Robotic-assisted surgery in medial unicompartmental knee arthroplasty: does it improve the precision of the surgery and its clinical outcomes? Systematic review

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REVIEW ARTICLE

Robotic-assisted surgery in medial unicompartmental knee arthroplasty: does it improve the precision of the surgery and its clinical outcomes? Systematic review

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Abstract

There is a high prevalence of knee osteoarthritis that affects only the medial tibiofemoral compartment. In this group of patients with severe disease, the medial unicompartmental knee arthroplasty (UKA) is an excellent choice. However, this technique has a great learning curve due to the lower tolerance of improper positioning and alignment. In this context, the robotic-assisted surgery (RAS) arises as an option to improve the accuracy and secondarily enhance the clinical outcomes related to the UKA. The objective in this study is to determine if there are significant advantages with the use of RAS over conventional surgery (CS). In the systematic review of the literature, classification of the results in three main subjects: (A) precision and alignment; (B) functional results and clinical parameters; (C) survivorship. We found 272 studies, of which 15 meet the inclusion and exclusion criteria. There is mostly described that RAS significantly improves the accuracy in position (80–100% of planned versus performed $P < 0.05$), alignment (2–3 times less error variance $P < 0.05$) and selection of the proper size of the implants (69.23% of correct size femoral implants versus 16.67% using CS $P < 0.0154$). Recently, there is mild evidence about benefits in the early rehabilitation and post-operative pain, but in all studies reviewed, there is no advantages of RAS in the long-term functional evaluation. There is no strong literature that supports a longer survival of the prothesis with RAS, being the longest mean follow-up reported of 29.6 months. RAS is a useful tool in increasing the precision of the medial UKA implant placement. However, there is still a lack of evidence that properly correlates this improvement in accuracy with better clinical, functional and survival results.

Keywords Robotic-assisted surgery · Robotic surgery · Robotics · Unicompartmental knee arthroplasty · Unicondylar knee · Knee · Arthroplasty

Introduction

Osteoarthritis of the knee is a high prevalence illness in the world population, it is estimated that it affects 19% of people over 45 years of age and it produces a significant alteration in quality of life and is also associated to a high health-care system cost [1–4]. It is primarily related to diffused tricompartmental osteoarthritis, but in up to 25% of the cases the medial tibiofemoral compartment is involved in an isolated way [5]. In the specific group of patients terminally affected with a severe disease, a medial unicompartmental knee arthroplasty (UKA) could be a convenient solution. In comparison with the total knee arthroplasty (TKA) evidence shows that UKA offers fast recovery, higher range of movement, less bleeding, lower risk of infection, better functionality and higher rate of satisfaction [6–8].

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These advantages would explain the increase of UKA surgeries performed on a global level, especially in countries like Sweden and Denmark where its indication has doubled over the last years [9-13]. However, this technique is not without difficulties, since it requires a greater learning curve due to the lower tolerance of improper positioning and alignment [14-16]. Murray et al. [17] suggested that the volume of a surgeon's UKA surgeries performed is required to be 40% of its annual arthroplasties to achieve optimal results. At present time, evidence still represents diverse clinical results and, probably, these high demanding technical conditions explain that in general the survival time of the UKA is less than that of the TKA [18-21].

Several methods of surgical assistance by computerized navigation and robotic support systems have been developed to improve the accuracy in positioning of the implants and to achieve a shorten learning curve; aiming to improve clinical results. The first UKA performed using robotic-assisted surgery (RAS) was done in the first half of the 2000 decade; since then the technology industry has evolved constantly, seeking to offer more trustworthy data collection, more accurate preoperative planning and a reliable assistance in the execution of the surgery.

By definition, for a system to be considered as robotic-assisted, it must play an active role in surgery. Chen et al. [22] classifies them according to the level of control that the surgeon exercises, there being passive (navigational or non-robotic), semi-autonomous and autonomous systems.

Given the growing interest in this matter, the objective of this systematic review is to determine if there are significant differences between robotic-assisted surgery (RAS) and conventional surgery (CS) in terms of accuracy and alignment, functional results and implant survival. Our hypothesis is that with RAS the accuracy is higher, with better functional results and greater survival compared to conventional surgery (CS).

Materials and method

A systematic review was designed following the PRISMA guidelines [23]. This study was approved by the ethics committee of our institution. The search was conducted by two independent authors (MS and NJ), using the following terms "Unicompartmental Knee", "Unicondylar knee", "Partial knee", "Arthroplasty", "Robotics" and "Robotic-assisted surgery" in the data bases PubMed, Medline, Embase, Cochrane and Web Of Science, dated December 1, 2019.

Inclusion criteria were clinical or cadaveric studies which compared the accuracy of implants positions and clinical studies that compared functional results, survival and complications between RAS and conventional surgery. The exclusion criteria were reports in a language other than English, repeated texts, studies with non-comparative results between RAS and CS and those lacking specific identification of the population under intervention.

The titles and abstracts were reviewed independently by two authors. Then, the authors reviewed the full text separately, and then discuss together the eligibility according to the selection criteria. Repeated studies and those with lack of specific identification of the population were excluded. When different studies with same cohort population but with added data were founded, only the newest was selected. In case of any differences between the evaluators, it was addressed by consensus among the group of researchers. Finally, the references of the selected studies were reviewed to identify studies that were not found in the initial search (Fig. 1).

The included studies were classified in three groups according the outcome reported and extracted for this study:

A Precision and alignment: imaging evaluation of implant position, size and axis correction.
B Functional results and clinical parameters: Validated functional scales, pain scales, clinical studies that include response to the use of analgesics, immediate post-operative parameters, quality of life and the capacity to fulfill activities of daily living.
C Survivorship: Revision rates and causes associated.

The quality of the studies was analyzed by the two authors (MS, NJ) using the National Institute for Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies [24].

Results

The database search found a total of 272 studies, of which 58 met the selection criteria. After the full text revision only 15 studies were included, which are detailed in Table 1. The studies were published between 2005 and 2019.

Quality of the evidence

Regarding the level of evidence, there were eight studies level III, six level II and one level I. Eight of the included studied were prospective and seven were randomized. The Cochrane risk of bias analysis is shown in Table 2.

Population studied

A total of 2176 patients were analyzed, of whom 1451(66.7%) patients underwent robotic-assisted surgery (RAS) and 695 (31.9%) patients underwent conventional

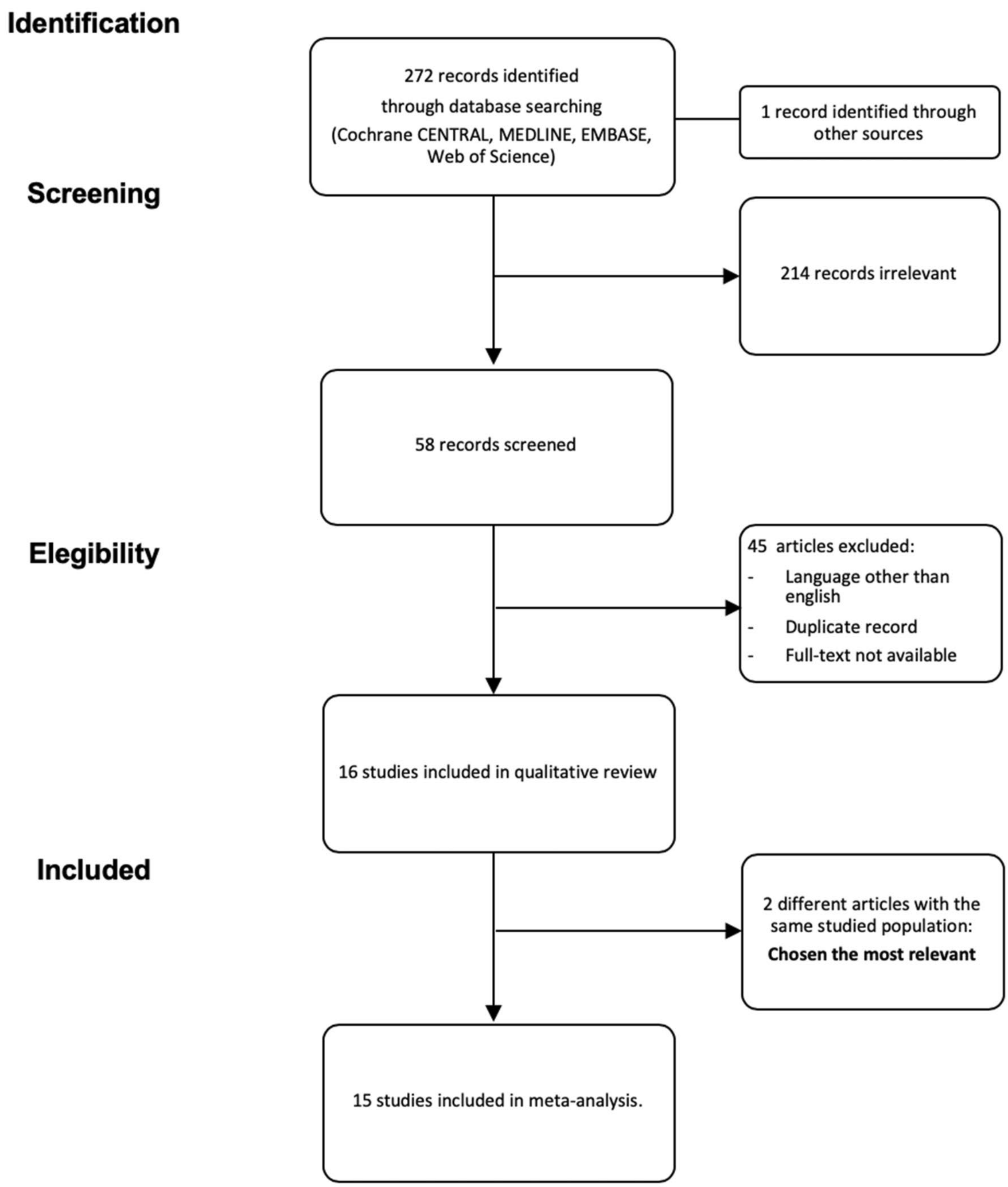

Fig. 1 Study flow diagram

surgery (CS). The mean age in the studies ranged from 55 to 70 years.

Robotic-assisted systems used and date of publication

In total, two studies were conducted using ACROBOT (The Acrobot Co. Ltd., London, United Kingdom), which were published in 2005 and 2006 [24, 25]. Ten studies used the MAKO system (Stryker, Mahwah, New Jersey) [26–30, 32, 33, 35, 36, 38], being the first the study published in 2010 by Looner et al. [26]. Three studies that used the BlueBelt NAVIO (Blue Belt Technologies, Smith & Nephew, Plymouth, Minnesota) [31, 34] were included, being the first published in 2017 [31].

Table 1 Studies included in systematic review

Author (year of publication)	Level of evidence and type of study	Journal of publication	Robot used	No. of patients	Mean age (years)	Mean Follow up	Implant used	Analyzed variables
Rodriguez [24]	II—Ramdomized prospective?	*Int J Med Robot Comp*	ACROBOT	28 (13 RAS vs 15 CS)	NR	NR	NR	Precision, satisfactory results and time of surgery
Cobb [25]	II—Ramdomized prospective	*JBJS (Br)*	ACROBOT	27 (13 RAS vs 14 CS)	69 (ras) – 70 (cs)	18 months	Oxford	Precision, satisfactory results and multiaxial femorotibial alignment
Looner [26]	II—Case – control prospective	*Clin Orthop Relat Res*	MAKO	58 (31 RAS vs 27 CS)	64 (ras) – 55 (cs)	NR	NR	Sagittal and coronal tibial alignment
Citak [27]	III—Cadaveric	*The Knee*	MAKO	12 (6 RAS vs 6 CS)	NR	NR	Restoris Onlay	3D alignment of femoral and tibial implants
Hansen [28]	III—Case – control retrospective	*J Arthroplasty*	MAKO	62 (30 RAS vs 32 CS)	57 (ras) – 60 (cs)	Over 24 months	Restoris (ras) – Zimmer High-Flex (cs)	Preop vs post op coronal femoral alignment Preop vs post op coronal and sagittal tibial alignment Implant size
Bell [29]	II—Ramdomized prospective	*JBJS (Am)*	MAKO	120 (62 RAS vs 58 CS)	62 (ras) – 62 (cs)	3 months	Restoris MCK (ras) – Oxford (cs)	Coronal, sagittal and axial alignment of the femur and tibia
MacCallum [30]	III—Ramdomized retrospective	*Eur J Orthop Surg Traumatol*	MAKO	264 (87 RAS vs 177 CS)	70 (ras) – 70 (cs)	2.7 years	Restoris (ras) – High-Flex/ Journey/ Miller Galante (cs)	Mechanical axis of the tibia Coronal tibial baseplate alignment Posterior tibial slope
Herry [31]	III—Case – control retrospective	*International Orthopaedics*	NAVIO	46 (23 RAS vs 23 CS)	69 (ras) – 68 (cs)	NR	HLS Uni Evolution Tornier	Postoperative joint-line restitution

Table 1 (continued)

Author (year of publication)	Level of evidence and type of study	Journal of publication	Robot used	No. of patients	Mean age (years)	Mean Follow up	Implant used	Analyzed variables
Blyth [32]	II—Ramdomized prospective	*Bone Joint Res*	MAKO	126 (64 RAS vs 62 CS)	NR	8 weeks 3 months 1 year	Restoris MCK (ras) – Oxford (cs)	American Knee Society Score (AKSS) Oxford Knee Score (OKS) Forgotten Joint Score Hospital Anxiety Depression Scale University of California at Los Angeles (UCLA) activity scale Short Form-12 Pain Catastrophizing Scale Somatic disease (Primary Care Evaluation of Mental Disorders Score) Pain visual analogue scale, analgesic use, patient satisfaction, complications relating to surgery, 90-day pain diaries Revision rate
Pearle [33]	III—Cohort study	*The Knee*	MAKO	909 (RAS)	69 (ras)	29.6 months	NR	Implant survivor and revision rate
Batallier [34]	III—Case – control retrospective	*Knee Surgery*	NAVIO	114 (57 RAS vs 57 CS)	69 (ras) – 68 (cs)	19.7 months (ras) 24.2 months (cs)	HLS Uni Evolution Tornier	Limb alignment and percentage of outliers Tibial slope and percentage of outliers International Knee Score (IKS) Revision rate

Table 1 (continued)

Author (year of publication)	Level of evidence and type of study	Journal of publication	Robot used	No. of patients	Mean age (years)	Mean Follow up	Implant used	Analyzed variables
Kayani [35]	II—Case – control prospective	*JBJS (Br)*	MAKO	176 (73 RAS vs 73 CS)	65 (ras) – 66 (cs)	90 days	Restoris MCK (ras) – Oxford (cs)	Intraoperative blood loss Postoperative pain score Opiate analgesia consumption Time to straight leg raise in supine position Number of inpatient physiotherapy sessions Need for physiotherapy adjuncts Time to discharge from hospital Complications within 90 days of surgery
Motesharei [36]	III—Case – control retrospective	*Gait & Posture*	MAKO	70 (31 RAS vs 39 CS)	63 (ras) – 65 (cs)	1 year	Restoris MCK (ras) – Oxford (cs)	Gait quality in a biomechanical analysis at one year since surgery
Iñiguez [37]	II—Ramdomized Cadaveric	*The Knee*	NAVIO	26 (13 RAS vs 13 CS)	NR	NR	Journey UNI	Femoral and tibial coronal alignment Tibial slope Tibiofemoral angle Sagittal femoral angle Femoral and tibial component size
Wong [38]	III—Case – control retrospective	*Knee Surgery*	MAKO	176 (58 RAS vs 118 CS)	70 (ras) – 68 (cs)	2.8 years (ras) 3.8 years (cs)	Restoris MCK (r) – Miller-Galante, Journey UNI (c)	SF-12 physical and mental Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index for pain, stiffness and function Knee Society Function Score (KSFS) Intraoperative time Revision rate

Table 2 Cochrane risk of bias

Author (year)	Rodriguez (2005)	Cobb (2006)	Looner (2010)	Citak (2013)	Hansen (2014)	Bell (2016)	MacCallum (2016)	Herry (2017)	Blyth (2017)	Pearle (2017)	Batallier (2018)	Kayani (2018)	Moteshareri (2018)	Iñiguez (2019)	Wong (2019)
Random sequence generation	-	-	+	-	+	-	+	+	-	+	+	?	+	-	?
Allocation concealment	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Blinding of participants	?	-	?	+	+	-	?	?	-	?	?	?	?	?	?
Blinding of outcomes assessment	?	?	?	+	-	-	-	?	-	-	-	-	?	-	?
Incomplete outcome data (attrition bias)	+	-	-	-	-	-	-	-	-	?	-	-	-	-	-
Selective reporting	?	-	-	-	-	-	-	-	?	-	-	-	-	-	-

Grading system		
	+	High risk of bias
	?	Unclear risk of bias
	-	Low risk of bias

Group A: precision and alignment

There were ten studies included in this analysis, nine of which [24–27, 29–31, 34, 37] found significantly favorable results for RAS in accuracy, alignment, position and/or size of the components (Table 3).

In the first study with the use of ACROBOT, Rodriguez et al. [24] found no variances over ± 2° in the tibio-femoral coronal alignment (planned versus implanted) in 13 of 13 (100%) UKAs performed with the use of RAS (100%). Instead only 6 of 15 (40%) UKAs implanted with the use of CS performed the same level of accuracy ($P = 0.001$).

Cobb et al. [25] found the same level of accuracy for ACROBOT (difference between planned and performed ≤ 2°) in the coronal tibio-femoral alignment in all patients (13/13) operated using RAS (SD 0.59; − 1.6° to 0.3°). On the other hand, 40% (6/15) of the CS UKA reached a deviation less than 2° between planning and the final position (SD 2.75; − 4.2° to + 4.2°) ($P = 0.001$).

Scanning the benefits of MAKO, Lonner et al. [26] found that the variation in tibial slope was 2.6 times greater in CS compared to RAS, with a root mean square (RMS) error of 3.1° for CS compared with 1.9° with the use of RAS ($P = 0.02$). Also, they estimated a variance for coronal alignment with an RMS error of 3.7° (SD 2.7° ± 2.1°) for CS compared with an RMS error of 1.8° for RAS (SD 0.2° ± 1.8°) ($P = 0.0001$).

Similarly, Citak et al. [27] in a cadaveric study found that the RAS has in all measurements of the tibial component position an average RMS error of 1.4 mm and 5° while the CS has an average RMS error of 5.7 mm and 19.2°. Also, according to this study, the average RMS error were 1.9 mm and 3.7° in the femoral component with the use of RAS compared with an average RMS error of 5.4 mm and 10.2° for CS. MacCallum et al. [30] also confirmed a significantly lower coronal and axial variability of the tibial and femoral component in the use of RAS versus CS (2.6° ± 1.5° vs. 3.9° ± 2.4°, $P < 0.0001$).

In a prospective randomized study, Bell et al. [29] calculated the number of implants with a mismatch greater than 2° compared with the previously planned target position (defined as outliers). This group estimated that with the use of RAS compared with CS 57% of the implants were within this target versus 26% in the sagittal position of the femoral component ($P = 0.0008$), 70% versus 28% in the coronal position of the femoral component ($P = 0.0001$), 53% versus 31% in the axial position of the femoral component ($P = 0.0163$), 80% versus 22% in the sagittal position of the tibial component ($P = 0.0001$) and 48% versus 19% in the axial position of the tibial component ($P = 0.0009$), respectively. They also found that in the coronal, sagittal and axial positions of the femoral and tibial components the use, of RAS presented a lower RMS error ($P < 0.01$).

With regard to the size of the tibial component, the study by Hansen et al. [28] measured a mean medial tibial overhang of 0.014 ± 0.035 mm for RAS (MAKO) and 0.132 ± 0.144 mm for CS ($P < 0.001$). Iñiguez et al. [38] found that NAVIO system offers greater precision in the choice of femoral component with 69.23% of correct size implants compared with only 16.67% using CS technique ($P < 0.0154$).

Studying the NAVIO system, Batallier et al. [34] estimated a higher precision in postoperative limb alignment for RAS compared with CS (16% versus 32% outliers $P = 0.038$) and also a higher precision in tibial slope for RAS compared with CS (3.5% versus 17.5% outliers, $P = 0.015$). Conversely, no differences were observed in the variability of tibial slope between both techniques. Iñiguez et al. [37] as well with NAVIO, performed a cadaveric study with randomized and blind radiological evaluations elaborated by independent

Table 3 Reported results related to precision and alignment

Parameter studied	Results		Study	Robot studied	*P*
	Robotic-assisted	Conventional			
Coronal alignment					
Accuracy % within ± 2° target planned	100%	40%	Rodriguez [24]	ACROBOT	0.001
	100%	40%	Cobb [25]	ACROBOT	0.001
	80%	28%	Bell [29]	MAKO	0.0001
	89%	65%	Batallier [34]	NAVIO	< 0.001
Tibiofemoral varus/valgus RMS error	1.8°	3.4°	Looner [26]	MAKO	NA
Femoral varus/valgus RMS error	3.7°	10.2°	Citak [27]	MAKO	NA
	2.09°	5.09°	Bell [29]	MAKO	NA
Tibial varus/valgus RMS error	5°	3.9°	Citak [27]	MAKO	NA
	2.58°	3.71°	Bell [29]	MAKO	NA
Coronal tibial implant variance	1.64° ± 1.3°	1.1° ± 0.94°	Hansen [28]	MAKO	0.037
	2.6° ± 1.5°	3.9° ± 2.4°	MacCallum [30]	MAKO	< 0.001
	1.28° (0.05–5.87)	1.28° (0.08–14.1)	Iñiguez [37]	NAVIO	0.0064
Sagittal alignment					
Accuracy % within ± 2° target planned	80%	22%	Bell [29]	MAKO	0.0001
	96.5%	82.5%	Batallier [34]	NAVIO	0.015
Tibial slope RMS error	1.9°	3.1°	Looner [26]	MAKO	NA
	1.7°	4.6°	Citak [27]	MAKO	NA
	1.64°	4.43°	Bell [29]	MAKO	NA
Sagittal tibial implant variance	2.4° ± 1.6°	4.9° ± 2.8°	MacCallum [30]	MAKO	< 0.001
	5.25° (0.79–8.93)	4.72° (0.37–15.54)	Iñiguez [37]	NAVIO	0.0343
Axial alignment					
Femoral rotacional RMS error	1.6°	7.4°	Citak [27]	MAKO	NA
	2.7°	5.78°	Bell [29]	MAKO	NA
Tibial rotacional RMS error	4°	19.2°	Citak [27]	MAKO	NA
	2.97°	7.95°	Bell [29]	MAKO	NA
Joint line restitution					
Bone resection for implant placement (mm)	1.4 ± 2.6	4.7 ± 2.4	Herry [31]	NAVIO	< 0.05
	1.5 ± 2.3	4.6 ± 2.5			< 0.05
Limb alignment					
Accuracy % within ± 2° target planned	84%	68%	Batallier [34]	NAVIO	0.038

RMS root mean square, *NA* not applicable, *SD* standard deviation

researchers who did not participate in the surgeries, where it was found that with the use of RAS, there is a greater precision and less variability in the coronal position of the femoral component and in the coronal and sagittal position of the tibial component, with a better recovery of the previous anatomy ($P < 0.05$). This group did not evidence significant differences in the mechanical axis of limbs with implants positioned with RAS compared to CS ($P = 0.1214$).

Iñiguez et al. [38] with the use of NAVIO they did not show significant differences in the mechanical axis compared to CS ($P = 0.1214$). Controversially, Batallier et al. [34] found, during the postoperative follow-up, that the limb alignment in the medial UKA group with the RAS the presence of up to twice as many outliers compared to CS.

Herry et al. [31] evaluated the position in the coronal plane of both components in the coronal plane, and more accurate restitution of the original joint line using RAS was found. The mean difference was ± 1.4 mm (SD ± 2.6 mm) with the use of RAS; meanwhile, the CS group reached a mean difference of ± 4.7 mm (SD ± 2.4 mm) ($P < 0.05$).

Group B: functional results and clinical parameters

Six studies reported the clinical and immediate post-operative results, mid-term functional scales and long-term quality of life [25, 28, 32, 34, 35, 38]. Additionally, one study [36] reported the gait analysis after UKA comparing CS and RAS (Table 4).

Cobb et al. [25] studying ACROBOT found an increase in the post-operative American Knee Society Score (AKSS) at 18 weeks of 65.2 (SD 18.36) in patients operated with RAS versus an increase of 32.5 (SD 27.46) in patients operated with CS ($P = 0.004$).

In a group of 112 randomly operated patients, Gilmour et al. [39] found no statistically significant differences in the Oxford Knee Score (OKS) nor in the American Knee

Table 4 Reported results related to functional results and clinical parameters

Parameter studied	Results			Study	Robot studied	P
	Robotic-assisted	Conventional	Time of evaluation			
Post-operative functional score improvement						
American Knee Society Score (AKSS)	166.6 (SD 18.36)	137.4 (SD 27.46)	18 weeks	Cobb [25]	ACROBOT	0.004
	164 (131 to 178)	143 (132 to 166)	3 months	Blyth [32]	MAKO	0.041
	171 (153 to 179)	164 (144 to 182)	1 year	Blyth [32]	MAKO	NS
WOMAC functional	24 (SD 10)	17 (SD 11)	18 weeks	Cobb [25]	ACROBOT	NS
	83.6 (SD 16)	79.9 (SD 23)	2 years	Wong [38]	ACROBOT	NS
WOMAC pain	8 (SD 3)	6 (SD 2)	18 weeks	Cobb[25]	ACROBOT	NS
	90.7 (SD 16.6)	87.8 (SD 15.7)	2 years	Wong[38]	ACROBOT	NS
WOMAC stiffness	3 (SD 2)	2 (SD 2)	18 weeks	Cobb [25]	ACROBOT	NS
	76.4 (SD 20)	72.6 (SD 27.8)	2 years	Wong [38]	ACROBOT	NS
VAS (0–100)	8 (2 to 21)	9 (4 to 28)	3 months	Blyth [32]	MAKO	NS
(0–10)	2.6 (SD 0.7)	5.6 (SD 1.3)	Day 2	Kayani [35]	MAKO	< 0.001
SF-12 physical	46.8 (SD 9.8)	44.6 (SD 9.8)	1 year	Blyth [32]	MAKO	NS
	43.9 (SD 9.5)	45.7 (SD 11.2)	2 years	Wong [38]	MAKO	NS
SF-12 Mental	54.9 (SD 8.3)	54.6 (SD 8.3)	1 year	Blyth [32]	MAKO	NS
	53.8 (SD 7.3)	53.1 (SD 8.7)	2 years	Wong [38]	MAKO	NS
IKS Score	90 ± 11	87.7 ± 15	≈2 years	Batallier [34]	NAVIO	NS
	83.4 ± 14.7	77.7 ± 21.3	2 years	Wong [38]	MAKO	NS
ROM, rehabilitation and walk						
Time to straight-leg raise (hrs)	18.7 (SD 3.4)	24.9 (SD 4.3)	NA	Kayani [35]	MAKO	< 0.001
Length of first ambulation (ft)	43.50 ± 47.77	21.16 ± 27.99	Day 1	Hansen [28]	MAKO	0.027
ROM	69.08° ± 15.9°	54.81° ± 20.26°	Day 0	Hansen [28]	MAKO	0.045
	98.5° (SD 8.8°)	93.3° (SD 4.9°)	Day 3	Kayani [35]	MAKO	< 0.001
Time before physical therapy (h)	42.17 ± 14.55	52.47 ± 19.77	Day 1	Hansen [28]	MAKO	0.024
Physical therapy sessions before discharge	5 (5 to 6)	9 (8 to 10)	NA	Kayani [35]	MAKO	< 0.001
Time to discharge (h)	42.5 (SD 5.9)	71.1 (SD 14.6)	NA	Kayani [35]	MAKO	< 0.001
Knee excursion from foot-strike to mid-stance	18° (SD 4.9°)	15.7° (SD 4.1°)	1 year	Motesharei [36]	MAKO	< 0.001
Post-operative complications						
Medial sided knee pain	20%	3.3%	6 months	Hansen [28]	MAKO	0.041
Wound complications	7%	22%	1 year	Blyth [32]	MAKO	NR
Revision rate	7%	9%	≈2 years	Batallier [34]	NAVIO	NS
	12%	6.8%	2 years	Wong [38]	MAKO	< 0.05

NR not reported, *NS* not significant

Society Score (AKSS) for the use of RAS (MAKO) compared with CS (Oxford Phase 3). However, in the sub-group of more active patients (35 patients with UCLA score > 5), they found significant differences in the OKS (46 vs. 41, $P = 0.036$) and in the AKSS (193.5 vs 174, $P = 0.017$) that favors RAS over CS exceeding the minimally important clinical difference.

Subsequently, in the study published by Blyth et al. [32] from the same research group, they reviewed the results previously obtained from the same cohort, finding that overall at 8 weeks, the patients operated with the use of RAS underwent 55.4% less pain in comparison with those operated with CS ($P = 0.040$). Also, they found that at 3 months after surgery there is a significant difference ($P = 0.0405$) in the AKSS that favors the use of RAS over CS (164 versus 143). However, this difference was no longer significant after 1 year follow-up ($P = 0.106$). There were no differences in the OKS at 3 months. The hospitalization was 0.54 days shorter in the RAS group, but with no statistical significance ($P = 0.07$).

Concordantly, the studies of Batallier et al. [34] (NAVIO) and Wong et al. [38] (MAKO) found no significant differences in the IKS, SF-12, WOMAC nor KSFS scores at 2 years of follow-up between RAS and CS.

In the analysis of post-operative results during hospitalization, Hansen et al. [29] found subtle, but significant differences in favor of RAS (MAKO). The average ROM in the day of surgery was better ($P = 0.045$), these patients were able to walk twice as much during their first ambulation ($P = 0.027$), they needed in average 10.3 h less before starting physical therapy ($P = 0.024$) and their hospital length of stay was 8.8 h shorter ($P = 0.066$). However, there were no differences in ROM in days 1 and 2 after surgery, average time to first ambulation, average postoperative hematocrit or hemoglobin.

Kayani et al. [35] published a randomized prospective cohort of 146 patients, where the MAKO system was used. This group found that RAS was significantly associated to less pain after surgery (days 0, 1, 2 and before discharge $P < 0.001$), less use of opioids ($P < 0.001$), fewer physical therapy sessions required (mean 9 versus 5 sessions, $P < 0.001$), fewer hours before being able to raise the operated limb (mean 71.1 versus 42.5 h, $P < 0.001$) and a better range of movement immediately before hospital discharge ($P < 0.001$). The patients operated with RAS were discharged in average 28 h earlier in comparison with the group operated with CS ($P < 0.001$).

Moteshareі et al. [36] used a specific biomechanical laboratory to evaluate the gait after a medial UKA and found that a year after surgery the group of patients operated with RAS ($n = 31$) had a better knee excursion during the early stance phase of the gait. In contrast, patients operated with CS ($n = 39$) had a significant loss of flexion (mean 15.7° versus 18°, $P < 0.001$) during the transition between foot-strike and mid-stance. Flexion and knee excursion during the other gait phases, and other parameters like speed of the walk, did not present significant differences between RAS and CS.

Group C: survivorship

Three studies [33, 34, 38] were gathered in which follow-up was detailed and where the survival rates, revision rates and their main causes were calculated.

The group led by Pearle [33] conducted a multicenter study with 909 patients from 6 different institutions with the use of MAKO system, achieving an average follow-up of 29.6 months. The average survival of the implants using RAS at 2.5 years for these six groups of patients was estimated in 98.8%, with a revision rate of 0.49 for each 100 cases per year.

On their behalf, Batallier et al. [34] compared two patient groups ($n = 57$ each one) with average follow-ups of 19.7 months for RAS and 24.2 months for CS, not finding a significant difference between the annual revision rate for both groups of patients ($P =$ NS). However, they observed that in 86% of the cases operated with CS, the cause of the revision was an aseptic loosening of the implant associated to a deficient alignment of the components. On the other hand, in the case of the implant revisions with RAS, none of these were linked to an incorrect alignment.

In contrast, in the recent study by Wong et al. [38], where they conducted a retrospective cohort of 178 patients ($n = 58$ RAS, $n = 118$ CS) and significantly encountered a revision rate of 12% for RAS in comparison to a revision rate of 6.8% for CS at similar post-operative follow-up (24.5 and 25.9 months, respectively). There were no differences in the revision causes between the two groups.

Discussion

Based upon the revision performed, literature confirmed the hypothesis that, in the unicompartmental medial knee arthroplasty, surgery with the robotically assisted technique is more precise than surgery with conventional techniques. This greater precision is reflected specially in a lower number of outliers comparing planned versus performed and in a greater capacity to predict the size of the femoral and tibial components.

This observation may partly explain the fact that robotically assisted surgery has gained such high interest in the last years. Furthermore, it has been proposed as a valid alternative to improve results of medial UKA, especially those that depend upon surgical technique and the surgeon's ability to conform with an adequate preoperative planning.

The need to optimize the results associated to UKA emerges when observing its survivorship in comparison to the total knee implant. At a global level, upon analyzing the annual registries from different countries [9–12, 21], it has been observed that medial UKA does not have the same survival rate as the TKA. However, these national registries contrast with what has been published from specialized centers with high volume of surgeries [40–46], where the procedure is mostly performed by expert surgeons and in which it is shown that medial UKA has an equal or even greater survival than the total knee implant. This discrepancy in the results may be explained, according to Murray et al. [17] by the fact that for the UKA must occupy between 20 and 40% of the total arthroplasties performed by a knee surgeon per year to be considered a safe procedure.

In the pursuit to quantify and objectify the improvements attributed to robotically assisted surgery in UKA, Christ et al. [47] classified the different variables that would influence the results. There is a group of modifiable factors by the use of RAS; the implant position, balance of soft tissues, limb alignment and the proper implant size. On the other side, there is another group of variables not related to the RAS performance; patient selection, soft tissue management, implant design or fixation method.

Poor positioning of the components is one of the frequent complications associated with medial UKA surgery. There is currently evidence that correlates an alignment with excessive varus of the tibial component [48, 49] or a positioning of the tibial slope greater than 7° [50] with an increase in the rate of implant failure. In the same way, an inappropriate size can potentially jeopardize the knee function or deteriorate the clinical outcomes, especially in the cases of oversizing [51].

Currently, it is known that the joint-line preservation is relevant for the homogenous load distribution between the medial and lateral femorotibial compartments. Kwon et al. [52] in a finite elements analysis established that an alteration of ± 6 mm or more of the native joint-line alters the load balance between compartments and could be implied either in the failure of the medial UKA or in the progression of the osteoarthritis in the lateral component. In this context, the observation that the restoration of the joint-line is more accurate with the use of RAS than in CS could be of great interest [31].

These excellent results in the orientation of the implant are in contrast with the fact that the current evidence still does not show benefits for RAS in its survivorship or in the functional results in the long term. The group of Pearle et al. [33] presented a survival of about 98.8% at 2.5 years for RAS. These values were compared with cohorts from other similar studies published with the use of CS, finding an advantage in average survivorship at equivalent 2–3 years of follow-up. This difference in favor to the RAS was even greater (98.8% versus 95.5%) when comparing the UKA national survival registries in Australia, New Zealand and the United Kingdom. However, this study has its methodological limitations as it does not included a comparison group intervened under the same circumstances.

Otherwise, in the studies with follow-up of over a year, there is no evidence of differences in the functional evaluation between RAS and CS even with the application of different scales. Although the group of Motesharei et al. [36] showed that in 1 year, there was a pattern of more normal gait in the RAS comparing it to CS, they did not manage to establish the real impact over the patient's quality of life.

One of the limitations of this review is the quality of the evidence reported. This also has been informed in other studies about this same subject [53] and they also observed that there are no enough studies with Type I evidence level. Other limitations observed are that there is a high variability in the implants used, in the measurements taken and in the mode that the results are presented, which difficulties the preparation of a proper statistical comparison. Furthermore, there are other factors like a heterogeneous representation of the number of patients recruited for follow-up for each robotic system. ACROBOT, of European origin, is currently not available in the market and the only alternatives in use are the MAKO and NAVIO devices. The heterogeneity of the parameters recollected not only difficulties a precise statistical analysis, but also impacts in the estimation of the real clinical impact of the robotic-assisted technology.

Taking into account all the factors mentioned above and also considering that actual panorama may continue evolving, in the current study, our workgroup propounded to diminish the number of distractors, focusing exclusively on the medial UKA and selecting investigations that have a group of patients with comparable conventional surgeries available. Probably over time, with a higher quality of the accumulated evidence, we will be able to properly focus in the specific analysis of the parameters with a real impact in the patient's quality of life. Considering the high cost of acquisition for these technologies (over $500,000 for the devices only), the quality of the evidence that supports potentials benefices is key in the success and incorporation of the robotic-assisted surgery into the health systems.

Additionally, future studies should be conducted to identify and compare the actual benefits and potential complications for each type of robotic device presented in the market.

Conclusion

Surgery with robotic-assistance is a useful tool in increasing the precision of the unicompartmental medial knee implant placement.

While this may in theory improve clinical, functional and survival results, it is not possible to confirm so with the current evidence. There is still contradictory literature in relation to survivorship, initial clinical results and long-term functional results.

There is moderate evidence in favor of the initial clinical results that may be improved with robotic-assisted surgery, such as the gait at 1 year, which is more normal in comparison to conventional surgery. However, the real impact of these effects in the quality of life of the patients operated is not clear.

More prospective and comparative studies are required in conjunction with a follow-up of a larger group of patients to confirm or dismiss other benefits of RAS.

Availability of data and materials Yes.

Compliance with ethical standards

Conflict of interest Roberto Negrín has received a speaker honorarium from Zimmer Biomet and Smith and Nephew. Jaime Duboy has received a speaker honorarium from Smith and Nephew. Gonzalo Ferrer has received a speaker honorarium from Arthrex. Magaly Iñiguez, Manuel Saavedra, Nicolas Reyes, Nicolas Jabes and Maximiliano Barahona declare that they have no conflict of interest.

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