willebrand factor and factor VIII (FVIII) resulting in higher blood loss.[22] Furthermore, research in Japan states that people with that blood group have a higher risk of death from severe trauma due to excessive bleeding.[23] We consider that the blood group is not determining factor in blood loss during arthroplasty surgeries.

Another thing that we wanted to point out is whether patella resurfacing is an important factor in blood loss during TKA. In patella replacement, more bone is cut and there are more traumas to the surrounding tissue. We did not find significant blood loss in patients with the resurfaced patella. Similar to our research, Ha *et al*. did not find significant blood loss in their clinical trials. Based on this research and most of the others, blood loss should not be considered in patella resurfacing. Resurfaced patients showed lower pain scores and longer prosthesis survival.[24,25]

One of the constraints of this research is that it is a retrospective study in which we collected data from patients' records where some of the data were absent or of poor quality. Furthermore, we did not have data about intraoperative suction and the patients' height record. With those data, our blood loss calculations in milliliters would be more accurate. We did not measure intraoperative crystalloid replenishment. It could affect our Hb drop measurements on the day of operation.

Conclusions

TXA proved to be the best currently available hemostatic agent in reducing blood loss during TKA. It reduced postoperative bleeding on the 1st postoperative day, 7 days after surgery, and on the discharge. Along with that, it reduced the need for blood transfusions and blood loss in drains.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Outcomes of Patients Undergoing Total Knee Arthroplasty with Spinal Anesthesia: A Comparison of Mepivacaine versus Bupivacaine

Samuel Elliott Holbert, Jane Brennan, Shreeya Bahethi, Madilyn Mandich, Minahil Cheema, Justin J. Turcotte, James Macdonald, Paul King
Anne Arundel Medical Center, Annapolis, Maryland, USA

Abstract

Introduction: Previous literature indicates that mepivacaine used for spinal anesthesia may lead to reduced recovery time and urinary retention compared to bupivacaine in patients undergoing total knee arthroplasty (TKA). We sought to compare outcomes between spinal anesthetics in our high-volume joint institution. **Materials and Methods:** A retrospective review of 553 unilateral primary TKA patients who received spinal anesthesia was conducted. Patients were divided by their receipt of mepivacaine or bupivacaine. Univariate comparisons before and after propensity score matching were used to compare outcomes for TKA patients receiving mepivacaine with those who did not. **Results:** Of the 553 patients, 102 received mepivacaine, and 451 received bupivacaine. After propensity score matching, patients who received bupivacaine experienced longer lengths of stay, received more oral morphine milligram equivalents (OMMEs), and were less likely to be discharged home. No differences in rates of nausea, urinary retention, or 30-day readmissions were observed between the groups. **Discussion:** In patients undergoing TKA with a spinal anesthesia, after adjusting for potentially confounding factors using propensity score matching, the use of mepivacaine was associated with shorter length of stay, less overall OMME requirements, and increased likelihood of home discharge, with no increase in complication rates. Based on these results, mepivacaine appears to be a viable alternative to bupivacaine for use in TKA rapid recovery protocols.

Keywords: Bupivacaine, mepivacaine, patient outcomes, spinal anesthesia, total knee arthroplasty

Introduction

Total knee arthroplasty (TKA) is one of the most commonly performed procedures in the US and the demand for this surgery is expected to increase with an estimated 3.48 million TKAs performed annually by 2030.[1] Anesthesia selection is a critical decision that influences early postoperative outcomes after TKA. General anesthesia has previously been associated with reduced perioperative tissue oxygen tension as well as postoperative nausea, vomiting, and delirium, which can be avoided using spinal (neuraxial) anesthesia.[2] In a recent study comparing the use of general versus neuraxial anesthesia in total joint arthroplasty (TJA), Turcotte *et al*. demonstrated patients receiving a spinal had higher postoperative hematocrit, were less likely to require transfusion, had shorter lengths of stay (LOS), lower-90 day emergency room visits, and were more likely to discharge home than those receiving general anesthesia.[3] Given its potential benefits, spinal anesthesia has become increasingly utilized for patients undergoing primary TJA.[4]

Bupivacaine and mepivacaine are both local amide anesthetic medications administered intrathecally for TKAs with similar mechanisms of action. Bupivacaine is a long-acting anesthetic while mepivacaine is an intermediate-acting anesthetic with a shorter duration of action.[5] However, the onset and duration of bupivacaine may be manipulated depending on the formulation such as hyperbaric or isobaric. Hyperbaric bupivacaine has a

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Address for correspondence: Dr. Justin J. Turcotte, Anne Arundel Medical Center, 2000 Medical Parkway, Suite 503, Annapolis 21401, Maryland, USA.
E-mail: jturcotte@luminishealth.org

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density greater than cerebrospinal fluid whereas isobaric has a density equal to cerebrospinal fluid. Different densities will affect the spread of the anesthetic as gravity causes hyperbaric solutions to move caudally while it has no effect on truly isobaric solutions.[6,7] In a prospective study of 60 patients, Helmi *et al*. demonstrated that isobaric bupivacaine produced more rapid onset of anesthesia and longer duration of action when compared to hyperbaric bupivacaine.[7] Lidocaine has recently grown in popularity as a potential alternative due to its short duration of action (90–120 min); however, in some cases, this may be too short for single-shot spinal anesthesia and its use is associated with a higher frequency of transient neurological symptoms.[5]

Previous literature indicates that mepivacaine administered intrathecally during TKA reduced recovery time and lessened urinary retention compared to bupivacaine use.[8] While TKA anesthetic approaches have shifted toward neuraxial anesthesia in recent years, this study compares mepivacaine and bupivacaine, used in combination with multimodal analgesics and periarticular injections to evaluate if local anesthetic choice is associated with improved early postoperative outcomes after primary unilateral TKA with spinal anesthesia.

Materials and Methods

This study was deemed institutional review board exempt as a type 4 retrospective study of de-identified existing medical records by the institutional clinical research committee. A retrospective chart review of all patients undergoing primary unilateral TKA by 10 board-certified surgeons at a single institution was performed. Fifty-seven anesthesiologists were included, with each physician covering an average of 12 surgical cases. The timeline for inclusion was between February 1, 2020, and September 1, 2020. Data were collected using an administrative database for patient demographics including age, sex, body mass index (BMI), and procedure performed. The use of adductor canal blocks (ACBs), intrathecal fentanyl, intravenous (IV) fentanyl, IV hydromorphone, IV or topical tranexamic acid (TXA), and IV dexamethasone were also recorded for each patient. American Society of Anesthesiologists (ASA) score was used to quantify preoperative health status.

Perioperative protocol

All patients were cared for in a coordinated Joint Replacement Center and received education materials including written materials, preoperative medical evaluations, preoperative home exercise or outpatient physical therapy (PT), and an education class for patients and their caregivers. Based on clinical history, patients received preemptive oral medications including celecoxib, acetaminophen, and pregabalin 2 h before their procedure. No robotics, navigation, and/or sensors were used in the performance of any case. Foley catheters were only utilized in male patients with a history of benign prostatic hypertension. A total of 9 (1.6%) patients included in this study received a catheter preoperatively. If a Foley catheter was placed, it was removed prior to discharge. ACBs were performed at the discretion of the anesthesiologist with consultation of the surgeon and patient. Single-shot spinal anesthesia was paired with propofol sedation and consisted of either 12–15 mg of hyperbaric or isobaric bupivacaine or 50–70 mg of mepivacaine, in alignment with the recommended dosing for patients undergoing TJA.[9] Spinal anesthesia type was selected at the discretion of the anesthesiologist and surgeon at the bedside, preoperatively. At the discretion of the anesthesiologist, intrathecal fentanyl was used in addition to the local anesthetic. Patients received IV opioids administered intraoperatively and in the postanesthesia care unit (PACU). The opioids that were utilized included fentanyl and hydromorphone. Intraoperative opioids were administered at the discretion of the anesthesiologist based on clinical evaluation of physiologic responses indicating patient pain perception and in the PACU based on patient need. All patients received a standard periarticular anesthetic injection of a 30 mL solution of saline, 10 mL of 0.5% ropivacaine, and 0.3 mg epinephrine using an 18G–22G needle before closure. All patients were treated utilizing a multimodal pain management protocol which depending on patient factors included acetaminophen, oral nonsteroidal anti-inflammatory drugs, pregabalin, ketorolac, and oral opioid medications as needed. All TKA patients received assisted ambulation on the day of surgery when appropriate. Prior to ambulating, patients were confirmed to have stable vital signs, controlled nausea, adequate pain control, be alert and oriented, and have return of sensory and motor function. These criteria were also used to indicate readiness for PT.

Study population

All patients included in this study underwent primary unilateral TKA between February 1, 2020, and September 1, 2020. Patients undergoing bilateral TKA or revision TKA were excluded from this study. A total of 553 patients met the inclusion criteria. Of the 553 patients, 451 received bupivacaine and 102 received mepivacaine.

Study outcomes

Postoperative outcomes of interest included PACU nausea and pain, receipt of nausea medication within 24 h of surgery, ability to participate in the first postoperative PT session, urinary retention, oral morphine milligram equivalent (OMME) consumption, length of stay (measured in hours), discharge disposition, recovery time, pain score, and 30-day readmissions. Reasons for inability to complete PT included patient pain, dizziness, and/or orthostatic hypotension. Patients with multiple reasons for inability to complete PT were counted in each group. Urinary retention was defined as any incidence of postoperative re-catheterization during the patient's hospital stay. Postoperatively, catheters were placed if the patient was unable to void and had ≥500 mL of urine on a bladder scan. Opioid consumption was measured as OMME and OMME per hour and included all opioids received outside of the operating room. Nonhome discharge was defined as any discharge to a skilled nursing facility.

Statistical analysis

Patients were grouped based on whether they received mepivacaine or bupivacaine at the time of surgery. Statistical analyses were used to determine the impact of mepivacaine or bupivacaine on postoperative outcomes. Univariate analyses including Chi-square tests and two-sided independent samples *t*-tests were used to determine differences between the groups. The Fisher's exact test was performed when the assumptions of Chi-square testing were not met, and the Mann–Whitney *U* test was used for nonparametric continuous data. Propensity score matching was used to strengthen causal inference by reducing selection bias. The groups were matched by BMI, use of an ACB, receipt of dexamethasone, and receipt of TXA. These variables were selected as possible confounding factors because they were significantly different at $\alpha < 0.10$ between the groups in preliminary univariate analysis. The data were matched using a 1:1 ratio. After propensity score matching, univariate analysis was used to determine the impact of mepivacaine or bupivacaine on postoperative outcomes. Statistical significance was assessed at $P < 0.05$. All statistical analyses were performed using RStudio (Version 1.4.1717© 2009–2021 RStudio, PBC).

Results

Of the 553 patients included in this study, 451 (81.5%) received bupivacaine and 102 (18.4%) received mepivacaine. Within the bupivacaine group, 97% of patients received a hyperbaric formulation. Prior to matching, there was no significant difference in age, sex, marital status, race, and ASA score between those who received mepivacaine or bupivacaine. There was a statistically significant difference in BMI (mepivacaine: 30.22 ± 4.81, bupivacaine: 31.54 ± 5.23; $P = 0.015$) [Table 1]. Intraoperatively, there were no significant differences in the rates of intrathecal fentanyl, IV fentanyl, or IV hydromorphone use between the mepivacaine and bupivacaine groups. However, mepivacaine patients were more likely to receive IV dexamethasone intraoperatively compared to bupivacaine patients (mepivacaine: 82.4%, bupivacaine: 53.2%; $P < 0.001$) [Table 2].

During their hospitalization, patients receiving bupivacaine experienced longer LOS (mepivacaine: 24.87 h. ±10.24, bupivacaine: 32.47 ± 19.13; $P < 0.001$), received more overall OMME (mepivacaine: 67.33 ± 38.62, bupivacaine: 80.23 ± 56.47; $P = 0.006$), and were less likely to be able to complete the first PT session (PT failure rate: mepivacaine: 0.9%, bupivacaine: 7.9%; $P = 0.007$). These patients were less likely to complete PT due to pain (mepivacaine: 0.9%, bupivacaine: 4.9%; $P = 0.012$), orthostasis (mepivacaine: 0.0%, bupivacaine: 2.4%; $P = 0.006$), and dizziness (mepivacaine: 0.0%, bupivacaine: 6.4%; $P = 0.003$). However, there were no differences in nausea, urinary retention, OMME per hour, rate of discharge to home, PACU recovery time, and last PACU pain score between those who received mepivacaine or bupivacaine [Table 3].

Table 1: Prematching population demographics

Patient demographics	Bupivacaine ($n=451$)	Mepivacaine ($n=102$)	*P*
Age	67.69±8.30	66.5±8.28	0.201
Sex			
Female	262 (58.1)	57 (55.9)	0.766
Male	189 (41.9)	45 (44.1)	
Married	277 (61.4)	69 (67.6)	0.289
White race	372 (82.5)	80 (78.4)	0.415
BMI	31.54±5.23	30.22±4.81	**0.015**
ASA 3 or 4	171 (37.9)	39 (38.2)	1

P<0.05 in bold. Data are expressed as mean±SD or *n* (%). BMI: Body mass index, ASA: American Society of Anesthesiologists Classification, SD: Standard deviation

Table 2: Concomitant intraoperative medications received (prematch)

Medication received	Bupivacaine ($n=451$)	Mepivacaine ($n=102$)	*P*
ACB	97 (21.5)	69 (67.6)	**<0.001**
Intrathecal fentanyl	62 (13.7)	20 (19.6)	0.052
IV or topical TXA	383 (84.9)	94 (92.2)	0.079
IV dexamethasone	240 (53.2)	84 (82.4)	**<0.001**
IV fentanyl	261 (57.9)	59 (57.8)	0.242
IV hydromorphone	80 (17.7)	12 (11.8)	0.188

P<0.05 are in bold. Data are expressed as *n* (%). ACB: Adductor canal block, TXA: Topical tranexamic acid

Table 3: Hospital and 30-day postoperative outcomes (prematch)

Postoperative outcomes	Bupivacaine ($n=451$)	Mepivacaine ($n=102$)	*P*
Nausea in PACU	134 (29.7)	22 (21.6)	0.126
Unable to complete 1st physical therapy	36 (7.9)	1 (0.9)	**0.007**
Reason: Pain	22 (4.9)	1 (0.9)	**0.012**
Reason: Orthostasis	11 (2.4)	0	**0.006**
Reason: Dizziness	29 (6.4)	0	**0.003**
Urinary retention	13 (2.9)	4 (3.9)	0.533
LOS (h)	32.47±19.13	24.87±10.24	**<0.001****
OMME	80.23±56.47	67.33±38.62	**0.006**
OMME/hour	2.63±1.34	2.67±1.36	0.789
Discharge to home	433 (96.0)	102 (100)	0.056*
30-day readmission rate	15 (3.3)	2 (1.9)	0.751*
PACU recovery time	151.92±55.44	148.25±57.30	0.559
Last PACU pain score	2.64±2.25	3.04±2.13	0.094

*Fisher's exact test, **Mann–Whitney *U*-test. *P*<0.05 are in bold. Data are expressed as mean±SD or *n* (%). OMME: Oral morphine milligram equivalent, PACU: Postanesthesia care unit, SD: Standard deviation, LOS: Length of stay

Mepivacaine and bupivacaine were matched using a 1:1 nearest match. Figure 1 shows that matching by propensity score decreased variability and increased comparability of the two groups. After matching, univariate analysis showed that there were no differences in patient demographics:

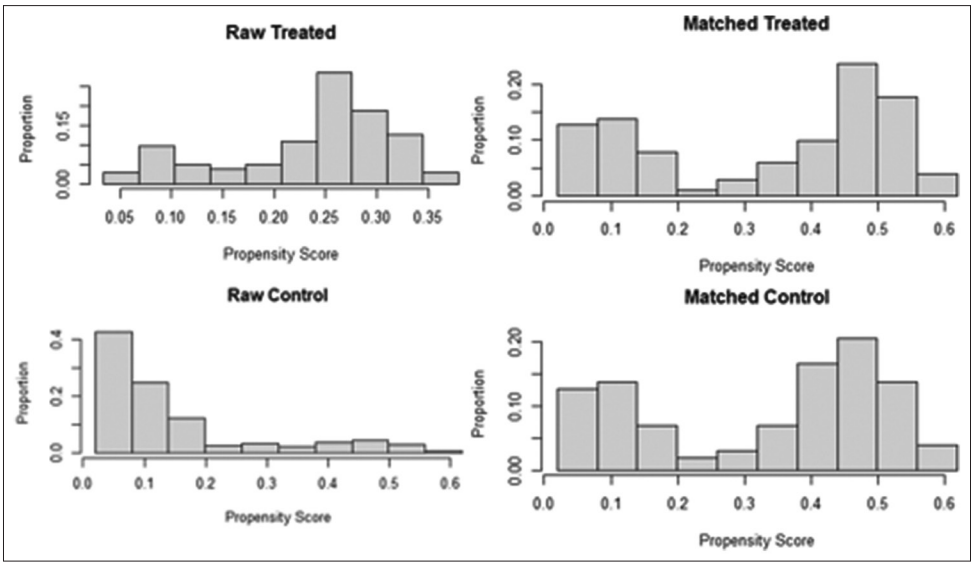

Figure 1: Histogram of propensity scores; a 1:1 nearest neighbor match without replacement was used

age, sex, marital status, race, BMI, or ASA score [Table 4]. Matching successfully removed any variation in concomitant intraoperative medications received as there was no significant difference in the use of ACBs, intrathecal fentanyl, IV or topical TXA, IV dexamethasone, IV fentanyl, and IV hydromorphone between the groups [Table 5].

Univariate analysis of postoperative outcomes confirmed that patients receiving bupivacaine experienced longer LOS (mepivacaine: 24.87 ± 10.24, bupivacaine: 30.89 ± 17.63; P = 0.041) and received more OMME (mepivacaine: 67.33 ± 38.62, bupivacaine: 82.31 ± 47.25; P = 0.039). In addition, patients who received bupivacaine were less likely to be discharged home than those who received mepivacaine (mepivacaine: 100%, bupivacaine: 95%; P = 0.029). However, there were no differences in nausea, inability to complete the first PT session, urinary retention, OMME per hour, PACU recovery time, and last PACU pain score between those who received mepivacaine or bupivacaine [Table 6].

Discussion

As rapid recovery protocols evolve, same-day discharge and ambulatory surgery center-based TKAs continue to increase in prevalence. To facilitate the safe performance of TKA in these settings, it is essential that anesthesia approaches be tailored to control early postoperative pain while allowing for early ambulation and avoiding anesthetic-related complications. Our findings indicate that mepivacaine may be equivalent to bupivacaine for achieving these goals, as evidenced decreased OMME consumption overall, decreased length of stay, and increased rates of discharge to home after controlling for confounding factors using propensity score matching. Based on our results and those of other modern studies, we support the use of mepivacaine as an alternative to bupivacaine to facilitate rapid recovery after TKA.

Table 4: Postmatching population demographics

Patient demographics	Bupivacaine (n=102)	Mepivacaine (n=102)	P
Age	67.78±8.38	66.52±8.28	0.279
Sex			
Female	59 (57.8)	57 (55.9)	0.887
Male	43 (42.2)	45 (44.1)	
Married	61 (59.8)	69 (67.6)	0.308
White race	85 (83.3)	80 (78.4)	0.476
BMI	30.76±4.87	30.22±4.81	0.426
ASA 3 or 4	36 (35.3)	39 (38.2)	0.772

P<0.05 in bold. Data are expressed as mean±SD or n (%). BMI: Body mass index, ASA: American Society of Anesthesiologists Classification, SD: Standard deviation

Table 5: Concomitant intraoperative medications received (postmatch)

Medication received	Bupivacaine (n=102)	Mepivacaine (n=102)	P
ACB	70 (68.6)	69 (67.6)	1
Intrathecal fentanyl	17 (16.7)	20 (19.6)	0.716
IV or topical TXA	93 (91.2)	94 (92.2)	1
IV dexamethasone	82 (80.4)	84 (82.4)	0.857
IV fentanyl	56 (54.9)	59 (57.8)	0.185
IV hydromorphone	16 (15.7)	12 (11.8)	0.0542

P<0.05 are in bold. Data are expressed as n (%). ACB: Adductor canal block, TXA: Topical tranexamic acid

General versus spinal anesthesia

The traditional drawbacks of general anesthesia for TKA, including postoperative nausea, vomiting, and delirium, can be largely avoided using modern spinal anesthetic techniques.[2] In a 2-year prospective observational study of 2242 patients undergoing primary TJA, Paziuk *et al*. demonstrated an association between spinal anesthesia and lower morbidity

Table 6: Hospital and 30-day postoperative outcomes (postmatch)

Postoperative outcomes	Bupivacaine ($n=102$)	Mepivacaine ($n=102$)	*P*
Nausea in PACU	24 (23.5)	22 (21.6)	0.887
Unable to complete 1st physical therapy	5 (4.9)	1 (0.9)	0.212
Reason: Pain	3 (2.9)	1 (0.9)	0.854
Reason: Orthostasis	2 (1.9)	0	0.937
Reason: Dizziness	0	0	1
Urinary retention	5 (4.9)	4 (3.9)	1
LOS (h)	30.89±17.63	24.87±10.24	**0.041****
OMME	82.31±47.25	67.33±38.62	0.039
OMME per hour	2.68±1.43	2.67±1.36	0.997
Discharge to home	97 (95.0)	102 (100)	**0.029***
30 days readmission rate	3 (2.9)	2 (1.9)	1*
PACU recovery time	151.64±65.48	148.25±57.30	0.695
Last PACU pain score	2.66±2.22	3.04±2.13	0.152

*Fisher's exact test, **Mann–Whitney *U*-test. $P<0.05$ are in bold. Data are expressed as mean±SD or *n* (%). OMME: Oral morphine milligram equivalent, LOS: Length of stay, PACU: Postanesthesia care unit, SD: Standard deviation

and mortality, as well as shorter hospital length of stay when compared to general anesthesia.[4] Similarly, in a retrospective, propensity score-matched cohort study, Perlas *et al*. reported a strong association between spinal anesthesia and lower 30-day mortality rate following TJA.[10] In another study, 5914 consecutive TJAs were examined and the results demonstrated that spinal anesthesia was associated with decreased LOS, short-term complications, and transfusions while facilitating home discharge after both TKA and THA.[3] These findings support the transition in standard of care from general to spinal anesthesia and lead us to the question: What is the optimal anesthetic drug for spinal anesthesia?

Bupivacaine versus mepivacaine

Historically, bupivacaine has been frequently used for spinal anesthesia in this population due to its reliability and desirable side effect profile. It is a long-acting local amide anesthetic producing a partial motor and sensory blockade providing a surgical anesthetic effect of 1.5–2.5 h, with effects lasting up to 9 h depending on dosage and formulation.[11,12] Mepivacaine is an intermediate-acting amide local anesthetic that produces a predictable anesthetic effect for 90–150 min.[11] Prior to the use of mepivacaine at our institution, anecdotal concerns regarding the potential for surgical times outlasting the 150-min window were raised. While 42 cases in this series (15.7%) lasted over 150 min, no intraoperative conversions to general anesthesia with endotracheal intubation occurred, suggesting that mepivacaine provided adequate blockade for the duration of the case. Several modern studies have shown that mepivacaine has a faster recovery from induction, decreased urinary retention, and increased patient and surgeon satisfaction.[5] In 2018, Mahan *et al*. conducted a retrospective review of 156 patients undergoing a TKA with either mepivacaine or bupivacaine and found that patients receiving mepivacaine had an average length of stay that was 5 h shorter and had less urinary retention.[8] In a separate 2019 study, Mahan *et al*. compared the time to return of neurologic function in 31 TKA patients receiving either mepivacaine or bupivacaine. They found that patients receiving mepivacaine had a faster return of motor and sensory function, faster time to urination, and decreased time to discharge by 71 min, than patients receiving bupivacaine.[5] Our findings are consistent with those made by Mahan *et al*. regarding length of stay, pain control, and nausea. However, we found there to be no differences in urinary retention while Mahan *et al*. reported significant improvements.[8] Both studies used similar methods of assessing urinary retention by the occurrence of postoperative catheterization based on a standard protocol. In comparison to the Mahan studies, we observed a significantly larger reduction in time to discharge of 6 h with mepivacaine, compared to 5 h and 71 min in the 2018 and 2019 studies, respectively. While further studies are needed to replicate these trends, reliably decreasing LOS by anywhere from 1 to 6 h with the use of mepivacaine holds significant potential to facilitate the transition of TKA to ambulatory care settings.

Another finding from the current study was that patients receiving mepivacaine received less OMME during the early postoperative period, although when compared by OMME/time, there was no significant difference. This finding is contrary to that of Mahan *et al*., who found that patients receiving mepivacaine received significantly more OMME in the early postoperative period than those receiving bupivacaine. Schwenk *et al*. further demonstrated the potential benefits of mepivacaine over bupivacaine. In a randomized controlled trial of 154 patients, the authors found patients receiving mepivacaine spinal ambulated earlier and were more likely to be discharged on the day of surgery than those receiving either isobaric or hyperbaric bupivacaine.[8,11] In another prospective, double-blinded, randomized clinical trial with 154 TJA patients by Wyles *et al*., the authors evaluated the return of motor function when using either mepivacaine or bupivacaine spinal anesthetic.[13] Patients who received mepivacaine had a return of lower extremity motor function an average of 26 min faster than those patients who received bupivacaine. More significantly, patients receiving mepivacaine demonstrated a more consistent return of motor function with fewer outliers than their bupivacaine-receiving counterparts.[13] In our study, we found that patients receiving mepivacaine were more likely to complete their first PT session but not after controlling for confounding factors using propensity score matching. In a sensitivity analysis (data not presented), we found that significant differences between the anesthetic groups existed when controlling for BMI, TXA, and dexamethasone but did not remain after the use of an ACB was incorporated into the matching algorithm. This finding suggests that the use of a peripheral block rather than the type of anesthetic selected may have a greater impact on early physical function, and suggests that additional

randomized controlled trials are required to confirm which component of anesthesia has a greater effect. Although each of the studies presented focused on different parameters, the findings converge on a consistent conclusion: when compared to bupivacaine, mepivacaine has proven to be just as safe – having minimal postoperative adverse events, and may facilitate earlier discharge based on its shorter duration of action. The results of the current study are largely in alignment with those previously reported, and add further support to the conclusion that mepivacaine is safe and effective for use in TKA with spinal anesthesia.

Limitations

This study was limited by the nature of its retrospective observational design conducted at a single institution. Although the single institution design and use of a standard protocol helps to minimize the variation among surgeons and anesthesiologists and negates geographic differences among patients, our results may not be generalizable to the general population. Despite having these standard protocols in place, we were unable to evaluate protocol compliance at a patient-specific level. For example, preoperative medications were ultimately decided at the discretion of the surgeon on a patient-specific basis. Further, our finding of reduced OMME consumption in the mepivacaine group was likely driven by decreased length of stay, given that OMME consumption per hour of hospitalization did not differ between the groups. In addition, we did not account for preoperative opioid use which has been demonstrated to affect the overall OMME requirements.[14] With regard to patients in the mepivacaine group having a greater ability of completing their first PT session in the unmatched cohorts, our study was limited in that there was no standardization to when the first PT session was attempted. Considering this, the time of surgery may have affected when the PT session was attempted. Another possible confounding variable in this study may be the level of sedation or drugs utilized for sedation, as these were not evaluated. Finally, the largest limitation in our study was selection bias. The large number of anesthesiologists included in this study introduces high potential for variability in individual practice patterns, although we suggest that this is likely reflective of anesthesia staffing patterns across most institutions. Based on the over 4:1 use of bupivacaine over mepivacaine, it is clear that bupivacaine remains the spinal anesthetic of choice at our institution. We hypothesize that this is largely a result of historical anesthesiologist training and practice patterns, and due to concerns over anesthetic duration with mepivacaine – which was not observed to result in any conversions to general anesthesia in the current study. Given the multitude of factors that may have influenced selection of the spinal anesthetic used, our use of propensity score matching was critical to develop similar cohorts for comparison and mitigate the risk of selection bias. Further, because anesthetic medication was chosen based on surgeon and anesthesiologist preference, it is possible that patients expressing a desire for early discharge were more likely to be given mepivacaine because of the presumed benefit. Because of this, the LOS findings may be confounded and consequently, the OMME findings, as total OMME is directly related to LOS. Therefore, our finding of significantly less overall OMME requirements must be interpreted with caution as it was likely driven by decreased LOS, rather than differences in postoperative pain control. In addition, because 97% of bupivacaine patients received a hyperbaric formulation, we are unable to comment on any differences in outcomes that may occur with isobaric bupivacaine specifically. Finally, this study did not differentiate between standard and complex primary TKAs requiring stems or augmentation with additional instrumentation, which could influence the results. Despite the limitations, the strength of this study was in the use of propensity score matching to create the most similar groups possible and control for confounding factors including BMI, ACBs, TXA, and dexamethasone use. Given the significant body of literature highlighting the effect of these drugs on our outcomes of interest,[15-17] it is essential that studies control for the use of these medications. Despite our attempts to control for all observed differences between the groups, it is possible that unknown confounders and selection bias influenced our results. Regardless of our findings, bupivacaine still has an important role in TKA with spinal anesthesia such as with complex primary cases or early career surgeons with longer operative times. Given the multiple confounding factors that may influence the results presented in this and other observational studies comparing mepivacaine and bupivacaine, further randomized controlled trials are needed before the superiority of either anesthetic can be declared.

Future directions

While the current study evaluates the use of mepivacaine and bupivacaine as spinal anesthetics specifically, multiple alternative nonnarcotic pain management techniques have been recently described that warrant further evaluation. Although it was not considered in this study, another anesthetic technique to be considered is combined spinal-epidural anesthesia. This technique utilizes a spinal anesthetic dose insufficient for surgery in an attempt to reduce hypotension, and then, the block is extended with the use of an epidural drug.[18] Combined spinal-epidural anesthesia is growing in popularity due to the ability to prolong the block; however, the return of motor function is delayed in these patients due to the epidural supplementation given to prolong the block. In addition, combined spinal-epidural anesthesia is associated with more hypotensive episodes and need for vasoconstrictor use than spinal anesthesia alone.[19,20] Currently, this technique is more often utilized with older, high-risk patients.[18] When considering regional anesthesia techniques, ACBs are frequently performed over femoral nerve blocks, due to their noninferior effect on pain control or opioid consumption, and improved sparing of quadriceps strength leading to decreased fall risk and faster functional recovery.[21] Alternative regional blockade approaches that have been described include infiltration between

the popliteal artery and capsule of the posterior knee (IPACK) block and surgeon-administered direct adductor canal blocks (DACBs) or saphenous nerve blocks (SNBs). Early data are mixed regarding the efficacy of IPACK blocks. Studies have found that the addition of an IPACK block to an ACB may lead to lower pain scores during early recovery, but that the impact may be of little clinical significance.[22,23] Conversely, others have cautioned that the addition of IPACK to ACB may result in higher opioid requirements and worse immediate functional performance.[24] The concept of surgeon-administered blocks such as DACBs or SNBs holds significant potential to yield time and cost savings if proven to be safe and effective in comparison to traditional ultrasound-guided blocks performed by the anesthesiologist.[25] In a retrospective comparison of a surgeon performed, high-dose periarticular injection and SNB versus an ACB catheter placed postoperatively by an anesthesiologist, the SNB group demonstrated lower pain scores and less IV narcotic use on the day of surgery with no difference in complications.[26] Similarly, Greenky *et al*. prospectively randomized subjects to receive an anesthesiologist-administered, ultrasound-guided, preoperative ACB or a surgeon-administered, intraoperative DACB. The authors found that the surgeon-administered DACB was noninferior to the traditional ACB with respect to pain, opioid consumption, range of motion, patient satisfaction, or short-term functional outcomes.[27] As rapid recovery TKA protocols continue to evolve, further research is required to identify the combinations of regional and local anesthetic techniques and multimodal analgesics that optimize patient outcomes.

Conclusion

In patients undergoing TKA with spinal anesthesia, after adjusting for potentially confounding factors using propensity score matching, the use of mepivacaine was associated with decreased LOS, increased rates of discharge to home, and less total OMME requirements, with no increase in complication rates. Based on these results, mepivacaine appears to be a viable alternative to bupivacaine for use in TKA rapid recovery protocols.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

CT Based Measurement of Coracoid Process Dimension and a Technique to Measure in our Population

Arun GR, Ashish Suresh Babhulkar[1], Vishnu Unnithan[2], Namratha Srinivasan[3], Sindhu B[4], Sunil Kumar PC[5]

Assistant Professor, Mysore Medical College and Research Centre, Mysore, Karnataka, [1]Consultant and Head, Department of Shoulder Surgery, Deenanath Mangeshkar Hospital, Pune, Maharashtra, [2]Consultant, PRS Hospital, Thiruvananthapuram, Kerala, [3]Senior Resident, Mysore Medical College, Mysore, Karnataka, [4]Assistant Professor, Saptagiri Institute of Medical Sciences, Mysore, Karnataka, [5]Associate Professor, Mysore Medical College, Mysore, Karnataka, India

Abstract

Aim: The aim of this study was to do computed tomography (CT)-based measurement of coracoid process dimension and a technique to measure in our population. **Materials and Methods:** One hundred and twenty-three shoulder CT scans were analyzed in the adult Indian population. The images were processed using curviplanar reconstruction method to straighten out the curved coracoid process. The mean dimensions of coracoid process in relation to anteroposterior length, mediolateral distance, and supero-inferior distance were measured and tabulated along with age and gender differences. Paired *t*-test or Wilcoxon signed-rank test was used as a test of significance, and $P < 0.05$ was considered statistically significant. **Results:** In the study, the mean anteroposterior length was 25.80 ± 3.09 mm, the mean mediolateral length was 12.02 ± 1.82 mm, and the mean supero-inferior length was 10.27 ± 1.64 mm. No statistically significant difference was seen between the two observers, giving power to the method used. **Conclusion:** In this CT-based analysis of coracoid process, we can estimate the average dimension of coracoid process available in our population and also the preference of surgical procedure according to the glenoid bone loss. Furthermore, it was concluded that CT-based measurements of coracoid process were well correlated between the orthopedician and the radiologist. Hence, these measurements can be used as a tool to estimate the average length available for transfer in the Latarjet procedure in our population.

Keywords: Coracoid process, computed tomography scan, glenoid bone loss, Latarjet, shoulder instability

Introduction

As we know, the shoulder joint is the most mobile joint of the human body. Due to its increased range of movements, it is also highly susceptible to dislocation. In recent years, there are a wide variety of options to treat shoulder instability from open surgery to arthroscopic repair. However, the chances of failure are relatively high, which is about 13% in arthroscopic repair and more especially in patients with a significant glenohumeral bone loss which is about 67%.[1-3]

In the Latarjet procedure, we use coracoid process as a graft to increase the diameter of glenoid, and also conjoint tendon acts as a dynamic stabilizer to prevent shoulder instability. Hence, the measurement of coracoid process dimension is crucial before surgery to avoid incomplete harvest of the graft which will affect the outcome of the procedure.[4,5]

There are many studies described in the literature to measure coracoid process dimension in cadavers and computed tomography (CT) scans. However, those studies do not describe and measure the surgically excisable coracoid process length, which can help the surgeon to plan preoperatively. Only limited literature is available that defines the dimension of coracoid process using three-dimensional (3D) CT with curviplanar reconstruction technique, but there is limited literature available in the Indian population.[6]

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Address for correspondence: Dr. Arun GR, No-155, A Block, 2nd Main, 4th Cross, SBM Layout, Bogadi, Mysore - 570 026, Karnataka, India.
E-mail: drgrarun@gmail.com

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This study will help in measuring the dimension of coracoid process, it will help to define a technique to measure in CT scan and the role of preoperative measurement of coracoid process in the Latarjet procedure. Although there are many literatures available, there are very few studies from within our population.

Materials and Methods

This is a descriptive study. Institutional ethical clearance was not needed as no personal patient data were accessed. All shoulder CT scans performed in our hospital for shoulder surgery were evaluated. The age group selected was above 18 years for the completion of skeletal maturity.

All CT scans which were performed for shoulder surgeries in preoperative screening between 2015 and 2017 were included in the study.

Exclusion criteria were coracoid process fracture, the anomaly of coracoid process, degenerative changes, already harvested coracoid process, skeletal immaturity, and tumors around the shoulder joint. None of the CT scans were excluded due to the above reasons.

All patients were scanned using a 64-slice CT scanner from Siemens (Siemens SOMATOM Sensation 64). The scan was done in a lying-down position.

The axial slices were acquired with 3.00 mm thickness and reconstructed to 1.00 mm contiguous sections. The field of view (FOV) (500 mm × 512 mm), milliamperes (MAs) (220 MAs), and kilovoltage peak (KVp) (120 KVp) were used. The axial images so obtained were subsequently transferred to the OsiriX MD workstation (Apple Mac Inc.).

FOV, MA, KVp, and Osirix MD–FDA approved medical image viewer.

Osirix is an open-source program which turns Apple Macintosh into a DICOM PACS workstation for medical imaging and image processing. It has been specially designed for navigation and visualization of multimodality and multidimensional images.

The images were processed using curviplanar reconstruction method to straighten out the curved coracoid process. The straightened coracoid process was measured [Figure 1]. Subsequently, cross-sectional images were obtained through the coracoid process at its midpoint [Figure 2]. The measurement was done using an electronic caliper.

The mean dimensions of coracoid in relation to anteroposterior (A-P) length, mediolateral distance, and supero-inferior distance were measured and tabulated along with age and gender differences.

The length was defined as the distance between the midpoint on the apex and another point, which is the midpoint on the elbow of coracoid process perpendicular to coracoid stalk

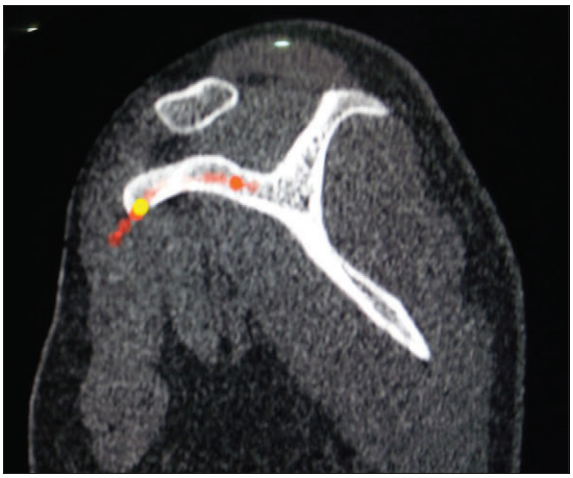

Figure 1: Mapping of coracoid process in sagittal plane in Osirix software

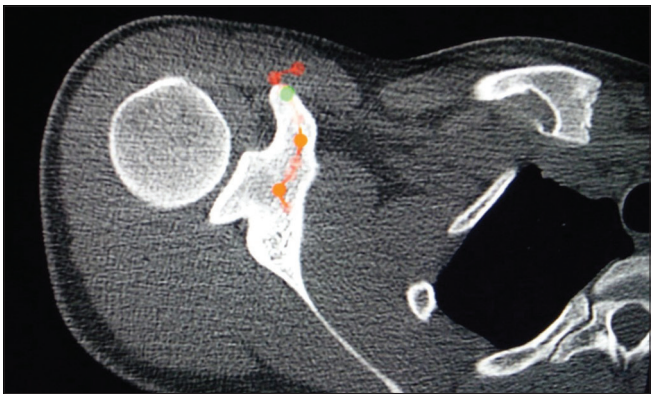

Figure 2: Mapping of coracoid process in coronal plane

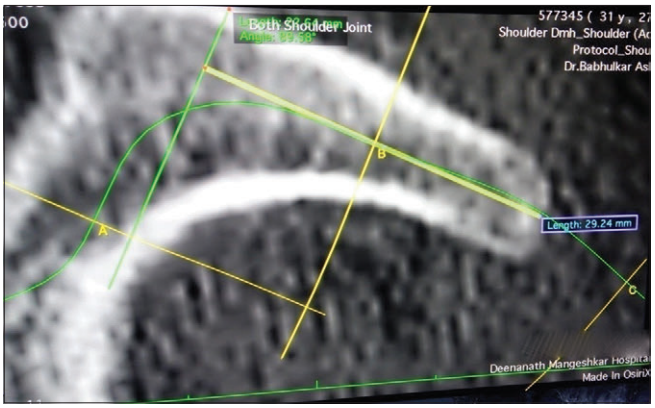

Figure 3: Measuring AP length

which corresponds to the intraoperative length of the available coracoid process [Figure 3].

The author describes this as "useful surgical coracoid length." At midpoint of the A-P length, mediolateral distance and superio-inferior distance were measured at the coracoid cross section on the coronal and sagittal sections, respectively, [Figure 4].

Proper protocol for measurement was defined between the orthopedician and the radiologist. After understanding the technique properly, the values were measured independently to study interobserver variation. Observations were recorded by both authors without access to each other's results and were blinded.

Statistical analysis

The SPSS version 22 (IBM SPSS statistics, Somers NY, USA) of the software was used to analyze the data, which was put into a Microsoft Excel datasheet. Data that were categorical, were shown as frequencies and proportions. Mean and standard deviation were used to depict continuous data. Wilcoxon test or paired *t*-test is the significance test for paired data which is for observer 1 and observer 2, and for quantitative data, it is a signed rank test.

To create many sorts of graphs, including bar diagrams, pie diagrams, and scatter plots, Microsoft Word and Excel were employed. *P* value (probability that the result is true) of <0.05 was considered statistically significant after assuming all the rules of statistical tests.

Results

One hundred and twenty-three adult shoulder CT scans were evaluated, in which 83.7% were males and 16.3% were females. In this, 31.7% were in the age group <30 years, 26% were in the age group 31–40 years, 15.4% were in the age group 41–50 years, 8.1% were in the age group 51–60 years, 10.6% were in the age group 61–70 years, and 8.1% were in the age group >70 years. The mean age of subjects was 41.26 ± 17.059 years. About 60.2% were right side and 39.8% were left side coracoid process [Table 1].

In the study, the mean A-P length was 25.80 ± 3.09 mm, with a maximum of 33.91 mm and a minimum of 18.67 mm. In mediolateral measurement, the mean was 12.02 ± 1.82 mm with a maximum of 17.38 mm and a minimum of 7.27 mm. In supero-inferior measurement, the mean was 10.27 ± 1.64 mm with a maximum of 17.19 mm and a minimum of 5.1 mm.

In the study, the mean A-P length of coracoid by observer 1 was 25.80 ± 3.09 mm and by observer 2 was 25.66 ± 3.19 mm. The mean mediolateral length of coracoid by observer 1 was 12.02 ± 1.82 mm and by observer 2 was 11.78 ± 1.76 mm. The mean supero-inferior length of coracoid by observer 1 was 10.27 ± 1.64 mm and by observer 2 was 10.15 ± 2.10 mm. *P* value was calculated to know the difference between the measurements of two observers. There was no significant difference in A-P length, mediolateral length, and superoinferior length between observer 1 and observer 2 [Table 2].

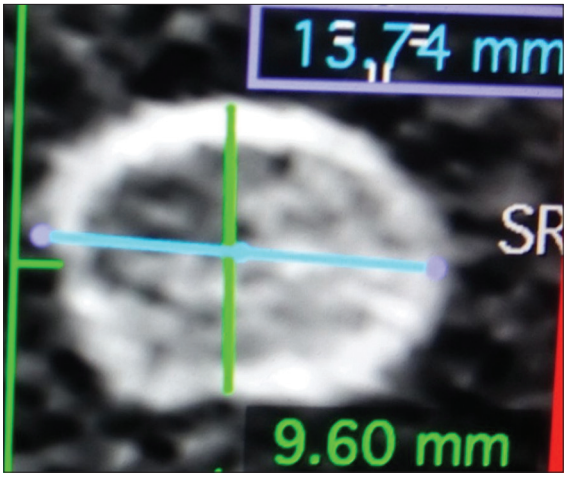

Figure 4: Measuring mediolateral and supero-inferior length

Table 1: Profile of subjects in the study

	Count	Percentage
Age (years)		
<30	39	31.7
31-40	32	26.0
41-50	19	15.4
51-60	10	8.1
61-70	13	10.6
>70	10	8.1
Sex		
Female	20	16.3
Male	103	83.7
Side		
Left	49	39.8
Right	74	60.2

Table 2: Mean of A-P length, mediolateral and supero-inferior comparison between observer 1 and observer 2

	Mean±SD	*P*
A-P length (mm)		
Observer 1	25.80±3.09	0.635
Observer 2	25.66±3.19	
Mediolateral length (mm)		
Observer 1	12.02±1.82	0.213
Observer 2	11.78±1.76	
Supero-inferior length (mm)		
Observer 1	10.27±1.64	0.502
Observer 2	10.15±2.10	

Table 3: Correlation of observer 1 A-P length and observer 2 A-P length

	A-P length (mm)	A-P length (mm)
A-P length (mm)		
Pearson correlation	1	0.458
P		<0.001
n	123	123

Table 4: Correlation of Observer 1 Medio lateral length and Observer 2 Medio lateral length

	Medio lateral length	Medio lateral length
Medio lateral length		
Pearson Correlation	1	0.357
P		<0.001
n	123	123

Table 5: Correlation of Observer 1 Supero inferior length and Observer 2 Supero inferior length

	Supero inferior length	Supero inferior length
Supero inferior length		
Pearson Correlation	1	0.458
P		<0.001
n	123	123

There was significantly positive correlation between observer 1 and observer 2 in the A-P length measurement (r = 0.448, P < 0.001*), mediolateral length measurement (r = 0.357, P < 0.001*), and supero-inferior length measurement (r = 0.458, P < 0.001*), i.e., with increase in one value, there was significant increase in other value and vice versa [Table 3-5].

Discussion

Latarjet procedure is a safe and effective treatment in managing shoulder instability with glenoid bone loss. The literature reports good success with the classic Latarjet procedure.[7] In this, after the osteotomy, coracoid process is brought down and reconstructed to glenoid surface. In the congruent-arc Latarjet procedure, the graft is rotated to 90° so that its under surface sits flush with the articular surface of glenoid.[8] The size of coracoid process graft is crucial in the success of these surgeries.

According to the method of evaluation, the results for the length of the coracoid process in earlier research differed significantly, specifically from the measurements in cadavers varied more than measurements from studies using X-rays and CT scans.[5] Within cadaver measurements, values vary between dry and fresh cadavers. This is because the values measured in dry cadavers will always be less as compared to living due to shrinkage of the tissues either due to drying of cadavers or the use of preservatives.[9]

It is a common practice among many to perform the classic Latarjet procedure in all glenoid deficient patients in recurrent shoulder instability. According to the literature,[10] we can do either the classic Latarjet procedure or congruent-arc Latarjet procedure for shoulder instability with >20% bone loss. This study will help us to know the average length of coracoid process, the role of preoperative measurement, and also a reproducible technique to measure.

Young *et al*.[11] suggested a coracoid graft of more than 25 mm can be harvested routinely in the Latarjet procedure. In the cadaveric analysis done by Lo *et al*.,[12] the average measurement of coracoid process was 15.9 mm × 22.7 mm × 10.4 mm (width × length × height).

The safety margin for harvesting was defined to be 28.5 mm by Dolan *et al*.[13] in 2011. The safety margin for osteotomy was shown as 26.4 mm in 2012 by Terra *et al*.[14] In our study, a safety margin of 25.80 ± 3.09 mm was derived from our population, which is corresponding to the above references.

From this study, we can come to a conclusion that the dimension of coracoid process in our population is comparable in relation to Caucasian population as compared with other previous studies.[15] This can be termed as surgically excisable coracoid process which differs from the anatomical coracoid process. Perhaps, this is one study that measures factual "surgical coracoid length" to be meaningful in the application for Latarjet and other similar procedures.

The congruent-arc Latarjet methodology was created by De Beer and Roberts[8] in 2009 after they improved the conventional Latarjet method. The coracoid graft is rotated by 90 ° along its longitudinal axis, transferred inside the joint so that the inferior surface recreates the glenoid articulation, and fixed with two 3.5-mm screws.

Hantes *et al*.[16] in his study demonstrated the ability of the congruent-arc Latarjet procedure to treat large glenoid bone defects as compared to the classic Latarjet procedure because of the width of coracoid process. This is supported by the increased thickness of coracoid process in mediolateral measurement as compared to supero-inferior measurement.

Joshi *et al*.[17] in their study had similar outcomes, where they showed congruent-arc technique is superior than classical Latarjet in reconstructing larger glenoid bone defects.

The above literature supports our study which showed coracoid width was greater than its thickness. From this, we can come to the conclusion that coracoid process oriented in the congruent-arc technique would reconstitute more glenoid defects than a classic Latarjet.

This also signifies, if there is a larger glenoid defect, we can do congruent-arc Latarjet and if the bone loss is lesser, we can do the classic Latarjet procedure as we know from the result coracoid process is thicker mediolaterally than superioinferiorly. Hence, this makes classic Latarjet is no more an absolute procedure for all shoulder instability with glenoid bone loss. When we do congruent-arc Latarjet in lesser degree bone loss, according to wolf's law, the mechanotransduction effect of humeral head on graft will be less when there is inadequate bone loss in the glenoid, which may end up in lysis of the graft.[18] This gives an inference that the congruent-arc Latarjet procedure can be done when there is a greater glenoid deficiency.[19] This study further helps to stress the importance

of glenoid loss measurement preoperatively and plan the procedure accordingly.

Limitations of the study

The parameters studied in this study were obtained from CT scans. Therefore, clinical correlation is not there, which corresponds to intraoperative measurement in patients. Similarly, the role of labrum and other stabilizing structures were unaccounted in CT scan measurements. Measurement of the curvature of the coracoid is difficult in CT scan. There is no defined technique for the measurement of coracoid process in a CT scan. Defining the dimensions of coracoid process in CT scan is a difficult task due to its tortuous shape.[20] The main challenge in this study was identifying the bony landmarks and portions of the coracoid process on the CT scan images. The 3D images had to be flipped and turned until they assumed the best position for measurement, as close to examining the native or cadaveric samples, which required a lot of expertise.

By the results of interobserver variation, CT-based measurements of coracoid process were well correlated between the orthopedician and the radiologist. Therefore, we can suggest this study for preoperative assessment in the Latarjet procedure, although a larger randomized controlled trial is necessary to generalize the usefulness of this technique.

Conclusion

In this CT-based analysis of coracoid process, we can come to a conclusion that the average length of coracoid process available for the Latarjet procedure in the Indian population is 25 mm, which is comparable to the western population and also coracoid process is thicker mediolaterally than superoinferiorly. Hence, congruent-arc Latarjet can be done when there is greater glenoid bone loss and classic Latarjet in a lesser degree of bone loss. To conclude, CT-based measurements of coracoid process were well correlated between the orthopedician and the radiologist. Hence, these measurements can be used as a tool to estimate the average length available for transfer in the Latarjet procedure.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Comparative Reliability of 3-Tesla Magnetic Resonance Imaging to Arthroscopy Findings in Femoroacetabular Impingement

Chun Hong Tang[1], Emma Rowbotham[2], Bill Pass[2], Colin Holton[1], Philip Robinson[2]

Departments of [1]Trauma and Orthoapaedics and [2]Musculoskeletal Radiology, Leeds General Infirmary, Great George Street, Leeds, UK

Abstract

Purpose: We have found that 3-tesla magnetic resonance imaging (3TMRI) is as clinically effective as magnetic resonance (MR) arthrogram when it comes to investigating patients with femoroacetabular impingement (FAI). It is also a noninvasive procedure that can be done more efficiently, with equivalent radiological and surgical outcomes. We would recommend 3TMRI as the primary investigation for patients presenting with FAI-type symptoms. **Methods:** This was a retrospective review of a single surgeon series of 59 operative cases, over 3 years. The inclusion criteria were arthroscopically confirmed diagnosis of FAI and preoperative imaging with 3TMRI scans. The surgical reports were analyzed and compared to the radiological reports, that were produced independently by two consultant musculoskeletal radiologists. The key findings included were the presence of labral tear, femoral CAM deformity, and acetabular and femoral cartilage damage. **Results:** We found that 3T MRI is sensitive in detecting the presence of labral tears and CAM deformities. (96% and 83% respectively). It was however, less sensitive in detecting femoral and acetabular cartilage damage. (50% and 69% respectively). The specificity of excluding cartilage wear on both the femoral and acetabular side was also high, (83% and 86%) but low for labral tears and CAM deformities (9% and 69%). The positive predictive value of 3TMRI was high in labral tears, CAM deformities, and acetabular wear (82%, 74%, and 97%) but low in predicting femoral cartilage damage (25%). The negative predictive value was high in detecting CAM lesions and femoral wear (80% and 94%) but low for labral tears and acetabular wear (33% and 27%). **Conclusion:** 3T MRI is particularly good at detecting the presence of labral tears, and CAM deformities. It is less sensitive at detecting cartilage damage, but more accurate in diagnosing the location of cartilage wear when present. This is a level 3 study, being a retrospective case–control study. The clinical relevance of this study is to determine if the less invasive 3TMRI study can be used to substitute for MR arthrography in the diagnosis of FAI in patients.

Keywords: 3-tesla magnetic resonance imaging, femoroacetabular impingement, hip arthroscopy, hip surgery, magnetic resonance arthroscopy

Introduction

Femoroacetabular impingement (FAI) can cause pain and discomfort, particularly among a younger- to middle-aged population. It is a precursor to the development of secondary osteoarthritis (OA) in later life.[1] It is a condition that is caused by anatomical abnormalities at either the femoral (CAM) or acetabular (pincer) side, or both (mixed type), resulting in damage to the labrum, cartilage, and subsequent OA.

It is inferred that damage to the labrum can result in pain and symptomatic discomfort for patients. The labrum is made up of type I collagen and fibrocartilage and is also supplied by free nerve endings and sensory nerve end organs. The anterosuperior parts of the labrum are thought to be the most highly innervated.[2] Damage to the labrum can produce pain and discomfort.[3]

In addition, degenerative changes within the cartilage and development of secondary OA have been seen to occur

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Address for correspondence: Dr. Chun Hong Tang, Leeds General Infirmary, Great George Street, Leeds, LS1 3EX, UK.
E-mail: chun.tang@nhs.net

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with labral damage, as its function as a shock absorber and joint lubricator is diminished. Groh *et al*. reported that the labrum deepens the acetabulum by 21% and increases its surface area by 28%, thus helping to distribute load and dissipate stresses around the hip joint.[2] We infer that this role is best employed when the circumferential nature of the labrum is maintained, but once a tear extends down to the chondrolabral junction, then its overall function will decrease significantly. It is for this reason, that many surgeons advocate repairing labral tears, rather than simple debridement, both for pain relief and to prevent further disease progression.

A diagnosis of FAI may be confirmed radiologically with the use of magnetic resonance (MR) after suitable clinical signs and symptoms have been elicited. Conventionally, this has been performed using MR arthrography (MRA). This is an invasive procedure which requires an injection into the hip joint with contrast and is routinely performed using a 1.5 tesla MR imaging (MRI) scanner.

Recently, there has been increasing evidence that supports the use of 3 tesla MRI (3TMRI) rather than 1.5T MRA in FAI, with equivalent results for diagnosing labral tears and cartilage delamination.[4-6]

We set out to determine the correlation of 3TMRI scans in FAI to intraoperative arthroscopic findings. We compared our results to the study by Crespo Rodríguez *et al*.[7] We hypothesize that 3TMRI is as sensitive and specific as MRA, with comparable predictive values in the diagnosis of FAI.

Methods

This was a retrospective review of cases which presented to our institution between January 2016 and June 2019. The cases were obtained from a single surgeon's (author CH) nonarthroplasty hip register.

The inclusion criteria for our study were:

i. Clinical diagnosis of FAI confirmed with MR and arthroscopy findings
ii. Cases where 3TMRI were performed preoperatively
iii. FAI cases that were treated operatively.

The exclusion criteria:

i. Cases where FAI was suspected on clinical examination and MRI but refuted arthroscopically
ii. Cases where 1.5TMRA was used preoperatively.

The surgical reports were analyzed. Four main domains were investigated, namely, labral tears, CAM lesions, and acetabular and femoral cartilage damage. This corresponded with the four common surgical procedures performed during hip arthroscopy, which were labral repairs, debridement of a CAM deformity, and either debridement – chondroplasty of a partial thickness cartilage tear, or needing to perform different procedures (e.g. microfracture) for a full-thickness cartilage tear.

Labral tears were classified as either present or absent. The presence or absence of a CAM lesion on the femoral neck was also noted, and no classification of this was felt appropriate as it does not change the surgical outcome. The degree and location of cartilage loss on the acetabulum were graded using the Haddad classification.[8] The severity of femoral cartilage loss was graded using the International Cartilage Regeneration and Joint Preservation Society (ICRS) grading system.[9] A standard hip arthroscopic system (Arthrex, Florida) and hip arthroscopic table (Smith and Nephew, London) were used for all procedures.

To correlate the surgical classification system with the radiological findings, with regard to the degree of cartilage damage, we further subclassified the Haddad and ICRS classification. This was based on the descriptions within the respective classification system itself. Therefore, Grade 0 was deemed to be normal, Grade 1–2 (with lesion depth extending to <50%) was partial thickness, and Grade 3–4 was full-thickness damage.

The 3TMRI scan (Siemens AG, Munich) images were analyzed independently by two consultant radiologists (authors ER and BP) and scored in the same format as the surgical reports above. Both were blinded to the clinical history and operative findings. The MRI scoring was done through a consensus with any discrepancies reviewed by both authors who then came to a mutual agreement on the final score.

The radiological findings were then compared to arthroscopy findings, which were used as the gold standard.

Statistical analysis

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated (Microsoft Excel, Washington) for 3TMRI scans for each of the four parameters investigated, and their results are as follows. We calculated the kappa coefficient to evaluate the diagnostic concordance between radiological and arthroscopic findings and interpreted the results according to Landis and Koch.[10]

Results

A total of 59 cases were obtained within the 2½ years of the study. There was a ratio of 1.7–1, of female-to-male patients. The mean and median age of patients was 31 and 29, respectively, with an interquartile range of 18–49 years old. Based on our inclusion and exclusion criteria, a total of 139 patients were retrospectively considered but 80 patients were excluded due to not having 3TMRI scans done preoperatively, which left a total of 59 patients analyzed for this study [Table 1].

The sensitivity of detecting labral tears on 3TMRI was 96%, specificity of 9%, PPV of 82%, and NPV of 33%.

3TMRI had 83% of sensitivity, specificity of 69%, PPV of 74%, and NPV of 80% when detecting femoral neck CAM deformity [Table 2].

Table 1: Comparison between 3-tesla magnetic resonance imaging and arthroscopy findings

3TMRI	Arthroscopy											
	Labral tear			CAM deformity			Femoral cartilage			Acetabular cartilage		
	Tear	No tear	Total	Lesion	No lesion	Total	Lesion	No lesion	Total	Lesion	No lesion	Total
Positive	46	10	56	25	9	34	3	9	12	36	1	37
Negative	2	1	3	5	20	25	3	44	47	16	6	22
Total	48	11	59	30	29	59	9	53	59	52	7	59

3TMRI: 3-tesla magnetic resonance imaging

Table 2: Statistical analysis of 3-tesla magnetic resonance imaging findings compared to arthroscopy

	Labral tear (%) (95% CI)	CAM deformity (%) (95% CI)	Femoral cartilage damage (%) (95% CI)	Acetabular cartilage damage (%) (95% CI)
Sensitivity	96	83	50	69
Specificity	9	69	83	86
PPV	82	74	25	97
NPV	33	80	94	27
Kappa coefficient	0.068 (−0.178-0.314)	0.524 (0.309-0.740)	0.229 (−0.070-0.527)	0.285 (0.068-0.502)

NPV: Negative predictive value, PPV: Positive predictive value, CI: Confidence interval

Detection of femoral cartilage damage on 3TMRI [Table 2] had a sensitivity of 50%, specificity of 83%, PPV of 25%, and NPV of 94%.

Acetabular cartilage damage detection on 3TMRI [Table 2] had a sensitivity of 69%, specificity of 86%, PPV of 97%, and NPV of 27%.

A further subanalysis of these results, looking into the correlation between full- and partial-thickness cartilage damage showed that, on both the femoral and acetabular sides, there was a 50% and 47% correlation, respectively. This, however, was only based on six cases which demonstrated damage on the femoral side and 53 cases on the acetabular side.

The kappa coefficient calculated in our study on the degree of cartilage damage was 0.229 for the femoral side (fair agreement) and 0.285 for the acetabulum (fair agreement). For labral tears and CAM lesions, the kappa value was 0.068 (slight agreement) and 0.524 (moderate agreement), respectively.

Discussion

We discuss our results by directly comparing our study and a similar study was done by Crespo-Rodríguez *et al*., comparing MRA and arthroscopy findings. Crespo-Rodríguez *et al*. found MRA to be very sensitive and specific in detecting labral tears and chondrolabral lesions. MRA also accurately defined extensive lesions of the cartilage and secondary osseous changes.[6]

With regard to the labrum, our results demonstrate that 3TMRI is a sensitive test to detect the presence or absence of labral tears, with a correspondingly high PPV. These findings are comparable to those seen in MRA, with a reported sensitivity of 94.6% and PPV of 100%. MRA however seems to demonstrate a higher degree of specificity and NPV (100% and 87.5%, respectively), compared to 3TMRI.[7] The kappa coefficient, therefore, demonstrated an almost perfect agreement for MRA (0.95) as compared to only a slight agreement for 3TMRI. This is due to a higher false-positive finding with 3TMRI. Figure 1 demonstrates the comparable MRI image to arthroscopic finding of a labral tear.

Therefore, 3TMRI is as useful in diagnosing labral tears as MRA.[4] The ability for contrast to enter a tear within the labrum and therefore make it more visible, and thus highlight a potential tear, was the main indication for performing an MR arthrogram. We have shown that 3TMRI is also as sensitive in detecting tears, although we report a higher false-positive rate.

Menge *et al*. and a previous study by Byrd and Jones seem to suggest that, where a pathological lesion has been identified, there is strong evidence that some form of intervention to either repair or debride the labrum, does result in improved outcomes for patients, especially in longer-term follow-up studies.[11,12] Therefore, we would infer that identifying a lesion preoperatively, using 3TMRI, can be beneficial to a patient's outcome, with its noninvasive nature posing minimal risks or side effects as compared to MRA.

Although it can be argued that there is still paucity in terms of the long-term evidence for labral repair versus debridement, with evidence from Menge *et al*. indicating similar patient-reported outcome measures in both, there are equally good short-term outcome data, that seems to suggest an earlier return to both sports and work with labral repairs compared with debridement alone.[9,11,13]

When the femoral aspect is taken into consideration, the presence or absence of a CAM deformity was not particularly reported by Crespo Rodriquez *et al*., although we would expect the findings on MRA and 3TMRI to be similar in this respect. The kappa coefficient in our study with regard to the

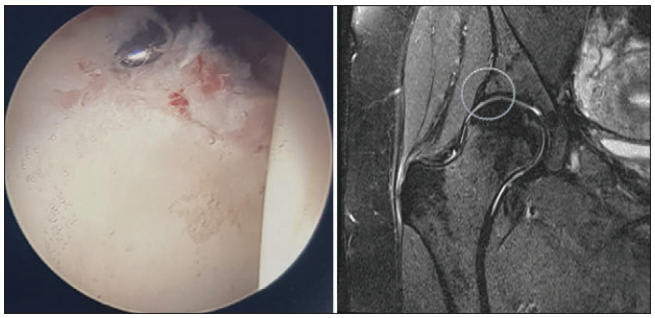

Figure 1: Demonstrates the comparable MRI image to arthroscopic finding of a labral tear. MRI: Magnetic resonance imaging

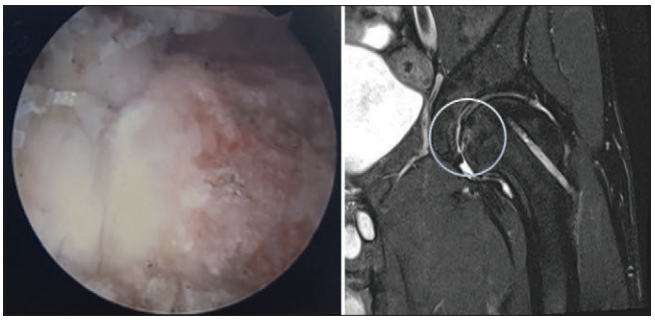

Figure 2: Demonstrates the comparable MRI image to arthroscopic finding of a femoral cartilage wear. MRI: Magnetic resonance imaging

presence or absence of a CAM deformity was the highest among all four domains, indicating a moderate degree of agreement between radiographic and arthroscopic findings. It is also sensitive, indicating its usefulness in detecting its presence among a population, with a high positive NPV. We infer from these findings that 3TMRI is reliable at detecting the presence of a CAM deformity before surgical intervention. Figures 2 and 3 demonstrate comparable MRI and arthroscopic findings of femoral and acetabular cartilage wear, respectively.

When the degree of cartilage damage seen radiologically was compared between two studies, the study by Crespo Rodríguez *et al*. grouped both femoral and acetabular cartilage lesions into a single group, but we have broken it down individually. Therefore, a direct correlation is difficult. MRA appears to have a higher sensitivity (92.5%) and lower specificity (54.5%) in both, but we have found that 3T MRI has inferior sensitivity, but a higher specificity.[7] This seems to imply that 3TMRI is better at excluding cartilage damage when it is detected radiologically.

The predictive value between MRA and 3TMRI, for cartilage damage, appears to be comparable with MRA having a PPV of 88.1% and NPV of 66.7%.[7] The grouped kappa value for cartilage damage with MRA at both the femoral and acetabular sides of 0.78 showed a more substantial agreement for MRA compared to 3TMRI.[7] We have found this to be due to the higher false-negative findings in our study compared to MRA. The accuracy of the degree of cartilage damage seen is also only around 50% using 3TMRI. This is in contrast to Crespo Rodriquez's results which showed a disagreement of only 15.7%, between MRA and arthroscopy findings.

This seems to suggest that MRA is still better at detecting cartilage lesions preoperatively. We accept that although it is useful to know if there will be a need for intraoperative cartilage procedures to be done preoperatively, in the majority of cases, procedures carried out are mostly either a debridement or microfracture, both of which, require basic instruments which are readily available in most theater units. Rarely, if a specialist procedure like autologous chondrocyte implantation is required, then this should be done in a tertiary specialist unit, with specifically directed funding, as advised by the United Kingdom National Institute for Health and Care Excellence.[14] Therefore, in such situations, an MRA would be advised preoperatively to quantify the degree and location of damage.

Therefore, our experience has demonstrated that for the majority of findings seen in FAI, 3TMRI is as effective as MRA in detecting these abnormalities. This is in tandem with the findings by Chopra *et al*. who concluded that 3TMRI may be at least equivalent to 1.5TMRA in detecting labral tears.[4] We, however, could not confirm their findings in regards to acetabular cartilage defects.

The practicalities of 3TMRI avoid the invasiveness associated with an arthrogram. This is both more convenient for the patient, but also negates the associated risks such as bleeding and infection. We hypothesize that this should improve the overall patient experience. In addition, the patient flow should improve within the department as the radiologist is not necessarily required to be present during MRI scanning, hence allowing the department to run more efficiently and effectively.

The risks and complications associated with gadolinium-enhanced MRI scans, although rare, can be severe and significant. Grobner first reported the development of nephrogenic systemic fibrosis (NSF) in patients with end-stage renal disease, that was associated with the use of gadolinium-based contrast agents in 2006.[15] This though was subsequently classified as low risk by international expert bodies, including the Food and Drug Agency and the Europeans Medicines Agency.[15,16] A further prospective observational study by Forsting and Palkowitsch also did not find any development of NSF within their cohort of 14,299 patients.[17]

The article by Forsting and Palkowitsch also provided further evidence that contrast reactions from gadolinium-enhanced MRI scans are rare and similar to those seen with iodinated contrast agents. Although this study encompasses the use of contrast in MRI scans across all disciplines, it did not report any specific complication with regard to the local use within the hip joint itself. Adverse drug reactions were reported in 0.55% of all patients, none of which reached a frequency of >1% across their cohort. The most common reactions observed were nausea, vomiting, dizziness, and urticaria.[17] We would agree that although such reactions are rare and relatively mild

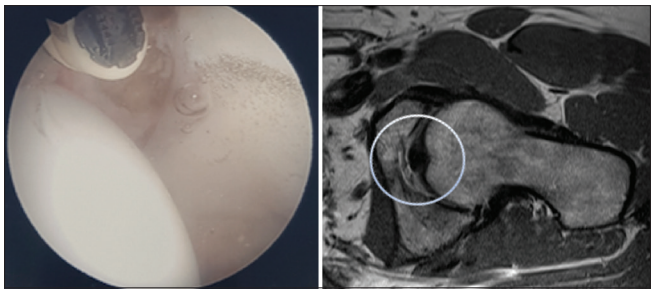

Figure 3: Demonstrates the comparable MRI image to arthroscopic finding of an acetabular cartilage wear. MRI: Magnetic resonance imaging

in nature, their occurrence can be prevented through complete avoidance of contrast material with the use of 3TMRI scans.

Limitations

We acknowledge that our study does present with its own limitations, particularly that there was no control group to compare our results against, which was not possible from an ethical standpoint. We decided against a group comparing MRA and arthroscopy, within our unit, as a previous study by Crespo Rodriquez *et al*. had already established the results of this and we were keen to avoid repetition of such results. We also acknowledge the potential for observer bias, particularly in the retrospective analysis of MRI images in our cohort, but we have tried to account for this with interpretation by two independent musculoskeletal fellowship-trained consultant radiologists, who were blinded to the results of the arthroscopy findings. There is also the presence of selection bias, as the cases were selected from the senior author's operating registry, hence cases that were treated nonoperatively, were not included in the study. There also may have been a discrepancy in the reporting of cartilage damage on the femoral side, as the radiologist tends to report the damage on the articular surface, where else arthroscopically, the damage is often seen on the CAM lesion laterally, rather than on the articular surface itself. However, we have tried to account for this by prospectively documenting the area of damage operatively and comparing this to the MR findings.

We feel, however, that our study sample size of 59 cases is one of the largest studies, currently reported in the literature, comparing 3TMRI scans against the gold standard of diagnostic arthroscopy. We have demonstrated that the sensitivities and PPVs of 3TMRI scans are equivalent to, if not better than MRA, when it comes to diagnosing labral tears and CAM deformities. We acknowledge that the diagnostic capabilities of 3TMRI fall short when it comes to diagnosing the presence and degree of cartilage damage, however, would infer that the benefits of avoiding an invasive procedure such as an arthrogram, outweighs this particular drawback.

Conclusion

We have found that 3TMRI, is as clinically effective as MR arthrogram when it comes to investigating patients with FAI. It is also a noninvasive procedure that can be done more efficiently, with equivalent radiological and surgical outcomes. We would recommend 3TMRI as the primary investigation for patients presenting with FAI-type symptoms.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Day Case Knee Osteotomy

Cezary Kocialkowski, Sam Hart[1], Bristol Knee Group*, James R. D. Murray

Avon Orthopaedic Centre, Southmead Hospital, [1]Medical School, University of Bristol, Bristol, United Kingdom

Abstract

Introduction: Knee osteotomy, both high tibial osteotomy (HTO) and distal femoral osteotomy (DFO), is a well-recognized treatment for young, active patients with unicompartmental knee osteoarthritis. Osteotomy around the knee is usually performed as an inpatient procedure. The aim of this study was to assess the effectiveness and patient satisfaction of our day-case protocol for knee osteotomy. **Methods:** All patients who underwent day-case knee osteotomy at the study unit, over a 3-year period, were reviewed to assess the success of ambulatory care for knee osteotomy. Patients were sent questionnaires to assess functional outcome and patient satisfaction with our day-case process. **Results:** Thirty-three knee osteotomies were performed as a day-case protocol, of which same-day discharge was achieved in 24 patients (73%) and discharge within 24 h achieved in 32 patients (97%). The mean postoperative Knee Osteoarthritis Outcome Score was 67.1% and 79% of patients rated their care as good or excellent. Return to sporting activities was achieved in 75% of patients, and 88% of the patients reported they would be happy to undergo day-case knee osteotomy again. **Conclusions:** Knee osteotomy, both HTO and DFO, can be performed as a day-case procedure with similar improvements in functional outcomes and no increased complication rate, compared to in-patient osteotomy.

Keywords: Day case, distal femoral osteotomy, high tibial osteotomy, knee osteoarthritis, knee osteotomy

Introduction

Knee osteotomy, including high tibial osteotomy (HTO) and distal femoral osteotomy (DFO), is frequently performed for young active patients with appropriate lower limb alignment and unicompartmental knee osteoarthritis.[1-3] Both HTO and DFO have been shown to improve patient function and quality of life and even permit return to sport.[2-4] Ten-year survival rates over 90% have been reported for HTO[3,5] and over 80% for DFO,[6] and both have been demonstrated to delay the need for total knee arthroplasty.[3,7]

HTO and DFO are usually performed as an inpatient procedure.[8,9] Recently, however; there has been an increasing emphasis on day-case surgery, in both trauma and elective orthopedics.[10] This has partly been driven by cost pressure, and more importantly by the reduction in the availability of inpatient beds.[10-12]

Dedicated day surgery programs have also been shown to improve patient satisfaction and allow postoperative recovery to take place in patients' own homes.[10,11,13,14] This has also been extended to hip and knee arthroplasty, with measurable reductions in cost and improvements in capacity, while not resulting in higher complication rates or worsening patient outcomes.[11,12,14-17]

A previous pilot study in the study unit assessed the feasibility of performing knee osteotomy as a day-case procedure.[18] Day-case knee osteotomy was found to be equally efficacious and safe, compared to inpatient procedures and therefore this protocol became the standard practice for all patients undergoing knee osteotomy, assuming social situations allow.

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Address for correspondence: Dr. Cezary Kocialkowski, Avon Orthopaedic Centre, Southmead Hospital, Bristol, United Kingdom. E-mail: kocialkowski@gmail.com

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*The Bristol Knee Group includes:

Andrew Porteous, James Robinson, Nick Howells, Damian Clark, Rachel Bray, Hywel Davies, Jonathan Eldridge, Mo Hassaballa, Karen MacDonald, Corina Negrut, Sue Miller

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The aim of this study was to assess the effectiveness of the day-case knee osteotomy protocol since it was formally introduced in January 2016.

Methods

A day-case knee osteotomy pathway was introduced to the study unit in January 2016. All patients who were planned to undergo HTO or DFO were counseled preoperatively by the operating surgeon in the preoperative consenting clinic regarding the overall procedure (standard protocol) and in addition to the day-case protocol. No patients declined the day-case option for discharge, but all were aware that should they need admission, overnight stay was possible.

Inclusion criteria for HTO and DFO were radiographic evidence of single-compartment knee osteoarthritis, associated with joint line pain and varus or valgus malalignment. Exclusion criteria included severe obesity (body mass index >40), symptomatic osteoarthritis of both knee compartments, rheumatoid arthritis, extension deficit >15°, and severe ligamentous deficiencies.

All operations were performed under general anesthesia with high volume local anesthetic infiltration. There were no femoral nerve blocks performed but adductor canal blocks were routinely introduced during this case series, with no detriment on early mobility. Perioperative practice was identical for in-patient and day-case knee osteotomy.

The operative bed was tilted slightly into a Trendelenburg position to raise the feet and lower the blood pressure in the knee; the head was also raised.

The protocol for local anesthetic infiltration was 150 ml 0.1% bupivacaine and 0.6 mg adrenaline, divided into three syringes, with 10 mg morphine and 30 mg ketorolac added to one of the syringes. The triple-mode syringe was then infiltrated deep around the periosteum of the osteotomized bone and popliteal the fossa approached through the operative window– tibial or femoral.

Preoperative intravenous (IV) antibiotics were used on induction (flucloxacillin and gentamicin, providing no allergies) and a repeat IV dose was used in recovery and then the last two doses of flucloxacillin (to provide 24-h cover) were given orally on discharge. All patients underwent an arthroscopy and chondroplasty to stabilize chondropathy at the time of HTO and DFO, and the osteoarthritis grade was documented.[19] Tourniquets were not used at all. All operations were performed by a single surgeon and implants used included the TomoFix plate (Synthes GmBh, Oberdorf, Switzerland) and the Activmotion plate (Newclip Technics, Haute-Goulaine, France), using contemporary surgical techniques as described by the AO expert group for osteotomies around the knee[20] and the UK osteotomy consensus group.[21] Bone graft and surgical drains were not used.

Patients were reviewed by a physiotherapist preoperatively to teach touch weight bearing with crutches for 2 weeks' postoperatively. Postoperatively, the patient was then mobilized safely by the nursing staff in the theatre recovery unit "Medi-rooms." These are single-patient rooms that are used for preoperative admission and postanesthetic recovery. Once the patient had mobilized, eaten a light meal and passed urine they were then passed as safe for discharge by the nursing staff in the Medi-rooms. Patients were instructed to mobilize touch-weight bearing for 2 weeks and then weight bearing as tolerated by pain thereafter. It was explained to the patients that their leg would take full weight bearing, but that by resting for 2 weeks they were less likely to have significant pain and swelling. Postoperative blood tests were not routinely performed and were not part of the discharge decision-making protocol. All surgeries were performed without the use of a tourniquet so any bleeding was immediately visible and appropriately coagulated with electrocautery.

Postoperative analgesic regimes included regular paracetamol (1 g, four times a time [QDS]) and codeine phosphate (30–60 mg QDS). In addition, naproxen (250 mg, QDS) and oral morphine solution (2.5 mg QDS) were provided for breakthrough pain. Venous thromboembolism prophylaxis was achieved with aspirin 150 mg once daily, for 6 weeks' postoperatively; intraoperative contralateral foot pneumatic compression devices were used.

Patients were not routinely contacted early postdischarge but were given a contact telephone number of the orthopedic ward to contact should they have any concerns in the immediate postdischarge period. Patients were instructed to remove the bulky bandage at 48 h, then, the clear occlusive dressing at 2 weeks; they were encouraged to shower with the clear occlusive dressing in place. A local wound review at the general practice surgery was performed at 2 weeks and patients were then reviewed clinically and radiographically, in the Orthopaedic outpatient clinic 6 weeks' postoperatively. Patients were then followed up face-to-face in the outpatient department with clinical and radiographic review until the radiographic union of the osteotomy with standing long leg alignment radiographs was obtained 3 months' postoperatively.

Local institutional service evaluation approval was gained before commencement of this project. All patients who underwent the day-case protocol from January 2016 to January 2019 were reviewed retrospectively using an electronic database (Bluespier Whiteboard, Bluespier International, United Kingdom). Patient demographic and operation details were obtained, and postoperative outcome and complications were documented.

A postoperative questionnaire was sent to all patients to assess outcome. This included the Knee Osteoarthritis Outcome Score (KOOS), as well as level of participation in sport activities, preoperatively and postoperatively. Patients were asked about postoperative symptoms including pain and analgesia use, nausea and vomiting, urinary dysfunction, and constipation.

Satisfaction with the day-case protocol was also assessed by asking patients to rate their satisfaction with the preoperative information received, the overall care, and whether or not they would be happy to undergo day-case knee osteotomy again. Patients who did not respond to the postal questionnaire were contacted by telephone once, in keeping with the terms of the local review board.

Results

In total, 33 knee osteotomy procedures (31 patients) were performed. The mean age was 43 years (range 20–58), 23 of the patients were male (74%), and the mean American Society of Anesthesiology score was 1.3 (range 1–3) [Table 1]. In 24 procedures (73%), patients were discharged on the same day, and in eight cases, patients were kept in the Medi-rooms overnight for analgesia but discharged the following day, <24 h after surgery. In total, 32 osteotomy cases (97%) were managed with a day-case protocol.

One patient required intraoperative exploration for bleeding secondary to an aberrant tibial artery and was subsequently discharged 4 days' postoperatively. One patient (3%) was re-admitted 3 days' postoperatively, due to ongoing leg pain and swelling, and following a negative Doppler scan, this was attributed to postoperative swelling and discharged the following day.

In 31 cases, the diagnosis was medial compartment osteoarthritis and a medial opening wedge HTO was performed. In two cases, the diagnosis was lateral compartment osteoarthritis, for which one patient underwent a medial closing wedge DFO, and the other underwent a lateral opening wedge DFO. The Activmotion plate was used in 18 cases and the Tomofix plate was used in 15 cases. The mean Outerbridge osteoarthritis grade was 3.3 (range 1–4) and the mean intraoperative correction performed was 10.1° (range 6°–16°) [Table 1].

Table 1: Patient demographics, surgical details, and postoperative outcomes

ASA, mean (range)	1.3 (1-3)
Osteoarthritis grade, mean (range)	3.3 (1-4)
Preoperative mechanical axis (°), mean (range)	
High tibial osteotomy (varus)	7 (2-14)
Distal femoral osteotomy (valgus)	6 (4-8)
Intra-operative correction, mean (range)	10.1 (6-16)
Type of procedure, *n* (%)	
Medial opening wedge high tibial osteotomy	31 (94)
Medial closing wedge distal femoral osteotomy	1 (3)
Lateral opening wedge distal femoral osteotomy	1 (3)
Type of implant, *n* (%)	
Activmotion plate	18 (55)
Tomofix plate	15 (45)
Postoperative range of movement (°), mean (range)	120 (105-130)
Union time (months), mean (range)	5.8 (2-13)
Complications, *n* (%)	
Removal of metalwork	20 (65)
Wound infection	3 (9)
Deep vein thrombosis	2 (6)
Loss of correction	1 (3)

ASA: American Society of Anesthesiologists

Radiological and clinical outcomes

The mean preoperative mechanical axis in patients who underwent medial opening wedge HTO was 7° varus (range 2°–14° varus) and mean postoperative axis was 1° varus (range 5° varus to 5° valgus), excluding one patient who had early loss of correction. The preoperative mechanical axis in the two patients who underwent DFO was 4° and 8° valgus, and the postoperative mechanical axis was 1° varus and 4° valgus, respectively. The mean time to radiographic union was 5.8 months (range 2–13 months) [Table 1].

Excluding three patients who developed deep wound infections and required repeat procedures, the mean time taken to regain a minimum of 110° flexion was 2.3 months (range 1–6 months) [Table 1].

Patient questionnaire outcomes

Twenty-four of the 31 patients (77%) completed the postoperative questionnaire. The mean time to completion of the postoperative questionnaire was 25.9 months (range 12–42). The mean postoperative KOOS was 67.1 (range 10.8–94.8) [Table 2]. Twenty-one patients (88%) indicated that they would undergo the procedure as a day-case again. The three patients who indicated that they would not undergo knee osteotomy as a day case again had all required an in-patient stay. Nineteen patients (79%) rated their care as good to excellent, and 18 patients (75%) rated the information they had received as good to excellent [Table 2].

Postoperative pain was rated as extreme or severe by 14 patients (58%), and 17 patients (71%) reported requiring full-dose analgesia [Table 3]. Nausea and vomiting occurred in nine patients (38%), one patient reported urinary dysfunction (4%), and nine patients (38%) reported constipation [Table 3]. Preoperatively, 15 patients (63%) were involved in regular or occasional sport activities and postoperatively 18 patients (75%) were involved in regular or occasional sport activities. The mean time taken to return to sporting activity was 6.9 months (range 3–12 months) [Table 2].

Complications

Twenty cases (all HTOs) required removal of metalwork due to soft tissue irritation (65%). Metalwork removal was performed at mean 15.2 months' postoperatively (range 10–26 months; standard deviation 4.7).

In six osteotomy cases (18%), patients had postoperative complications [Table 1]. Three patients developed deep wound infections, which were treated with debridement, irrigation and antibiotics in two cases; and debridement, plate exchange, and medial gastrocnemius flap in the third. The causative organism was *Staphylococcus aureus* in two cases and beta hemolytic streptococcus in the remaining case. No further procedures

Table 2: Functional outcome scores, patient satisfaction, and sports participation

Postoperative KOOS (range)					
Pain	**Symptoms**	**Activities of daily living**	**Sport**	**Quality of life**	**Global**
71.2 (8-100)	75.9 (25-97.2)	78.3 (26.5-100)	59.8 (0-100)	50.8 (0-100)	67.1 (10.8-95.9)
	Patient satisfaction				
	Excellent, *n* (%)	**Good, *n* (%)**	**Average, *n* (%)**	**Poor, *n* (%)**	
Information	7 (29)	11 (46)	3 (13)	3 (13)	
Overall care	10 (42)	9 (38)	1 (4)	4 (17)	
	Sport activity preoperatively and postoperatively				
	Total participants in sport, *n* (%)	**Regular sport, *n* (%)**	**Occasional sport, *n* (%)**	**None, *n* (%)**	
Preoperative	15 (63)	10 (42)	5 (21)	9 (38)	
Postoperative	18 (75)	10 (42)	8 (33)	6 (25)	

KOOS: Knee osteoarthritis outcomes scores

Table 3: Postoperative symptoms and analgesic use

	Postoperative symptoms				
	Extreme, *n* (%)	**Severe, *n* (%)**	**Moderate, *n* (%)**	**Mild, *n* (%)**	**None, *n* (%)**
Pain	8 (33)	6 (25)	7 (29)	2 (8)	1 (4)
Nausea/vomiting	1 (4)	2 (8)	5 (21)	1 (4)	15 (63)
Urinary problems	0	0	0	1 (4)	23 (96)
Constipation	0	1 (4)	4 (17)	4 (17)	15 (63)
	Analgesic use postoperatively				
Full dose		**More than half dose**	**Less than half dose**	**None**	
17 (71)		2 (8)	5 (21)	0	

have been performed on these cases and they remain off all antibiotics. Two patients sustained below-knee deep vein thromboses, treated with 3 months' anticoagulation. One patient had an early loss of mechanical correction but had good postoperative function therefore did not undergo revision.

One patient underwent conversion of HTO to unicompartmental knee replacement, which occurred at 18 months' post HTO due to ongoing medial pain. The remaining 32 knee osteotomies were not converted to arthroplasty during the study; therefore, the survival rate of day-case knee osteotomy was 97%.

Discussion

This study demonstrates that knee osteotomy can successfully be performed as day-case procedure, with 73% of patients being discharged on the same day and 97% of patients being discharged within 24 h and avoiding formal admission to the hospital ward. In addition, the re-admission rate was only 3%, meaning that the discharge process is safe and effective.

Day-case knee osteotomy provides benefit to patients, as postoperative recovery is able to take place in their own home; as well benefits to the service, as there are cost savings from reduced bed occupation and improved capacity for other elective operating, which is extreme relevance today in view of the exceptional bed pressures on health services across the globe due the tail of the COVID-19 pandemic and the massive volume of patients displaced from undergoing elective surgery during the earlier phases of the pandemic.

Day-case protocols have also recently been successfully introduced to joint arthroplasty procedures. Rates of successful day-case discharge of 85% have been reported in total hip arthroplasty,[16] 96% in total knee arthroplasty,[22] and 100% in unicompartmental knee arthroplasty.[14]

The key to successful day-case joint arthroplasty protocols has been reported to include: good preoperative patient education; multimodal analgesia; morning operating slots; a postoperative rehabilitation regime, which can be delivered remotely; and safe discharge criteria.[10,11,17,23] Another important element is patient selection, as increasing age and comorbidity status can reduce the suitability for day-case arthroplasty.[17] Most studies that have reported successful day-case protocols have therefore only included highly selected patient cohorts. In a study by Jenkins *et al.*, where day-case protocols were extended to all patients undergoing unicompartmental knee replacement, successful day-case discharge was only achieved in 39% of patients.[12] Knee osteotomy patients are in many ways perfect candidates for day-case procedures, as they tend to be relatively young and active individuals, with few comorbidities, as demonstrated by the patient demographic and baseline function in our study; and therefore, are all eligible for a day-case protocol.

A previous pilot study in the study department by Hart *et al*. demonstrated that day-case HTO was a feasible procedure and did not negatively impact on postoperative functional outcome or symptom control, compared to a control in-patient HTO cohort.[18] Interestingly, in the pilot study, postoperative pain was also rated as severe or extreme in 60% of in-patient tibial osteotomy patients, indicating that symptom control is not necessarily any worse in the day-case cohort.

The functional and return to sports outcomes in this study are similar to that which has been reported by other authors, which supports the use of HTO and DFO in improving quality of life and function in people suffering from unicompartmental knee osteoarthritis.[2,4,24] This study also demonstrates that these procedures can equally successfully be performed as a day case, with high rates of reported patient satisfaction.

There are of course limitations to this study, which include its retrospective nature, meaning it was not possible to obtain preoperative functional outcome scores to measure the full impact of HTO and DFO on postoperative function. In addition, patient outcome questionnaires were only obtained in 77% of cases. It is possible, therefore; that patients who did not return the questionnaires had worse outcomes, which may in turn have introduced an element of selection bias into our results. Although a formal control group was not performed as part of the study, a previous pilot study was performed to assess the feasibility of the day case protocol, and the complication rate and functional outcome of standard in-patient knee osteotomy is already well described in the literature, which demonstrates comparable results to this study, confirming the safety and efficacy of the day-case protocol.

Three patients in this cohort had wound infections (9%). This is consistent with previously published literature examining adverse events following knee osteotomy.[25] The preference in the study unit is to treat these infections aggressively with early washout and debridement, to prevent colonization of metalwork, in view of the limited soft tissue cover, particularly in HTO. This management strategy is supported by the resolution of infection in two of the cases, following appropriate early treatment, with only one case requiring metalwork exchange.

Conclusions

Knee osteotomy can be performed successfully as a day-case procedure in the vast majority of cases, provided that patients are provided with sufficient preoperative counseling and postoperative analgesia. Nonselective day-case HTO and DFO result in similar improvement in function and quality of life as the traditional in-patient osteotomy but convey benefits to both patients and the health economy by avoiding unnecessary overnight hospital admission.

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Conflicts of interest

There are no conflicts of interest.

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Case Report

Congenital Anterior Cruciate Ligament Deficiency and Meniscal Tear with Fibular Hemimelia Deformities Managed By Reconstructive Procedures in Two Stages

Nagashree Vasudeva, Srinivas B. S. Kambhampati
Sri Dhaatri Orthopedic Maternity and Gynaecology Centre, Vijayawada, Andhra Pradesh, India

Abstract

Congenital cruciate deficiency is associated with many musculoskeletal and congenital abnormalities. Long-standing instability eventually predisposes them to meniscal tears or cartilage damage. We report a case of anterior cruciate ligament (ACL) aplasia with fibular hemimelia and a bucket handle meniscal tear successfully managed with staged procedures. The meniscal tear was repaired, and ACL reconstruction was done in the first stage and was previously published. Valgus deformity of the tibial shaft along with splaying of toes was managed at the second stage (5 months from the first stage), and follow-up result at 3 years from the first surgery is presented. Meniscal pathologies should be suspected in patients with congenital malformations, and correction of the deformity can prevent further episodes of meniscal injuries.

Keywords: Congenital anterior cruciate ligament deficiency, fibula hemimelia, Ilizarov frame, meniscal tear

Introduction

Congenital cruciate ligament deficiency is extremely rare, occurring in about 1.7 of every 100,000 live births. Chronic anterior cruciate ligament (ACL) deficiency alters the biomechanics of the knee and predisposes it to meniscal injury. The incidence is as high as 98%.[1] Deformity of the lower limb predisposes to failure of reconstructions of traumatic ACL rupture, and it is recommended to correct the deformity before ACL reconstruction (ACLR). However, we report a rare case of ACL deficiency with fibular hemimelia with bucket handle horizontal cleavage tear treated in two stages. The meniscal tear was repaired, and the knee stabilized with ACLR in the first stage. Valgus deformity of the tibial shaft, along with splaying of toes, was managed at a second stage (5 months from the first stage), and follow-up result was presented at 3 years from the first surgery.

Case Report

A 22-year-old female presented with chronic right knee pain for 2 years that had aggravated for a week. She had a similar acute episode a year ago. There was no history of clicking/locking/swelling in the knee, previous trauma, or congenital abnormalities in the family. Clinically, 2 cm shortening of the right lower limb was seen. Since birth, she has had malformed and diverging fourth and fifth toes [Figure 1]. ACL deficiency and meniscal signs were positive, with medial joint tenderness and a painful full range of knee motion. The posterior cruciate ligament, posterolateral corner, and collateral ligaments were intact. No evidence of a neurovascular deficit or ankle instability.

Computed tomography scanogram revealed a 3.5 valgus deformity of the proximal tibia with the center of rotation of angulation (CORA) at the proximal tibial diaphysis. The lateral femoral condyle and tibial eminence had mild dysplasia. The fibula was intact, indicating a type 1 fibular hemimelia. Fused bases of proximal phalanges of the fourth and fifth toes

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Address for correspondence: Dr. Srinivas B. S. Kambhampati, Sri Dhaatri Orthopedic Maternity and Gynaecology Centre, Vijayawada - 520 008, Andhra Pradesh, India.
E-mail: kbssrinivas@gmail.com

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articulated with the head of the fourth metatarsal, and the fifth metatarsal was absent [Figure 2]. Magnetic resonance imaging images revealed an absence of ACL and a bucket handle rupture of the medial meniscus [Figure 3].

We planned a staged treatment by managing the knee pain and unstable knee immediately, followed by correction of the deformities. Informed consent for surgery and for publication of the case details was obtained from the patient. At stage 1, the ACL was reconstructed by quadrupled semitendinosus tendon graft using the all-inside ACLR system (Arthrex), and Meniscal Menders (Smith and Nephew) was used to perform an outside-in repair of the medial meniscus. This part of the case was published previously due to the rarity of the type of meniscal tear but had only 3 months of follow-up.[2] The current report has a 3-year follow-up of the meniscus repair and 2 years 7-month follow-up of deformity correction.

Stage 2 was planned 5 months after the index surgery. Osteotomy of both the tibia and the fibula at the level of CORA and the application of the Ilizarov fixator was done [Figure 4], along with closing wedge osteotomy of the proximal phalanges of fourth and fifth toes and stabilization with K-wires [Figure 5].

The tibia deformity was gradually corrected, and the fixator was removed at the end of 3 months [Figure 6]. At 3 years follow-up after the second surgery, the valgus deformity and limb length discrepancy had corrected [Figure 7], and she had a full range of motion at the knee, with a fully functional lower limb. She was able to carry out activities of daily living without any discomfort.

Discussion

Fibular hemimelia is common among the various anomalies associated with ACL aplasia.[3] In ACL-deficient knees, hypertrophy of the meniscofemoral ligament has been documented, but this was not detected in our case.[4] The valgus deformity of the tibia indicates Achterman and Kalamchi Type 1 fibular hemimelia, even though the fibula appears normal in our case. Findings in fibular hemimelia[4] include valgus tibia with medial bowing, aplasia of cruciate ligaments, dysplastic tibial eminence, a narrow intercondylar notch, dysplastic lateral femoral condyle, aplastic metatarsals, toe abnormalities and limb length discrepancy, most of which were seen in our case.

Literature review suggests that about 31% of patients develop pain and instability following a minor trauma due to alterations in the compensatory mechanisms.[1] The majority of the patients present clinically between 5 and 20 years of age. Hence, a differential diagnosis of congenital absence of ACL should be considered in young adults with ligament laxity, even when a history of trauma is present. Lu *et al*. reviewed the literature and suggested that surgical determinants are morphological changes in the knee, age of the patient, activity levels, and concomitant deformities that require correction.[5] While there

Figure 1: Preoperative image showing deformity of the leg and the toes

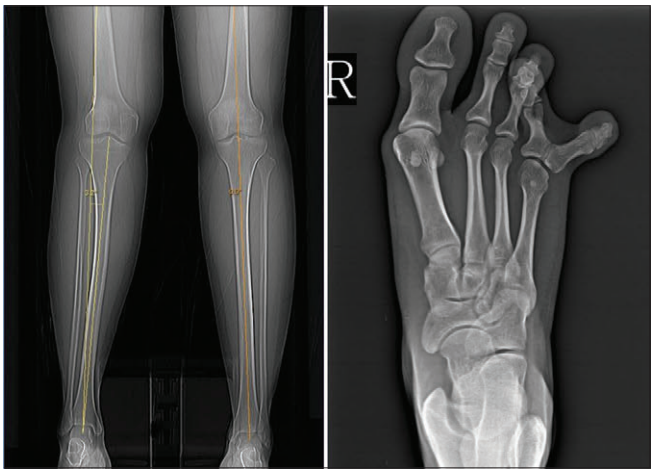

Figure 2: X-rays showing the valgus alignment of the lower limbs and deformity of the fourth and fifth toes. (Reproduced from Kambhampati SBS[4])

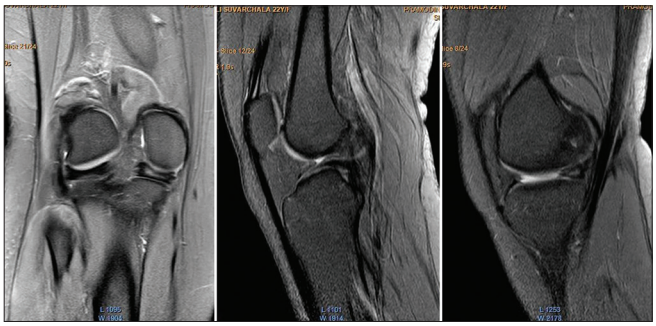

Figure 3: T1W MRI images showing bucket handle tear of the medial meniscus and absence of ACL. ACL: Anterior cruciate ligament, MRI: Magnetic resonance imaging, T1W: T1 weighted

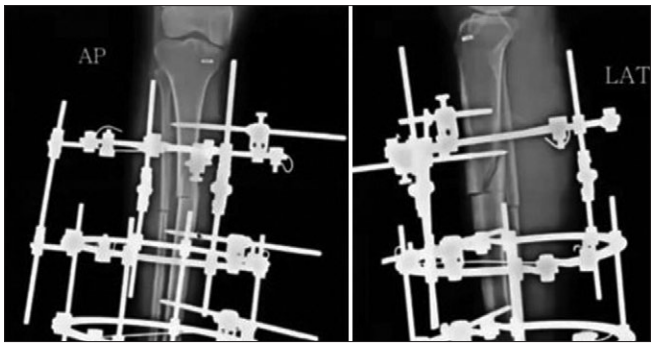

Figure 4: Postoperative X-ray showing the application of the Ilizarov apparatus. Due to the proximal propagation of the osteotomy, distraction was delayed

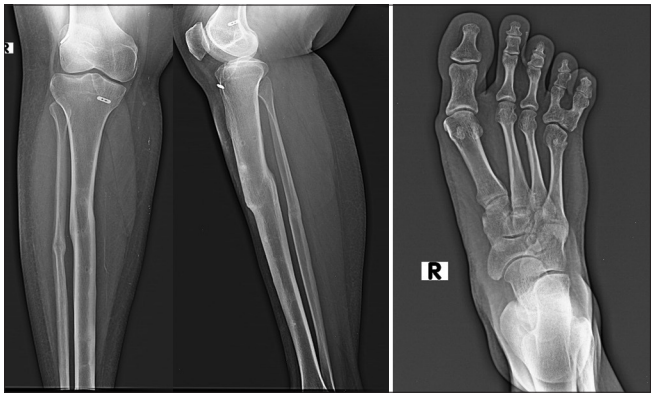

Figure 6: X-ray after removal of the Ilizarov frame and union of the osteotomy site showing the corrected alignment of the leg. Note the Endobutton used for ACL repair. X-ray showing corrected deformity of the toes. ACL: Anterior cruciate ligament

are no guidelines regarding the treatment options for the varied presentations in ACLA, recommendations are outlined in a recent systematic review.[6] The type and sequence of surgeries depend on the associated anomalies and are tailored according to the patient's needs. Although ACLR has been advocated following the correction of deformities, we repaired the meniscus at the first stage as it was a bucket handle tear responsible for the acute pain, and ACLR was simultaneously done to protect the repair. The osteotomy performed in the proximal third of the shaft does not alter the posterior tibial slope. Restoring the mechanical axis of the lower limb will protect the reconstructed ACL, meniscus and prevent any further disposition to knee injuries. We believe performing all the procedures in one stage may have predisposed to knee stiffness. Hence, acute symptomatic pathologies treated at stage one followed by careful rehabilitation in the interval period and correction of deformities performed in the second stage is advisable.

Conclusion

Meniscal pathologies should be suspected in patients with congenital malformations. Staged management may be recommended in patients with ACL aplasia with acute meniscal tear repaired and knee stabilized with ACLR at the first stage,

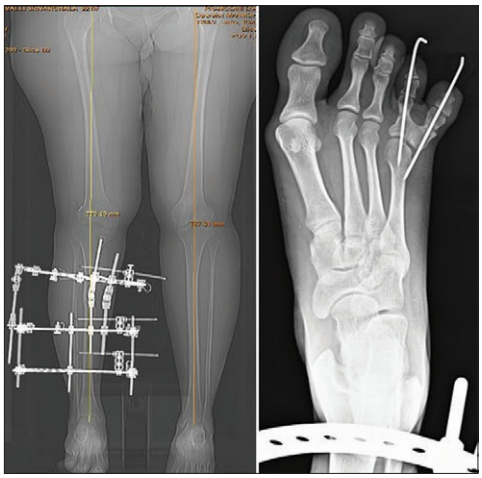

Figure 5: Postoperative lower limb scanogram showing corrected the alignment of the leg and osteotomy with K-wire fixation of the fourth and fifth toes

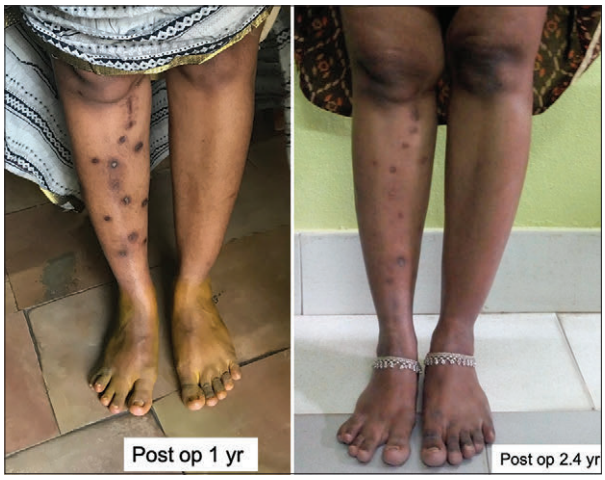

Figure 7: Clinical picture showing corrected limb alignment and limb length discrepancy

followed by correction of deformities at the second stage to prevent recurrences and protect the menisci.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given her consent for her images and other clinical information to be reported in the journal. The patient understands that her name and initials will not be published and due efforts will be made to conceal identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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