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REVIEW

Treatment of arthrofibrosis and stiffness after total knee arthroplasty: an updated review of the literature

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Abstract

Purpose There is currently no consensus regarding the optimal treatment for stiffness following total knee arthroplasty (TKA). With the increased utilization of value-based models, it is important to determine the most effective treatments that will reduce the need for further intervention and additional expenditure. A systematic review was performed to compare the outcomes of manipulation under anaesthesia (MUA), arthroscopic lysis of adhesions (aLOA), and revision TKA (rTKA) for arthrofibrosis and stiffness following TKA.

Methods PubMed and MEDLINE databases were reviewed for articles published through October 2020. Studies were included if they reported patient-reported outcome measures (PROMs) following MUA, aLOA, or rTKA. The primary endpoint was PROMs, while secondary outcomes included range of motion and the percentage of patients who pursued further treatment for stiffness.

Results A total of 40 studies were included: 21 on rTKA, 7 on aLOA, and 14 on MUA. The mean or median post-operative arc ROM was > 90° in 6/20 (30%) rTKA, 5/7 (71%) aLOA, and 7/10 (70%) MUA studies. Post-operative Knee Society (KSS) clinical and functional scores were the greatest in patients who underwent MUA and aLOA. As many as 43% of rTKA patients required further care compared to 25% of aLOA and 17% of MUA patients.

Conclusion Stiffness following TKA remains a challenging condition to treat. Nonetheless, current evidence suggests that patients who undergo rTKA have poorer clinical outcomes and a greater need for further treatment compared to patients who undergo MUA or aLOA.

Keywords Revision total knee arthroplasty · Manipulation under anesthesia · Arthroscopic lysis of adhesions · Complication · Stiffness · Arthrofibrosis · Outcomes · Range of motion · Systematic review

Introduction

Arthrofibrosis, one of the most common complications following total knee arthroplasty (TKA), is a debilitating condition that arises due to excessive scar tissue formation in a joint following injury or trauma [1–4]. With an occurrence of 1.3–19.8% [5, 6], the inconsistency regarding the definition of arthrofibrosis, especially with respect to flexion and/or extension loss, likely explains the wide range in the reported incidence [3, 5, 7–9]. In the USA, arthrofibrosis and stiffness account for 28% of 90-day hospital readmissions following TKA and up to 10% of revisions within years [10, 11].

Risk factors for arthrofibrosis and stiffness following TKA include genetics, low pre-operative range of motion (ROM), complexity of surgery, history of prior surgery, immobilization, and poor motivation during the rehabilitation process [12]. In general, treatment for arthrofibrosis and stiffness is initiated with intensive physical therapy, with or without bracing, and complemented with a multimodal pain regimen until 12 weeks post-operatively [12, 13]. If stiffness persists, manipulation under anesthesia (MUA) is performed between eight and 12 weeks post-op, following

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which, arthroscopic lysis of adhesions (aLOA) is most commonly performed [8, 13]. Failure of these interventions may warrant revision TKA (rTKA), depending on the patients' functional requirements. Nevertheless, current literature suggests that the improvements in ROM, pain, and function are only favourable for a select few rTKA patients [14–16]. The challenges of treating stiffness and arthrofibrosis have spurred investigation into novel therapies and peri-operative protocols such as low-dose irradiation as a supplement to rTKA [17], as well as the use of continuous passive motion following primary TKA [18]. In the current era of value-based healthcare, there is a growing need to elucidate the most effective and cost-efficient treatment that optimizes clinical outcomes for patients.

The purpose of this systematic review was to compare the functional outcomes of MUA, aLOA, and rTKA for the treatment of arthrofibrosis and stiffness after primary TKA.

Materials and methods

Search methodology

Two databases from the US National Library of Medicine, PubMed and Ovid MEDLINE, were queried in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement guidelines for all articles that were published prior to October 30, 2020. Four different search terms were utilized to screen for articles: ((total knee arthroplasty) AND (stiffness) OR (arthrofibrosis)), (manipulation under anaesthesia) AND (total knee arthroplasty), and (lysis of adhesions) OR (arthrolysis) and (total knee arthroplasty). Reference lists from each study and related citations from each search engine were explored for additional eligible studies to ensure that no studies were missed after the initial database query. Studies were then screened by two independent reviewers (AH, GG) for eligibility based on the title and abstract. The full text of studies that were deemed to meet the inclusion criteria were reviewed, after which only those that were eligible were included in the analysis. Disagreements were resolved by consensus, and by a third reviewer, if needed.

Inclusion and exclusion criteria

Articles were included if they involved the treatment of arthrofibrosis and/or stiffness following primary TKA and included patient-reported outcome measures (PROMs), ROM values, and the prevalence of treatment success/failure. The rate of treatment success/failure corresponded to the percentage of patients who experienced an increase/decrease in ROM that exceeded a threshold defined in each individual study, as well as the percentage of patients who pursued further treatment for arthrofibrosis. rTKA was defined to include the removal of at least one component from the index procedure (e.g., isolated polyethylene tibial insert exchange (IPTIE)). Only the most recent publication was included if a study published several interim results. Studies were excluded if they did not report the abovementioned outcome measures or clearly define the group the outcomes belonged to. Case reports, reviews, commentary pieces, and studies that were not available in English were also excluded.

Data extraction

All information and outcomes of interest, including author, date of publication, study design, number of patients, treatment modalities, length of follow-up, and PROMs, were recorded on a study-specific data extraction sheet. The primary outcome was PROMs after surgery with secondary outcomes including improvement in ROM and prevalence of treatment success as defined by the article.

Quality assessment

The level of evidence was determined using the Oxford Center for Evidence-Based Medicine Levels of Evidence. Assessment of quality for the included studies was performed by two of the authors (AH, GG) and scored in accordance with the methodological index for non-randomized studies (MINORS) instrument, a valid and reliable tool for study quality assessment [19]. The MINORS instrument is made of 8 and 12 items for non-comparative studies and comparative studies, respectively, with item scores of 0 (not reported), 1 (reported but inadequate), and 2 (reported and adequate). Non-comparative studies and comparative studies can achieve maximum scores of 16 and 24, respectively.

Results

In total, 2,035 articles were initially identified in the database review, and an additional 220 articles were found in relevant systematic reviews and meta-analyses (Fig. 1). Forty articles were included in this study after screening full texts, 16 with a level of evidence (LOE) of III and 24 with a LOE of IV. No level I or II studies were found in the literature. Two of the 40 studies were considered to be of moderate quality, while the 38 other studies were considered to be of poor quality (Table 1).

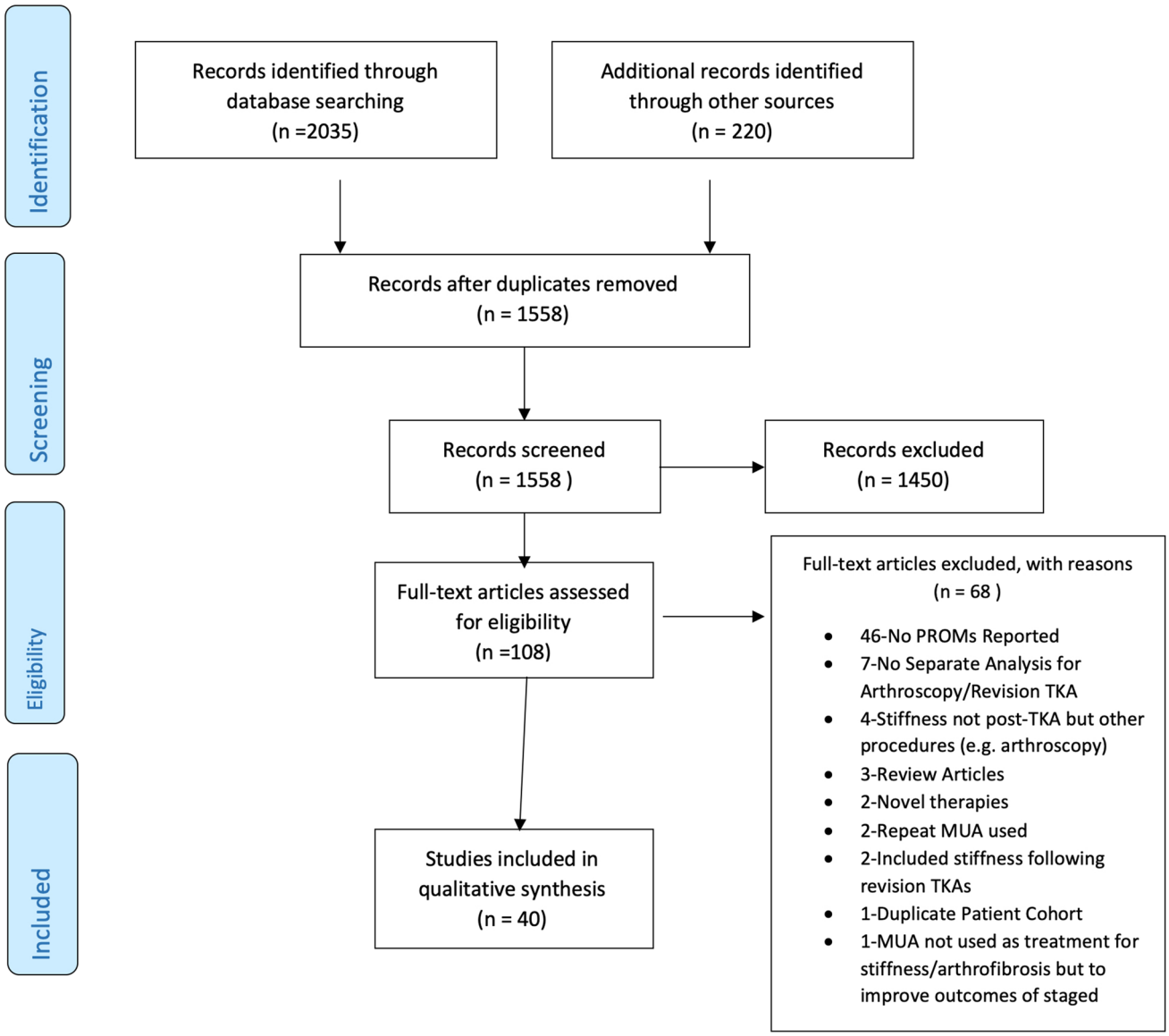

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram outlining the study selection process

Revision total knee arthroplasty

In the 21 studies, the mean time to surgery was 1.81 (95% CI (1.29–2.34)) years, and the average follow-up was 3.86 (95% CI (3.41–4.32)) years. Between 15 and 73% of patients underwent some form of treatment before rTKA, although this was only reported in seven studies [3, 15, 16, 31, 40, 48, 49]. Demographics, definitions of stiffness used, and indication of treatment are summarized in Table 2.

rTKA improved arc ROM in all the included studies, with average ROM increasing from 54.60° (95% CI (46.85–62.34°)) to 82.92° (95% CI (78.21–87.62°))—an increase of 28.32°. However, the mean or median post-op arc ROM remained below 90° in 14 of 20 studies [3, 16, 20, 24, 27, 30, 36, 39, 47–51, 54]. Three of the four studies that reported pre-operative and post-operative Knee Society [56] Pain (KSSP) scores showed improvement after surgery [16, 39, 49]. All studies that reported KSS clinical scores (KSSC) or KSS functional scores (KSSF) showed improvement over time but only one reported excellent KSSF, defined as a score > 70 [56].

Two publications compared the outcomes of IPTIE to full rTKA [20, 47] (Table 3). Patients who underwent IPTIE had greater post-operative ROM, flexion, and clinical outcomes than those who underwent complete revision [47]. Another study found that in patients with idiopathic arthrofibrosis, IPTIE leads to greater improvement in ROM and flexion with lower revision rates compared to complete revision.

Table 1 Included studies and methodological index for non-randomized studies (MINORS) for included studies

Publication name (year of publication)	Type of study	Level of evidence	Stated aim of study	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate for study aim	Unbiased evaluation of endpoints	Follow-up period appropriate to the major endpoint	Loss to follow-up not exceeding 5%	Prospective calculation of sample size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	MINORS score
Xiong et al. (2020) [20]	Retrospective consecutive series	III	1	2	0	2	0	2	2	1	N/A	N/A	N/A	N/A	10/16
Randsborg et al. (2020) [21]	Retrospective consecutive series	III	2	0	1	2	0	2	2	0	N/A	N/A	N/A	N/A	10/16
Boo et al. (2020) [22]	Retrospective case series	IV	1	0	0	2	0	2	0	0	N/A	N/A	N/A	N/A	5/16
Yao et al. (2020) [23]	Retrospective case control matched cohort study	III	2	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	7/16
Van Rensch et al. (2020) [24]	Retrospective case series	IV	2	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	7/16
Crawford et al. (2019) [25]	Retrospective case control study	III	1	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	6/16
Bingham et al. (2019) [26]	Retrospective matched cohort study	III	2	0	0	2	0	2	0	0	0	2	1	2	11/24
Hermans et al. (2019) [27]	Retrospective comparative series	III	1	0	0	2	0	2	0	0	0	1	1	2	9/24
Van Rensch et al. (2019) [28]	Retrospective case series	IV	1	0	0	2	0	2	2	0	0	N/A	N/A	N/A	7/16

Table 1 (continued)

Publication name (year of publication)	Type of study	Level of evidence	Stated aim of study	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate for study aim	Unbiased evaluation of endpoints	Follow-up period appropriate to the major endpoint	Loss to follow-up not exceeding 5%	Prospective calculation of sample size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	MINORS score
Cartwright-Terry et al. (2018) [29]	Retrospective case control study	III	2	0	0	2	0	2	0	0	N/A	N/A	N/A	N/A	6/16
Hug et al. (2018) [30]	Retrospective consecutive series	III	1	0	0	2	0	2	1	0	0	0	0	1	7/24
Rutherford et al. (2018) [31]	Retrospective case series	IV	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Filho et al. (2017) [32]	Retrospective comparative study	III	2	0	0	2	0	2	2	0	0	1	1	2	12/24
Moya-Angeler et al. (2017) [15]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16
Pierce et al. (2017) [33]	Retrospective case control study	III	1	0	0	2	0	2	0	0	N/A	N/A	N/A	N/A	5/16
Donaldson et al. (2016) [3]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16
Yoo et al. (2015) [34]	Retrospective case series	IV	1	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	6/16
Dzaja et al. (2015) [35]	Retrospective case control study	III	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Heesterbeek et al. (2016) [36]	Retrospective case series	IV	2	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	7/16

Table 1 (continued)

Publication name (year of publication)	Type of study	Level of evidence	Stated aim of study	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate for study aim	Unbiased evaluation of endpoints	Follow-up period appropriate to the major endpoint	Loss to follow-up not exceeding 5%	Prospective calculation of sample size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	MINORS score
Issa et al. (2014) [37]	Retrospective case control study	III	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Hegazy and Elsoufy (2011) [38]	Retrospective case series	IV	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Kim et al. (2011) [39]	Retrospective case series	IV	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Hartman et al. (2010) [40]	Retrospective consecutive series	III	2	1	0	2	0	2	2	0	N/A	N/A	N/A	N/A	9/16
Patil et al. (2010) [41]	Retrospective case series	IV	2	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	7/16
Arbuthnot and Brink (2010) [42]	Retrospective case series	IV	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Sharma et al. (2008) [43]	Retrospective comparative series	III	1	0	0	1	0	2	2	0	N/A	N/A	N/A	N/A	6/16
Keating et al. (2007) [44]	Retrospective case control study	III	2	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	8/16
Jerosch and Aldawoudy (2007) [45]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16
Mont et al. (2006) [46]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16

Table 1 (continued)

Publication name (year of publication)	Type of study	Level of evidence	Stated aim of study	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate for study aim	Unbiased evaluation of endpoints	Follow-up period appropriate to the major endpoint	Loss to follow-up not exceeding 5%	Prospective calculation of sample size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	MINORS score
Yercan et al. (2006) [5]	Retrospective case series	IV	1	0	0	2	0	2	0	0	N/A	N/A	N/A	N/A	5/16
Keeney et al. (2005) [47]	Retrospective comparative series	III	2	1	0	2	0	2	1	0	0	1	0	2	11/24
Haidukewych et al (2005) [48]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16
Kim et al. (2004) [16]	Retrospective case series	IV	1	0	0	2	0	2	2	0	N/A	N/A	N/A	N/A	7/16
Christensen et al. (2002) [49]	Retrospective consecutive series	III	1	2	0	2	0	2	1	0	N/A	N/A	N/A	N/A	8/16
Babis et al. (2001) [50]	Retrospective case series	IV	1	0	0	2	0	2	0	0	N/A	N/A	N/A	N/A	5/16
Ries and Badalamente (2000) [51]	Retrospective case series	IV	1	2	0	2	0	2	1	0	N/A	N/A	N/A	N/A	8/16
Williams et al. (1996) [52]	Retrospective case series	IV	2	0	0	2	0	1	2	0	N/A	N/A	N/A	N/A	7/16
Daluga et al. (1991) [53]	Retrospective comparative series	IV	2	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	7/16
Nicholls and Dorr (1990) [54]	Retrospective case series	IV	1	0	0	2	0	2	1	0	N/A	N/A	N/A	N/A	6/16
Campbell (1987) [55]	Retrospective case series	IV	1	0	0	1	0	2	1	0	N/A	N/A	N/A	N/A	5/16

Table 2 Demographics, range of motion information, and patient-reported outcome measures following revision total knee arthroplasty

Author (year)	Knees (patients)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Percentage of patients who failed prior treatment for stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex
Xiong et al. (2020) [20] Idiopathic Stiffness	101	61.1 (±9.61)	37:64	NR	NR	4.4 (2-6.2)	ROM < 90° or an extension deficit of > 5°	Idiopathic stiffness: 101	NR	60.4° (5–120°)	87.6° (15–130°)	72.2° (15–130°)
Xiong et al. (2020) [20] Non-Idiopathic Stiffness	88	61.4 (±9.64)	40:48	NR	NR	4.0 (2-6.7)	NR	Aseptic loosening: 44 Mal-positioning: 31 Oversized components: 9 Infection: 4	NR	62.8° (0–100°)	97.1° (20–127°)	71.5° (0–110°)
Van Rensch et al. (2020) [24]	(13)	NR	NR	NR	NR	Min 7.5	ROM ≤ 70°	E.	NR	58° (±22°)	62° (±31)	NR
Bingham et al. (2019) [26]	102	62.6 (±12.9)	39:63	30.8 (±6.1)	NR	6 (2–15)	NR	Arthrofibrosis: 102	NR	83.4° (±31.4°)	97.8° (±24.4°)	NR
Hermans et al. (2019) [27]	40	59.6 (44–76)	NR	NR	NR	3.2	Flexion contracture > 10° or a maximum flexion < 80°	Idiopathic arthrofibrosis: 40	NR	56.0°	87.7°	65.5
Van Rensch et al. (2019) [28]	(38)	64 (40–85)	12:26	NR	NR	Min 2	ROM ≤ 70°	Malpositioning: 15 Aseptic loosening: 7 Instability: 2 Undefined: 2	NR	50° (5°-70°)*	90° (50°-125°)*	NR

Table 2 (continued)

Author (year)	Knees (patients)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Percentage of patients who failed prior treatment for stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex
Hug et al. (2018) [30]	69	62 (±11.0)	30:39	30.9 (±24.8)	Min 1	3.59 (±3.08)	Flexion contracture >15°, or Arc ROM <75°, with pain and dysfunction	NR	NR	53° (±22°)	87° (±21°)	70° (±23°)
Rutherford et al. (2018) [31]	46	61.4 (±10.0)	15:31	28.4 (±5.33)	Min 1	4.9 (2–10)	Functionality limiting loss of motion resulting in a stiff knee	Internal rotation: 18 (Overstuffing): 10 Instability: 3 Malpositioning: 4 Undefined: 8 Other: 3	54.3% (25/46)	77.0°	100.0°	87.6° (±17.17°)
Moya-Angeler et al. (2017) [15]	42	61 (48–80)	14:28	33 (21–58)	NR	1.96 (2–9.08)	Flexion contracture ≥ 15°, and/or flexion < 75° and/or ≤ 90° ROM with chief complaint of limited ROM and pain	Arthrofibrosis: 34 Malrotation: 8 Oversized Implants: 13 F/E Gap mismatch: 7 Polyethylene Wear: 8 Loosening:12 Patellar Maltracking: 6	A.	72.0° (10–100°)	92.0° (15–140°)	81.5° (10–125°)
Donaldson et al. (2016) [3]	48	65.5 (42–83)	35:13	NR	3.6 (1.2–10.4)	5 (1–22)	Flexion contracture ≥ 15°, and/or 75° of flexion, or total arc of flexion of < 70°	Internal rotation: 20 Malalignment:6 Instability: 6 Oversize/overstuffing:10 Arthrofibrosis: 6	14.6% (7/48)	42.4°	87.4°	54.4° (±21.3°)

Table 2 (continued)

Author (year)	Knees (patients)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Percentage of patients who failed prior treatment for stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex
Heesterbeek et al. (2016) [36]	(40)	64 (±7)	9:31	NR	NR	Min 2	ROM ≤ 70°	Malpositioning: 27 Aseptic Loosening: 5 Instability: 5 Undefined: 3	NR	60°* (20–70°)	85°* (10–125°)	NR
Kim et al. (2011) [39]	37	60.8 (37–86)	14:22	30.7 (21.5–46.8)	3.1 (0.2–22.9)	3.1 (1.25–8)	ROM <90°	Idiopathic arthrofibrosis: 37	NR	67° (0–110°)	85° (10–120°)	70°
Hartman et al. (2010) [40]	35	62 (32–81)	20:15	NR	1.0 (0.3–3.3)	4.54 (2.1–11.2)	Symptomatic stiffness	F.	51.4% (18/35)	53.6° (10–90°)	98.1° (50–130°)	67.1°
Patil et al. (2010) [41]	(11)	NR	NR	NR	NR	NR	NR	G.	NR	NR	NR	NR
Yercan et al. (2006) [5]	2	NR	NR	NR	NR	NR	> 10° of extension deficit and/or <95° flexion in the 6 weeks of post-operative period	NR	NR	62.5° (±7.5°)	120° (±0°)	70° (±0°)
Keeney et al. (2005) [47]	(23)	62.1 (±10.5)	NR	34.2	1.8	3.0 (±6.5)	NR	NR	NR	60.9° (±17.26)	84.4° (±19.8°)	75.0°
Haidukewych et al. (2005) [48]	16	66.8 (±11.1)	6:10	NR	2 (0.25–3.5)	3.5 (2–6)	NR	H.	73% (11/15) B.	40.2° (±15.7°)	73.2° (±27.1°)	62.7° (±13.3°)

Table 2 (continued)

Author (year)	Knees (patients)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Percentage of patients who failed prior treatment for stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex
Kim et al. (2004) [16]	56	69 (36–89)	14:38	NR	1.5 (0.75–5.2)	3.6 (2–10)	Flexion contracture ≥ 15 degrees, and/or < 75 degrees of flexion	Component loosening: 18 Oversized components: 10 Heterotopic ossification:3 Undefined: 25	53.6% (30/56) C..	54.6° (±20.50°)	82.2° (±21.32°)	65.8° (±23.97°)
Christensen et al. (2002) [49]	11	62.1 (±7.7)	1:10	NR	1.6 (0.5–8)	3.1 (2–4.42)	ROM <70°	Arthrofibrosis: 2 Loosening: 4 Overstuffing: 2 Heterotopic bone: 2 Varus tibia: 1 Flexion imbalance: 1	36% (4/11)D	39.7° (±19.9)	82.7° (±23.8)	52.9° (±25.0)
Babis et al. (2001) [50]	7	61 (38–74)	2:5	NR	1 (0.3–2.5)	4.2 (2–8)	NR	Idiopathic arthrofibrosis: 7	NR	38.6° (±13.3)	58.0° (±11.7°)	55.7° (±16.1°)
Ries et al. (2000) [51]	6	65.7 (±7.31)	0:6	NR	1.7 (0.8–3.8)	2.75 (±1.18)	Soft tissue contracture that impaired knee function and who were unwilling to accept the limitations associated with stiffness	Soft tissue contracture: 6 I.	NR	35.8° (±18.04°)	85.8° (±13.57°)	57.5° (±20.43°)

Table 2 (continued)

Author (year)	Knees (patients)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Percentage of patients who failed prior treatment for stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex
Nicholls and Dorr (1990) [54]	13	52.1 (28–73)	6:7	NR	NR	NR	Flexion contracture >20° or flexion <45°	Malpositioning: 8 Aseptic loosening: 1 Quadricep dysfunction: 1 Arthrofibrosis: 3	NR	25.4° (10–60°)	57.7° (15–110°)	43.1° (20–90°)

Post-op Flex	Pre-op Ext (Flex. Con)	Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-op WOMAC	Post-op WOMAC	Other	Other
91.7° (30–130°)	11.9° (0–60°)	4.1° (0–25°)	NR	NR	NR	NR	NR	NR	NR	NR	VAS pain 5.4* (0–10)	VAS pain 2.4 (0–10)
100.1° (20–130°)	9.1° (0–60°)	3.0° (0–40°)	NR	NR	NR	NR	NR	NR	NR	NR	VAS pain 6.5* (0–10)	VAS pain 2.0 (0–8)
NR	NR	NR	NR	NR	30 (±22)	52 (±29)	41 (±24)	59 (±7)	NR	NR	VAS pain 71 (±20)	VAS pain 64 (±11) VAS satisfaction 40 (±22)
NR	NR	NR	NR	NR	42.3 (±20.7)	67.5 (±21.0)	48.8 (±24.6)	51.9 (±28.6)	NR	NR	NR	NR
91.6°	9.5°	3.8°	NR	NR	39.7	58.5	47.6	62.3	NR	NR	NR	NR
NR	NR	NR	NR	NR	43 (4-89)*	76 (10-100)*	30 (5-70)*	60 (5-100)*	NR	NR	VAS pain 62.5 (0–100)*	VAS pain 28.5 (0–96) VAS satisfaction 72 (0–100)*
92° (±19°)	17° (±10°)	5° (±7°)	NR	NR	42 (±9)	70 (±14)	41 (±11)	68 (±16)	NR	NR	NR	NR
103° (±18.36°)	10.6° (±11.68°)	3.0° (±6.19°)	11.63 (±11.40) (N)	25.98 (±17.63) (N)	57.17 (±22.72) (N)	70.98 (±25.98) (N)	NR	NR	NR	NR	KSS Total 100.17 (±34.78) (N)	KSS total 140.07 (±39.45) (N)

Table 2 (continued)

Post-op Flex	Pre-op Ext (Flex. Con)	Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-op WOMAC	Post-op WOMAC	Other	Other
94.3° (15–140°)	9.7° (0–35°)	2.3° (0–20°)	NR	NR	43.9 (15–67)	72.0 (50–93)	48.7 (35–80)	70.1 (30–90)	NR	NR	NR	NR
90.9° (±21.6°)	12° (±10.6°)	3.5° (±5.5°)	NR	NR	NR	NR	NR	NR	58.3 (±17.9)	36.0 (±20.9)	WOMAC pain 10.9 (±4.6) WOMAC stiffness 5.8 (±1.5) WOMAC function 41.5 (±13.0)	WOMAC pain 6.7 (±4.8) WOMAC stiffness 3.5 (±1.8) WOMAC function 26.8 (±15.4)
NR	NR	NR	NR	NR	43 (−14-59)	61 (17-94)	45 (−20-70)	60 (−10–100)	NR	NR	VAS pain 66 (10–100)	VAS pain 49 (1–99)
90°	12° (0–40°)	5° (0–30°)	16.9	33.2	45.7 (19–86)	67.9 (10–100)	41.8 (5–90)	62.9 (0–100)	NR	NR	NR	NR
100.7°	13.5°	2.7°	NR	NR	32.2	60.9	41.6	56.3	NR	NR	NR	NR
NR	NR	NR	NR	NR	41.3 (±13.5)	58.1 (±15.8)	41.2 (±18.5)	52.7 (±23.7)	NR	NR	SF-36 mental health: 42.0 (±9.6) SF-36 physical health: 31.0 (±5.9)	SF-36 mental health: 46.0 (±11.0) SF-36 physical health: 39.0 (±10.7)
120° (±0)	7.5° (±7.5°)	0° (±0°)	NR	50 (±0)	NR	NR	NR	NR	NR	NR	NR	NR
87.4°	14.2°	4.7°	NR	NR	28.3 (±18.6)	66.0 (±27.1)	44.1 (±11.1)	60.0 (±26.1)	NR	NR	VAS pain 7.6 (±2.2)	VAS pain 2.7 (±3.0)
81.3° (±21.4°)	22.5° (±16.0°)	8.1° (±8.8°)	NR	NR	30.4 (±12.9)	64.7 (±23.1)	45.2 (±16.5)	58 (±17.7)	NR	NR	NR	NR
85.4° (20.49°)	11.3° (±11.92°)	3.2° (±5.42°)	15.0 (±11.1)	46.9 (±7.54)	38.5 (±18.8)	86.7 (±12.3)	40.0 (±19.1)	58.4 (±17.4)	NR	NR	NR	NR
83.2° (±23.5°)	13.2° (±11.7°)	0.45° (±1.51°)	4.5 (±6.9)	44.1 (±6.3)	31.1 (±10.4)	75.5 (±9.7)	8.6 (±13.4)	62.3 (±21.5)	NR	NR	NR	NR
60.0° (±11.0°)	17.1° (±9.2°)	2.0° (±4.0°)	44.0 (±11.7)	39.6 (±9.4)	36.4 (±16.6)	46.0 (±3.7)	NR	NR	NR	NR	NR	NR
86.7° (±14.03°)	21.7° (±7.53°)	0.8° (±2.04°)	NR	NR	NR	NR	NR	NR	NR	NR	KSS total 38.33 (±24.63)	KSS total 126.67 (±15.55)

Table 2 (continued)

Post-op Flex	Pre-op Ext (Flex. Con)	Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-op WOMAC	Post-op WOMAC	Other	Other
63.8° (15–110)	17.7° (0–45°)	6.2° (0–15°)	NR	NR	NR	NR	NR	NR	NR	NR	HSS: 38.7 (23–57)	HSS: 69.1 (35-98)

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score, *VAS* visual analogue scale, *HSS* hospital for special surgery score, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index, *SF-36* 36-item Short Form Health Survey

*Values in medians

A. Physical therapy in all patients (100%), MUA in 10 knees (23.8%), and arthroscopic debridement in 5 knees (11.9%)

B. Of 15 patients, 8 had MUA, 3 had aLOA, and 2 had open lysis of adhesions with isolated polyethylene exchange. All patients had a trial of supervised PT

C. Of 56 knees, 29 had MUA, and 1 had aLOA

D. Of 11 knees, 1 had MUA, and 3 had open surgery (lysis of adhesions, polyethylene exchange, excision of heterotopic bone)

E. Included stiffness with component malpositioning but excluded stiffness caused septic loosening

F. Excluded patients with aseptic loosening

G. Some patients had stiffness associated with component mal-position/mal-rotation

H. Only included patients with well-fixed components

I. Excluded cases with mechanical failure of the components, wear, or prior infection. All components were well aligned and appropriately sized

Table 3 Sub-analysis of isolated polyethylene tibial insert exchange vs. complete revision TKA

Author (year)	Knees (patient)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Pre-op ROM	Post-op ROM	Pre-op flex	Post-op flex
Xiong et al. (2020) [20] -Isolated polyethylene exchange	42	60.1 (±9.72)	12:30	NR	NR	NR	ROM < 90° or an extension deficit of > 5° and as long as isolated liner exchange could help patients obtain good intraoperative ROM	Idiopathic Stiffness: 42	62.6° (15–90°)	93.2° (25–130°)	72.3° (20–100°)	96.8° (40–130°)
Xiong et al. (2020) [20] -Complete revision	59	61.9 (±9.53)	25:34	NR	NR	NR	ROM < 90° or an extension deficit of > 5° with intraoperative instability or intraoperative ROM	Idiopathic stiffness: 59	58.9° (5–120°)	83.9° (15–120°)	72.2° (15–130°)	88.4 (30–130°)
Xiong et al. (2020) [20] -Isolated polyethylene exchange	8	NR	NR	NR	NR	NR	NR	NR	63.8° (20–93°)	95.0° (20–125°)	66.7° (20–100°)	95.8° (20–125°)
Xiong et al. (2020) [20] -Complete revision	80	NR	NR	NR	NR	NR	NR	NR	62.7° (0–100°)	97.3° (45–127°)	71.8° (0–110°)	100.5° (45–130°)
Keeney et al. (2005) [47] Complete revision	11	60.8 (+9.6)	NR	35.7 (±10.6)	1.49 (±0.74)	2.9 (±1.8)	A	NR	49.4° (±19.7°)	67.3° (±20.8°)	72.8° (±18.8°)	76.2° (±21.4°)
Keeney et al. (2005) [47] Isolated polyethylene exchange	12	63.3 (±11.2)	NR	32.8 (±7,4)	2.08 (±1.25)	3.2 (±1,4)	B.	NR	70.6° (±13.5°)	96.3° (±11.0°)	77.1° (±18.3°)	97.6° (±11.4°)

Table 3 (continued)

Pre-op Ext (Flex Con)	Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-op WOMAC	Post-op WOMAC	Other	Other
9.7° (0–30°)	3.5° (0–25°)	NR	NR	NR	NR	NR	NR	NR	NR	VAS pain 5* (0-10)	VAS pain 4* (0-6)
13.3° (0–60°)	4.5° (0–20°)	NR	NR	NR	NR	NR	NR	NR	NR	VAS pain 6* (0–6)	VAS pain 3* (0–10)
2.8° (0–10°)	0.8° (0–5°)	NR	NR	NR	NR	NR	NR	NR	NR	8* (8–10)	4.5* (2–7)
9.6° (0–60°)	3.2° (0–40°)	NR	NR	NR	NR	NR	NR	NR	NR	6* (0–10)	1* (0–6)
21.6° (±16.3°)	8.90° (±10.0°)	NR	NR	21.9 (±15.7)	25.5 (±21.4)	51.4 (±28.8)	50.4 (±13.1)	NR	NR	7.09 (±2.51)	4.40 (±3.72)
7.45° (±8.02°)	0.82° (±3.25°)	NR	NR	36.9 (±19.7)	74.7 (±18.2)	41.7 (±10.1)	62.5 (±30.0)	NR	NR	7.91 (±1.92)	1.45 (±1.44)

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score, *VAS* visual analogue scale, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

*Values reported in medians

A. Complete revision: limited flexion contracture (<15°) and tibial insert at least 12 mm thick that could accommodate downsizing

B. Limited approach: severe flexion contracture (>20°) or inability to downsize tibial insert (10 mm thick)

Idiopathic arthrofibrosis was defined as a painful limitation in knee ROM without an underlying etiology. For patients with non-idiopathic arthrofibrosis, complete revision was a better option as patients had lower pain but equivalent values of post-operative ROM compared to those who underwent IPTIE. However, no other studies distinguished between rTKA performed for idiopathic and non-idiopathic causes of stiffness.

Two studies [26, 27] compared the outcomes of patients who underwent rTKA using either a rotating-hinge (RH) device or a traditional constrained condylar device (CC) (Table 4). rTKA patients with a RH device experienced a greater increase in arc ROM. While one study [27] showed that patients with a RH rTKA fared better than those with non-RH TKA in terms of KSS, the report by Bingham et al. [26] contrasted these findings, suggesting that non-RH patients fared better in all outcome measures.

In the twelve rTKA studies that reported the percentage of patients who experienced an improvement in ROM, four studies [15, 26, 50, 54] found that more than 10% of patients did not experience an improvement in ROM, while eight studies reported that 0–6.5% of patients did not experience improvement (Supplementary Table 1) [5, 31, 36, 39, 40, 48, 49, 51]. Furthermore, 14 of 18 studies reporting the percentage of patients who pursued further treatment for stiffness showed that at least 10% of patients required additional treatment.

Arthroscopic lysis of adhesions

Seven studies that evaluated aLOA for the treatment of stiffness and arthrofibrosis following TKA were included (Table 5). Patients were treated at an average of 1.03 (95% CI (0.77–1.30)) years after primary TKA and were evaluated at an average of 2.26 (95% CI (1.57–2.95)) years after aLOA. The percentage of patients who had failed prior treatment for stiffness was reported in six studies, ranging from 27.3 to 100%, in three studies [38, 45, 55]. All studies reported an increase in arc ROM from an average pre-operative value of 61.97° (95% CI (57.32–66.61°)) to a post-operative average of 101.78° (95% CI (86.97–116.58°)). Only one study reported Oxford Knee Scores [42]. Of the studies that reported pre-operative and post-operative KSS, all demonstrated improvements from baseline [38, 45, 46, 52].

Six studies reported values for the percentage of patients who did not improve with respect to ROM (Supplementary Table 2) [5, 38, 42, 46, 52, 55]. Four of 6 studies reported that all patients had an increase from their pre-operative arc ROM [5, 38, 52, 55]. Two studies reported that 4.5% and 5.6% of patients did not have an improvement in arc ROM [42, 46]. Four studies analyzed the percentage of patients who pursued further treatment for stiffness, with three of

Table 4 Sub-analysis of rotating hinge vs. constrained condylar revision TKA for stiffness

Author(year)	Knees (patient)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Pre-op ROM	Post-op ROM
Bingham et al. (2019) [26] Rotating hinge cohort	34	62.8 (±15.2)	13:21	29.8 (±5.4)	NR	Min. 2.0	74.3° (±36.4°)	94.0° (±26.3°)
Bingham et al. (2019) [26] Non-rotating hinge cohort	68	62.6 (±11.7)	26:42	31.2 (±6.4)	NR	Min. 2.0	86.8° (±29.3)	99.2° (±23.8)
Hermans et al. (2019) [27] Constrained-condylar knee device cohort	18	57.5 (44-70)	4:14	NR	NR	3.46	59.0°	75.2°
Hermans et al. (2019) [27] Rotating hinge knee device cohort	22	61.4 (46–76)	NR	NR	NR	2.95	53.6°	98.0°

Pre-op Flex	Post-op Flex	Pre-op Ext (Flex. Con)	Post-op Ext (Flex Con)	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF
NR	NR	NR	NR	43.5 (±20.4)	56.2 (± 22.8)	31.3 (±25.1)	40.9 (±27.8)
NR	NR	NR	NR	41.6 (±21.3)	71.4 (±19.2)	56.0 (±20.7)	56.9 (±27.8)
67.2°	81.4°	8.2°	6.2°	44.4	53.8	49.4	46.1
64.1°	99.9°	10.5°	1.9°	53.8	62.3	54.2	68.9

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score

Table 5 Demographics, range of motion, and patient-reported outcome measures following arthroscopic lysis of adhesions

Author (year)	Knees (patient)	Age	M:F tatio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Etiology of stiffness	Pre-op ROM	Post-op ROM	Pre-op Flex	Post-op Flex
Hegazy and Elsoufy (2011) [38]	8	67.6 (62–73)	3:5	NR	0.8 (0.7–1.5)	3.1 (2–4.33)	Flexion contracture ≥15° and/or flexion ≤ 75°	Arthrofibrosis: 8	60° (30–75°)	98.4° (85–120°)	87.5° (85–90°)	104° (97–120°)
Arbuthnot and Brink (2010) [42]	22	62 (45–77)	7:14	30.9 (23–40)	0.7* (0.2–2)	3.38 (0.42–10)	A.	Arthrofibrosis: 22	60.5° (±22.7°)	89.6° (±21.7°)	69.1° (±23.5°)	93.2° (±20.5°)
Jerosch and Aldawoudy (2007) [45]	(32)	71 (56–83)	10:22	NR	0.7 (0.2–1.5)	2.3 (1-6)	NR	Idiopathic Arthrofibrosis: 32	56.8°	96.0°	63° (35–85°)	97° (75–115°)
Mont et al. (2006) [46]	18	55.9 (±11.3)	11:7	NR	2.6 (0.6–9.5)	2.5 (2–3.42)	Flexion contracture ≥15° and/or knee flexion ≤90°	Arthrofibrosis: 18	63.3° (±19.2°)	94.7° (±19.8°)	75.3° (±10.6°)	98.3° (±14.9°)
Yercan et al. (2006) [5]	3	NR	NR	NR	NR	NR	Extension deficit ≥ 10° and/or 95° of flexion	NR	62° (±19°)	122° (±3°)	63.3° (±16.1°)	121.67° (±2.89°)
Williams et al. (1996) [52]	10	63.3 (43–84)	5:5	NR	2.4 (0.8–5.2)	1.6 (±0.8)	NR	NR	70° (±25.7°)	103° (±19.3°)	73.9° (±0.3°)	104.5° (±6.3°)
Campbell (1987) [55]	8	53 (26–73)	3:5	NR	1.0 (0.3–2)	0.97 (0.33–2)	NR	Arthrofibrosis: 8	71°	87.5°	81°	92°

Pre-op Ext (Flex. Con)	Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-op KSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-op WOMAC	Post-op WOMAC	Other	Other
27.5° (10–45°)	5.6° (0–15°)	30	41	70	86	68	85	NR	NR	NR	NR
8.6° (±7.25°)	3.6° (±4.52°)	NR	NR	NR	NR	NR	NR	NR	NR	OKS 36.3 (±8.3)	OKS 29.3 (±9.0)
6.3° (0–85°)	1.1° (0–10°)	30	41	70	86	68	85	NR	NR	NR	NR
11.9° (±11.4°)	3.61° (±7.0°)	NR	NR	34 (20–58)	77 (40–95)	NR	NR	NR	NR	NR	NR
1.6° (±2.8°)	0° (±0°)	NR	38.33 (±7.64)	NR	NR	NR	NR	NR	NR	NR	NR
4.0° (±1.2°)	1.5° (±1.1°)	33.5 (±2.8)	42.0 (±2.1)	70.9 (±3.8)	86.4 (±3.3)	71 (±3.1)	88 (±2.5)	NR	NR	NR	NR
10°	4.5°	NR	NR	NR	NR	NR	NR	NR	NR	7.5 VAS pain	5.25 VAS pain

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index, *OKS* Oxford Knee Score

*Values reported in medians

A. A clinical situation where the range of motion achieved by the patient following total knee replacement restricts their function and is considered by their surgeon to be below that which could have been achieved (with reference to on table post-operative

those reporting 0% and one reporting 25% (2 of 8 patients) [5, 40, 47, 54].

Manipulation under anaesthesia

Fourteen studies evaluated the outcomes of MUA. The average time to surgery was 0.24 (95% CI (0.14–0.33)) years with an average follow-up of 4.70 (95% CI (3.12–6.28)) years. The average pre-operative ROM was 78.69° (95% CI (64.14–89.23°)), and this increased to an average of 99.65° (95% CI (91.79–107.50°))—an increase of 20.97°. In six of the ten studies that reported post-operative ROM, the average value was greater than 100° [5, 22, 25, 34, 35, 43], and all studies that recorded the post-operative arc ROM showed means or medians of at least 80° (Table 6). Three studies reported both pre-operative and post-operative KSSP, of which, all three showed improvement [25, 37, 44]. In addition, all studies that reported pre-operative and post-operative KSSC and KSSF showed improvement at final follow-up [22, 25, 35, 37].

Only one study compared patients who underwent MUA with or without a glucocorticoid adjunct (Table 7) [43]. Subanalysis showed that patients who received this adjunct better retained the gains in ROM at 2-year follow-up despite achieving equivalent ROM during MUA.

Four studies reported the percentage of patients who did not experience an improvement in arc ROM (Supplementary Table 3) [5, 21, 34, 43], three [21, 34, 43] of which reported values less than 10%, with one study [5] reporting 15.2%. Five of seven studies found that less than 10% of patients needed to seek additional treatment for stiffness [33, 35, 37, 43, 44], with two studies reporting that at least 15% of patients had to undergo further treatment [21, 25].

Discussion

Stiffness following TKA is a challenging complication to treat. Multiple definitions of stiffness have been proposed, and the indications for treatment are not uniform [12]. This problem is further compounded by patients who perceive a limitation in knee ROM and are dissatisfied with their knee replacement but who nonetheless do not fit the established criteria for stiffness.

Our findings suggest that rTKA for stiffness and arthrofibrosis, even in the absence of component malposition, leads to inferior clinical outcomes and range of motion compared to MUA and aLOA. A greater percentage of patients who underwent rTKA needed to undergo further treatment for stiffness and arthrofibrosis, with figures reaching up to 42.9% [50]. While the need for additional treatment was greatest for rTKA patients, three of 4 aLOA studies reported a 0% incidence of patients requiring further treatment, while another reported an incidence of 25% [38]. The need for further treatment was also lower in MUA, with most studies reporting values less than 10% [25, 33, 35, 37, 43, 44]. Nonetheless, the reduced incidence of secondary surgery after MUA or aLOA may not indicate treatment success. It could instead possibly suggest a sense of realistic futility by the patient and/or the care team with the prospects of rTKA.

Analysis of KSSP showed that the three different procedures provided similar levels of pain relief following treatment, despite lower overall post-operative KSSC and KSSF after rTKA compared to both MUA and aLOA. While the majority of rTKA studies reported KSSC less than 70, the lowest reported KSSC was 70.7 for MUA and 77 for aLOA. This finding could be attributed to the nature of the procedures—MUA and aLOA preserve the index arthroplasty and bone stock, while rTKA is associated with bone loss during implant removal, precluding optimal fixation of implants [57]. Furthermore, during rTKA for stiffness, constrained condylar (CC) prostheses are often used due to the difficulty in achieving soft tissue balance [58]. As multiple studies having shown that the outcomes of rTKA are inferior to those of primary TKA [59–63], these factors could explain, in part, the more limited knee functionality among patients who undergo rTKA. Nonetheless, the poorer outcomes after rTKA could be indicative of a higher incidence of component malposition or failure of prior procedures such as MUA and aLOA. In other words, it is unclear how many patients in the rTKA had failed prior interventions and thus represented a more intrinsically complicated group.

Patients who underwent aLOA had greater improvement in total arc ROM from baseline compared to patients who underwent rTKA. With the exception of Campbell et al. [55], all the included studies on aLOA reported an increase of least 29° in ROM, whereas patients who underwent MUA had an increase in mean ROM of 21°. While rTKA significantly increased ROM by at least 40° in some studies [5, 27, 40, 49, 51], others reported only a modest increase of 4° at follow-up [24]. Improvement in mean ROM across all rTKA studies was 28°, and a subgroup analysis of 5 studies [20, 27, 39, 50, 51] that specified the indication for revision showed an increase in mean ROM of 27° in rTKAs performed for idiopathic arthrofibrosis alone. It is important to note that despite the higher pre-operative ROM in MUA compared to rTKA patients (79° vs. 55°), MUA patients had a similar, albeit slightly smaller increase in mean ROM (21°) compared to patients who underwent rTKA for idiopathic arthrofibrosis (27°) [20, 27, 39, 50, 51] (Table 8).

It has been reported that idiopathic stiffness rTKA patients have worse outcomes than non-idiopathic stiffness rTKA patients [22]. Although the distinction between idiopathic and non-idiopathic stiffness was not made in most studies, one study by Xiong et al. suggested that IPTIE may be more efficacious for these patients compared to complete

Table 6 Demographics, range of motion, and patient-reported outcome measures following manipulation under anesthesia

Author (year)	Knees (patient)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Type of anaesthesia	Pre-op ROM	Post-op ROM	Pre-op Flex	Post-Op Flex
Randsborg et al. (2020) [21]	(23)	61 (46–80)	6:17	28.1 (21.2–42.3)	0.35 (0.1–0.7)	2.5 (1.3–2.9)	A.	General anesthesia + femoral nerve block No steroid adjunct	70° I.Q.R[50°,80°]	97° I.Q.R[84°,116°]	80° I.Q.R[60°,85°]	107° I.Q.R[91°,116°]
Boo et al. (2020) [22] Objective cohort	(19)	60.3 (±9.4)	2:17	29.4 (±4.5)	0.3 (±0.7)	Min 2.0	ROM <70°, flexion contracture > 15°, flexion < 90°	General anesthesia No steroid adjunct	62° (±27.7°)	83° (±19.4°)	NR	NR
Boo et al. (2020) [22] Subjective cohort	(29)	65.9 (±8.6)	4:25	27.7 (±4.8)	0.9 (±1.5)	Min 2.0	B.	General anesthesia No steroid adjunct	109° (±16.7°)	105° (±18.5°)	NR	NR
Yao et al. (2020) [23]	(51)	66.4 (±9.1)	16:35	30.3 (±5.9)	10 days (±3)	3.0 (±0.4)	Flexion < 90°	General anesthesia No steroid adjunct	NR	NR	71.7° (±12.6)	107.4° (±15.3)
Crawford et al. (2019) [25]	182	58.6 (±9.4)	64:118	34.1 (±7.1)	NR	9.7 (2–15.9)	NR	Light anesthesia	105.3° (±15.4°)	104.7° (±5.8°)	NR	NR
Cartwright-Terry et al. (2018) [29]	(69)	63.78 (43–81)	36:33	NR	0.3*	Min 1	Symptomology and patient requirements	General anesthesia or spinal Anesthesia No steroid adjunct	64.3° (±12.0°)	81.9° (±20.9°)	72.3° (±18.0°)	85.0° (±17.9°)
Filho et al. (2017) [32]	42	62.2 (45-83)	16:26	NR	NR	(1-6.75)	Arc ROM <90°	Sedation+ femoral nerve block	47.7°	82.0°	63.1°	90.2°
Pierce et al. (2017) [33]	138	NR	NR	NR	NR	9 (5-11)	Flexion < 110° As well as cultural, religious, and personal reasons	NR	64.5° (±3.5°)	NR	NR	NR

Table 6 (continued)

Author (year)	Knees (patient)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Type of anaesthesia	Pre-op ROM	Post-op ROM	Pre-op Flex	Post-Op Flex
Yoo et al. (2015) [34]	22	66.9 (±8.6)	1:21	27.4 (±4.0)	0.1	4.7 (±3.7)	C.	General anesthesia or spinal Anesthesia No steroid adjunct	69.8°	111.6° (±30.8)	69.5° (±15.1°)	113.9° (±29.5°)
Dzaja et al. (2015) [35]	(72)	59.8 (42–83)	35:37	31.7 (21.8–54.1)	0.2 (0.1–0.3)	3.1 (1–10)	Flexion <90° and unresponsive to physiotherapy	Epidural anesthesia No steroid adjunct	69.8°	111.6°*[2]	79.8° (±14.8°)	116°*[2] (±13.9°)
Issa et al. (2014) [37]	145	55 (25–89)	44:88	32.9 (18–51)	0.1* (0.06–0.9)	4.25 (2–7.1)	D.	General anesthesia No steroid adjunct	NR	NR	101° (60–125°)	114° (85–134°)
Sharma et al. (2008) [43]	13	65 (54–80)	6:7	NR	NR	1.5 (1–3.2)	< 90° of knee flexion, > 15° of flexion contracture or an arc of motion < 70-80° at 6 weeks post-op	General + local anesthesia Steroid adjunctandgeneral anesthesia No steroid adjunct	70° (40–85°)	100.8° (40–131°)	NR	NR
Keating et al. (2007) [44]	113	65 (34–84)	47:66	28.8	NR	4.6 (0.5–15)	<90° Flexion at 2 months post-op	General snesthesia No dteroid adjunct 22% received general anesthesia+ epidural anesthesia	67° (±11°)	NR	70° (30–100°)	105.0° (50–130°)

Table 6 (continued)

Author (year)	Knees (patient)	Age	M:F ratio	BMI	Time to surgery (years)	Follow-up (years)	Definition of stiffness or indication for treatment	Type of anaesthesia	Pre-op ROM	Post-op ROM	Pre-op Flex	Post-Op Flex
Yercan et al. (2006) [5]	46	NR	NR	NR	NR	NR	> 10° of extension deficit and/or <95° of flexion in the first 6 post-operative weeks	34 General anesthesia 10 Spinal anesthesia 2 General anesthesia + Crural block No steroid adjunct	NR	114° (±16°)	68.9°	115°
Daluga et al. (1991) [53]	94	66 (±8)	15:45	NR	NR	NR	NR	General anesthesia No steroid adjunct	NR	NR	61° (±10°)	103 (±10°)

Pre-op Ext (Flex. Con)	Post-Op Ext (Flex Con)	Pre-OP KSSP	Post-Op KSSP	Pre-Op KSSC	Post-Op KSSC	Pre-Op KSSF	Post-Op KSSF	Pre-Op WOMAC	Post-Op WOMAC	Other	Other
5° I.Q.R[0°,15°]	0° I.Q.R [0°,2°]	NR	NR	NR	NR	NR	NR	NR	NR	NR	F.
NR	NR	NR	NR	30.4 (±19.2)	77.4 (±13.6)	52.9 (±18.8)	80.4 (±12.9)	NR	NR	OKS 35.3 (±6.8) G.	OKS 37.6 (±8.6) H.
NR	NR	NR	NR	40.8 (±13.6)	73.3 (±19.3)	52.7 (±21.0)	80.4 (±19.3)	NR	NR	OKS 19.8 (±5.4) I.	OKS 21.6 (±6.7) J.
NR	NR	NR	45* I.Q.R [49, 21]	NR	80* I.Q.R [57,95	NR	70* I.Q.R [60,100]	NR	430*	NR	SF-12 MCS 51±11 SF-12 PCS 36 ±13
NR	NR	7.7 (±8.8)	39.9 (±16.2)	39.6 (±13.7)	83.7 (±19.9)	51 (±14)	65.7 (±26.9)	NR	NR	NR	NR
8.0° (±7.5°)	4.3° (±6.9°)	NR	NR	NR	NR	NR	NR	54.4	41.2	SF-12 MCS 29.2 SF-12 PCS 52	SF-12 MCS 31 SF-12 PCS 50.8
15.4°	8.2°	NR	NR	NR	79.7	NR	82.7	NR	NR	NR	NR
NR	NR	NR	NR	NR	87	NR	87	NR	NR	NR	NR
5 (±7.2°)	2.7° (±4.9°)	NR	NR	NR	88.3 (±13.1)	NR	65.8 (±18.9)	NR	NR	NR	HSS 80.1 (±10.9)

Table 6 (continued)

Pre-op Ext (Flex. Con)	Post-Op Ext (Flex Con)	Pre-OP KSSP	Post-Op KSSP	Pre-Op KSSC	Post-Op KSSC	Pre-Op KSSF	Post-Op KSSF	Pre-Op WOMAC	Post-Op WOMAC	Other	Other
10° (±6.1°)	4.4°*[2] (±6.7°)	NR	NR	NR	NR	NR	NR	39.5 (±14.1)	69.5 (±22.3)	KSS Total 91.4 (±20.1) SF-12 MCS 53.1 (±11.1) SF-12 PCS 29.8 (±7.2)	KSS Total 158.8 (±32.4) SF-12 MCS 54.1 (±8.6) SF-12 PCS 39.1 (±11.5)
NR	NR	42[K] (31–67)	88[K] (65–100)	NR	NR	44[K] (25–62)	89[K] (75–100)	NR	NR		
NR	NR	11.3	46	NR	NR	NR	NR	NR	NR	NR	NR
1.9° (±3.7°)	1° (±3°)	NR	44 (±8)	NR	NR	NR	NR	NR	NR	NR	NR
NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	HSS 87 (±9)

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score, *OKS* Oxford Knee Score, *SF-36* 36-item Short Form Health Survey, *HSS* hospital for special surgery score

*Values reported in medians

1. Values reported in medians with exception of follow-up, which is reported in means

2. Values reported immediately following MUA

A. The indication to offer an MUA at our institution is a joint decision between the patient and surgeon. The patients need to feel restricted by the reduced ROM and dissatisfied with the function of daily activities. Normally, this means that the total ROM is less than 90°

B. Subjective self-reported difficulty in perform activities of living due to stiffness in patients whom physiotherapy rehabilitation has failed to produce improvement in symptoms over a minimal of 3 months

C. At the time of discharge, patients with <80° knee flexion or those with progressive stiffness of the knee in spite of ≥80° knee flexion were required to visit the outpatient clinic within 1 to 2 weeks afterwards. In these patients, if the range of flexion was limited to <80° in the outpatient visit, MUA was carried out

D. Absolute indication for MUA is flexion ROM < 90°, and relative indication for MUA is flexion ROM < 115°, and/or presence of religious, cultural, or personal reasons that would require higher range of motion for certain patients

E. Absolute indication for MUA is flexion ROM < 90°, and relative indication for MUA is flexion ROM < 115°, and/or presence of religious, cultural, or personal reasons that would require higher range of motion for certain patients

F. Lysholm 57.1 (17.9–92.9), Tegner 2.0 (0–7), VAS pain sitting 1.5 (0–6), VAS pain standing 2.25 (0–8), KOOS symptoms 57.1 (17.9–92.9) KOOS pain 58.3 (0–94.4), KOOS ADL 66.2 (0–100), KOOS Sports & Rec 25.0 (0–100), KOOS QOL 43.8 (0–81.3)

G. SF-36 Physical Function 37.1, SF-36 Role Functional (Physical) 16.7, SF-36 Bodily Pain 34.5, SF-36 General Health 72.7, SF-36 Vitality 62.4, SF-36 Social Function 57.1 , SF-36 Role Functional (emotional) 79.4, SF-36 Mental Health 66.5

H. SF-36 Physical Function 40, SF-36 Role Functional (Physical) 25, SF-36 Bodily Pain 32.4, SF-36 General Health 65.7, SF-36 Vitality 59.4, SF-36 Social Function 52.3, SF-36 Role Functional (emotional) 80.2 , SF-36 Mental Health 73.9

I. SF-36 Physical Function 69.5, SF-36 Role Functional (Physical) 72.6, SF-36 Bodily Pain 63.9, SF-36 General Health 70.6, SF-36 Vitality 70.2, SF-36 Social Function 86.3, SF-36 Role Functional (emotional) 79.4, SF-36 Mental Health 78.7

J. SF-36 Physical Function 65.0, SF-36 Role Functional (Physical) 72.2, SF-36 Bodily Pain 64.7, SF-36 General Health 71.0, SF-36 Vitality 68.0, SF-36 Social Function 88.0 , SF-36 Role Functional (emotional) 86.4

K. New Knee Society Score Used

Table 7 Steroid adjunct vs. non-steroid adjunct cohort sub-analysis

Author (year)	Knees (patient)	Age	M:F ratio	BMI	Follow-up (years)	Methodology of MUA	Pre-op ROM	Post-op ROM	Pre-op flex	Post-op flex	Pre-op Ext (Flex Con)
Sharma et al. (2008) [43] Intra-articular steroid cohort	6	65 (54–72)	1:5	NR	1.2 (1–1.5)	General + local anesthesia Steroid adjunct	77° (70–85°)	111° (105–131°)	NR	NR	NR
Sharma et al. (2008) [43] Non intra-articular steroid cohort	7	65 (54–80)	5:2	NR	1.7 (1–3.2)	General anesthesia No steroid adjunct	64° (40–85°)	92° (40–120°)	NR	NR	NR

Post-op Ext (Flex Con)	Pre-op KSSP	Post-op KSSP	Pre-opKSSC	Post-op KSSC	Pre-op KSSF	Post-op KSSF	Pre-opWOMAC	Post-op WOMAC	Other	Other
NR	NR	NR	53 (43–60)	88 (73–97)	49 (40–60)	90 (80–100)	NR	NR	NR	NR
NR	NR	NR	53 (43–75)	83 (56–95)	49 (40–60)	85 (45–100)	NR	NR	NR	NR

KSSP Knee Society Clinical Rating System Pain Score, *KSSC* Knee Society Clinical Rating System Clinical Score, *KSSF* Knee Society Clinical Rating System Functional Score, *WOMAC* Western Ontario and McMaster Universities Arthritis Index

rTKA, as IPTIE patients reported greater improvement in ROM and flexion with lower rates of revision [22]. However, approximately 17% of IPTIE patients with idiopathic arthrofibrosis still required further treatment, higher than reported figures for MUA and aLOA.

In rTKA, implant choice may also influence treatment outcomes. RH prostheses do not rely on ligamentous or soft tissue balancing for stability, allowing for the release of collateral ligaments and posterior capsule as well as elevation of the joint-line [26]. Patients who undergo rTKA with a RH prosthesis may experience less pain, better knee function, and greater improvement in extension and flexion compared to those who underwent rTKA with CC prostheses [26, 27]. Despite these benefits, patients who undergo rTKA with a RH device are at greater risk of implant failure and re-revision; hence, the trade-offs between ROM and implant durability should be evaluated and tailored to the needs of the patient [26].

Few of the included studies investigated the impact of timing from the index TKA on the outcomes of rTKA or aLOA. Mont et al. reported that patients who underwent aLOA at less than one year post-op had higher gains in ROM than those who underwent aLOA at greater than 1 year post-op [46]. One study found no difference in flexion, extension, and KSS gains in patients who underwent rTKA before (n=22) or after two years post-op (n=24) [33]. In contrast, Donaldson et al. reported that patients who underwent rTKA before two years post-op had superior improvement in ROM, and outcomes were reported [3]. However, the authors suggested that these results be interpreted with caution due to the small sample size and heterogeneity of the study population [3]. Nonetheless, further studies evaluating the effect of timing on the outcomes of rTKA for stiffness are warranted.

The timing of MUA is another important consideration that has been shown to influence the outcome of treatment. MUAs performed later in the post-operative period need to overcome a greater degree of fibrotic [5]. Several studies have shown improved function and ROM in MUAs performed before 12 weeks post-op compared to those performed after 12 weeks post-op [32, 64]. Further, of the included studies in this systematic review, only one compared the outcomes of MUA with and without a glucocorticoid adjunct. Despite achieving similar ROM during manipulation, MUA patients who received a glucocorticoid adjunct better retained the gains in ROM and had higher final ROM at two years (111° vs. 92°) [43]. Further studies are needed to confirm these clinical benefits in a larger cohort and explore the mechanisms behind the synergistic effect of steroid treatment.

The advent of value-based models has increased the pressure on healthcare systems to provide high-quality and cost-efficient care. As of 2018, the inpatient National Average Medicare CMS payment for performing rTKA was

Table 8 Average follow-up, time to surgery, and range of motion

Variable	MUA	aLOA	rTKA	*P* value
Follow-up	4.70 (3.12–6.28)	2.26 (1.57–2.95)	3.86 (3.41–4.32)	<0.001
Time to surgery	0.24 (0.14–0.33)	1.03 (0.77–1.30)	1.81 (1.29–2.34)	<0.001
Pre-op ROM	78.69 (64.14–89.23)	61.97 (57.32–66.61)	54.60 (46.85–62.34)	0.013
Post-op ROM	99.65 (91.79–107.50)	101.78 (86.97–116.58)	82.92 (78.21–87.62)	<0.001

MUA manipulation under anesthesia, *aLOA* arthroscopic lysis of adhesions, *rTKA* revision total knee arthroplasty, *ROM* range of motion

Table 9 Preoperative patient-reported outcome measures

Variable	MUA	aLOA	rTKA	*P* value
Pre-op KSS clinical	41.48 (33.95–49.02)	52.50 (16.34–88.66)	38.56 (35.21–41.91)	0.603
Pre-op KSS functional	54.09 (49.90–58.29)	71.00 (69.08–72.92)	39.82 (34.85–44.80)	<0.001

Mean values with 95% confidence intervals in brackets

KSS Knee Society Score, *MUA* manipulation under anesthesia, *aLOA* arthroscopic lysis of adhesions, *rTKA* revision total knee arthroplasty

$17,115.36, while the average outpatient costs for MUA and aLOA were $1209 and $2041, respectively. Future cost-effectiveness studies should be performed to directly compare the three options.

There were several limitations of our study. This systematic review only contained studies with a LOE of III and IV, likely resulting in cohorts that were unmatched in terms of demographics, aetiologies, indications, and other confounding variables such as time from TKA, prior surgeries, procedural techniques, and peri-operative protocols. Furthermore, patients in the three cohorts varied with respect to pre-operative KSSF and KSSC (Table 9). We also could not include studies that evaluated the efficacy of physical therapy as none of these studies analyzed PROMs, which was our primary endpoint. Finally, it is unclear whether patients in the rTKA group were similar to those in the other cohorts, as patients who underwent rTKA presented with significantly lower pre-operative ROM and at a significantly longer time following the index surgery. The extent of component malalignment, inaccurate implant sizing, or instability is poorly reported in the literature, and thus, their incidence in each group also remains unknown. Hence, it is uncertain how these factors could have influenced the results of each treatment modality. Furthermore, given the vagueries in the literature, our study could not elucidate potential differences for either MUA or rTKA done for idiopathic arthrofibrosis alone or with implant malposition. Nevertheless, we believe that the findings of this study still provide a valuable synthesis of the literature to guide clinical practice.

Conclusion

Manipulation under anesthesia (MUA) and arthroscopic lysis of adhesions (aLOA) patients had superior clinical outcomes, knee functionality, and range of motion after intervention compared to patients who underwent revision total knee arthroplasty (rTKA). As this was a systematic review of studies with LOE III and IV, additional prospective randomized studies are warranted to elucidate any differences among these treatment modalities. Future studies should also compare the cost-effectiveness of these treatment options, especially given the greater cost and unpredictable results of rTKA.

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Author contribution AH: data collection, analysis, manuscript writing. GSG: data collection, analysis, manuscript writing. YAF: data collection, analysis, manuscript review and editing. MTT: data collection, analysis, manuscript review and editing. JHL: data collection, analysis, manuscript review and editing.

Data availability N/A

Declarations

Ethics approval Review by an institutional review board was not required for this study.

Consent to participate N/A

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Competing interests The authors declare no competing interests.

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