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CLINICAL RESEARCH

How to Treat the Stiff Total Knee Arthroplasty?

A Systematic Review

Sean E. Fitzsimmons MD, Edward A. Vazquez BS, Michael J. Bronson MD, FACS

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Abstract

Background Multiple modalities have been used to treat the stiff TKA, including manipulation under anesthesia (MUA), arthroscopy, and open arthrolysis.

Questions/purposes We reviewed the literature to address three questions: (1) How many degrees of ROM will a stiff TKA gain after MUA, arthroscopy, and open arthrolysis? (2) Does the timing of each procedure influence this gain in ROM? (3) What is the number of clinically important complications for each procedure?

Methods We performed a PubMed search of English language articles from 1966 to 2008 and identified 20 articles, mostly Level IV studies.

Results For patients who have arthrofibrosis after TKA, the gains in ROM after MUA and arthroscopy (with or without MUA) are similar. Open arthrolysis seems to have inferior gains in ROM. MUA is more successful in increasing ROM when performed early but still may be effective when performed late. Arthroscopy combined with MUA still is useful 1 year after the index TKA. The numbers of clinically important complications after MUA and arthroscopy (with or without MUA) are similar.

Conclusions Stiffness after TKA is a common problem that can be improved with MUA and/or arthroscopic lysis of adhesions with few complications. The low quality of available literature makes it difficult to develop treatment protocols.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Stiffness after TKA is a common problem occurring in 8% to 60% of patients. Stiffness can be defined as limited ROM that affects a patient's ability to perform activities of daily living [3]. One study found patients require an average of 83° knee flexion to climb stairs foot over foot [15]. To sit in a chair without using one's hands requires, on average, 93° knee flexion. Tying one's shoes while seated requires 106° flexion on average [15].

There are multiple options for treatment of a stiff TKA: physical therapy (PT), MUA, arthroscopic débridement, open débridement, and revision surgery. The gain in motion using physical therapy is often modest: one study reported an average increase in knee motion of only 5° in a group of patients with arthrofibrosis after TKA treated with PT alone [9]. During MUA, the physician forcefully overcomes adhesions while flexing the knee. Arthroscopy allows the surgeon to examine the knee prosthesis and to treat soft tissue impingement, loose bodies, or adhesions [8, 11, 13]. Open release of adhesions and revision surgery often are used in refractory cases or in cases with component malposition or damage.

The ability of MUA, arthroscopic lysis of adhesions, and open lysis of adhesions to increase ROM in a stiff TKA has been questioned [3]. Numerous authors have examined the

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S. E. Fitzsimmons, M. J. Bronson (✉)
Department of Orthopaedics, The Mount Sinai Hospital, New York, NY 10029, USA
e-mail: Michael.bronson@mountsinai.org

E. A. Vazquez
The Mount Sinai School of Medicine, New York, NY, USA

literature regarding treatment of arthrofibrosis after TKA [3, 5, 7, 12, 23, 25, 27], and although each of their articles contributes to our knowledge, none provides a comprehensive review of these modalities to treat the stiff TKA. The articles often make treatment recommendations; however, no universal practice based on all of the available literature has been established.

We therefore performed a systematic review of the literature to compare MUA, arthroscopic lysis of adhesions, and open lysis of adhesions to treat arthrofibrosis after TKA to address three questions: (1) is there is a difference in the gain in ROM after the aforementioned procedures in patients who have a stiff TKA; (2) does the timing of the procedure affect the gain in knee ROM; and (3) does the number of clinically important complications differ between the various procedures?

Materials and Methods

We first performed a comprehensive literature search to locate articles describing MUA to treat the stiff TKA. PubMed was searched for articles published from 1966 to August 2008 with the following MeSH entries: "arthroplasty," "arthroplasty, replacement, knee," "manipulation, orthopedic," and "anesthesia." The dates of the searches were from September 8, 2008, to September 22, 2008. This yielded 681 citations. The following free text words were then entered into the search strategy: "arthroplasty," "knee," "total knee," "knee replacement," "stiff," "orthopedic manipulation," "manipulation," "arthrofibrosis," and "anesthesia." These terms were taken in various combinations using the Boolean operators "AND" and "OR." With additional limitations of English language only and studies on humans only, this PubMed search yielded 2996 citations. We also used the EMBASE database to search for appropriate articles from 1974 to August 2008. The same key words used in the PubMed search were used in the EMBASE search with limitations to English language only and studies on humans only. This search yielded 1198 citations. Finally, we searched for appropriate articles in the Cochrane Controlled Trials Register. The combined searches for articles evaluating MUA to treat a stiff TKA yielded 4194 citations (Fig. 1A). These were entered into the computer-based referenced management system EndNote X (Carlsbad, CA) to remove duplicates and provide a reference list once the search was complete. All abstracts were reviewed for applicability to the topic by two of the authors (SF, EV). The titles and abstracts were viewed electronically to determine if the article included patients who were treated for a stiff TKA using MUA, arthroscopic lysis of adhesions, or open lysis of adhesions. If the topic of the article and/or the inclusion/exclusion criteria were unclear from the abstract, the full text version of the article was retrieved and reviewed.

We excluded (1) articles that did not report the gain in ROM after MUA, arthroscopy, or open arthrolysis (Fig. 1); (2) articles reporting MUA, arthroscopy, or open arthrolysis as treatment for knee pain in patients with good ROM after TKA; (3) articles reporting MUA, arthroscopy, or open arthrolysis for patellar clunk syndrome; (4) surgical articles if the technique was substantially different from arthroscopic débridement of the suprapatellar pouch, medial and lateral gutters, and intercondylar notch and their inclusion would substantially increase heterogeneity in each treatment group; and (5) abstracts from meetings that did not have a full-text publication. No limits were placed on the studies for followup, study design, or number of patients. We reviewed bibliographies of identified studies for additional articles to include. In the MUA group, this search resulted in eight relevant articles for data extraction.

We performed a second set of literature searches to locate articles describing arthroscopy as a means of treatment for a stiff TKA. PubMed was searched for articles published from 1966 to August 2008 with the following MeSH entries: "arthroplasty," "arthroplasty, replacement, knee," and "arthroscopy." The dates of these searches were from September 8, 2008, to September 22, 2008. This yielded 341 citations. The following free text words then were entered in the search strategy: "arthroplasty," "knee," "total knee," "knee replacement," "stiff," "arthroscopy," "arthrolysis," and "arthrofibrosis." These terms were taken in various combinations using the Boolean operators "AND" and "OR." With additional limitations of English language only and studies on humans only, this PubMed search yielded 5805 citations. We also used the EMBASE database to search for relevant articles from 1974 to August 2008. The same key words used in the PubMed search were used in the EMBASE search with limitations to English language only and studies on humans only. This search yielded 1193 citations. We also searched for relevant articles in the Cochrane Controlled Trials Register. The combined searches for articles evaluating arthroscopy to treat the stiff TKA yielded 6998 (Fig. 1B). After reviewing the abstracts and using the five exclusion criteria described previously, 12 relevant articles for data extraction were identified.

We performed a third set of literature searches to locate articles describing open surgery as means of treatment for a stiff TKA. PubMed was searched for articles published from 1966 to August 2008 with a combination of MeSH entries and free text words, including: "arthroplasty," "arthroplasty, replacement, knee," "knee replacement," "knee," "knee joint," "total knee," "stiff," "arthrofibrosis," "open surgery," "open," and "arthrolysis." The dates

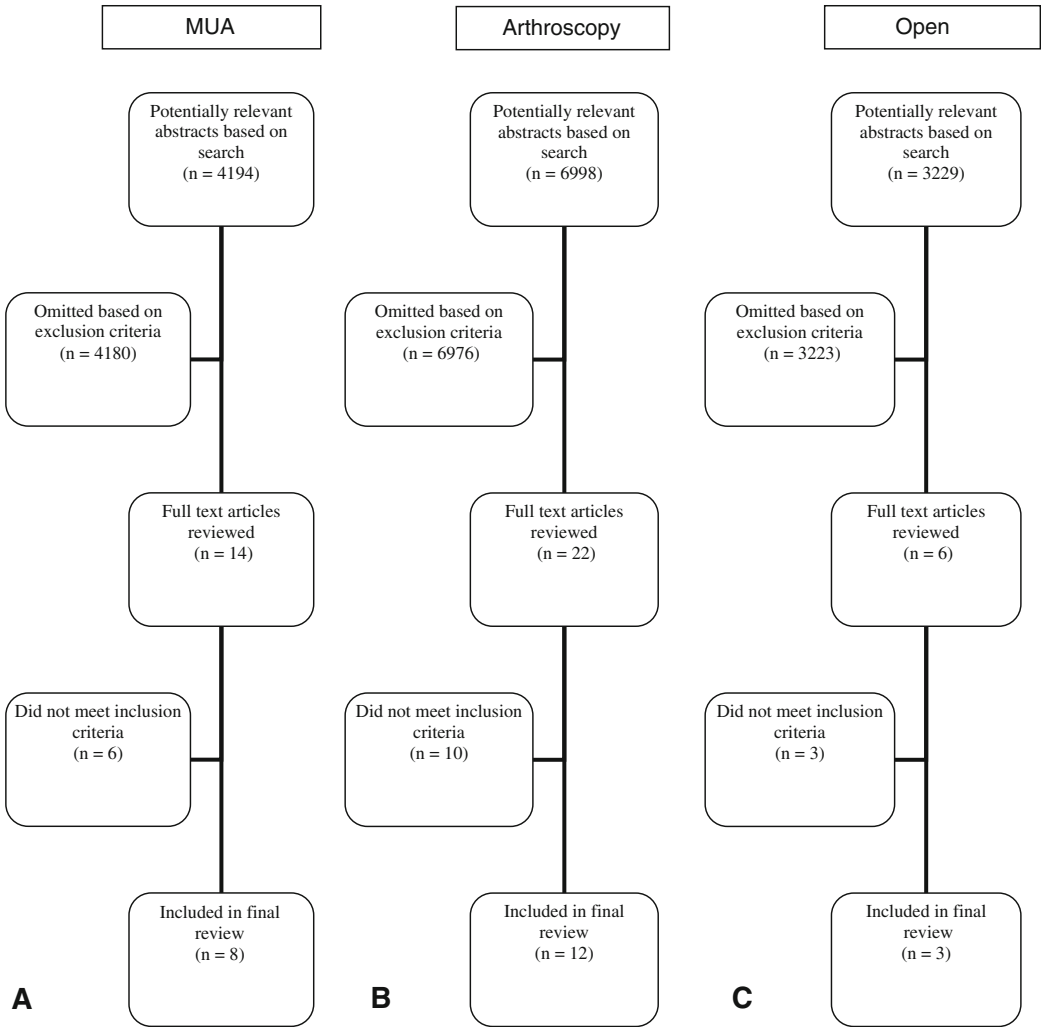

Fig. 1A–C Flowcharts of the literature searches for articles evaluating (**A**) manipulation under anesthesia, (**B**) arthroscopic lysis of adhesions, and (**C**) open lysis of adhesions to treat a stiff TKA are shown.

of these searches were from September 8, 2008, to September 22, 2008. These terms were taken in various combinations using the Boolean operators "AND" and "OR." With additional limitations of English language only and studies on humans only, this PubMed search yielded 2251 citations. We also used the EMBASE database to search for relevant articles from 1974 to August 2008. The same key words used in the PubMed search were used in the EMBASE search with limitations to English language only and studies on humans only. This search yielded 978 citations. We also searched for relevant articles in the Cochrane Controlled Trials Register without yield. The combined searches for articles evaluating open lysis of adhesions to treat the stiff TKA yielded 3229 citations (Fig. 1C). After reviewing the abstracts and using the five exclusion criteria described earlier in this article, three relevant articles for data extraction were identified.

We used a standardized paper form to assist in data extraction from each study. The form was used to extract patient-related factors, procedure-related factors, and outcomes. Patient-related factors included number of patients, number of knees, average age, and numbers of male and female patients from each article. Procedure-related factors, including indications for the procedure, timing of the procedure after index TKA, technique used to perform the procedure, adjunctive therapy, and type of anesthesia, were extracted from the articles. The outcomes extracted were final increase in knee motion, final increase in knee flexion, final increase in knee extension, followup time, and complications. Complications were extracted and reported only in tabular format if they were clearly reported in the article. If it was unclear if a complication could be attributed to the intervention, it was not included in this review. Complications were considered clinically important unless the

authors stated the complication did not influence the patient's recovery or final outcome.

After the data were extracted, a quality appraisal form was used to evaluate each study for inclusion in the systematic review. The form included questions to assess internal and external validity of each study. The appraisal form included assessment of patients' demographic data and risk factors for arthrofibrosis. The form also examined the study intervention to assure there was not significant heterogeneity between techniques. Definitions of outcome measures, including ROM, timing of intervention, and complications, were extracted [18]. Article title, objectives, sample size, statistical methods, additional interventions, followup, and generalizability also were examined [32]. We also assessed the studies for their level of evidence according to the description by Wright et al. [31]. The goal was to eliminate studies with any major flaws secondary to bias or mistakes in study methods. We also aimed to exclude studies that did not have generalizability. Two authors (SF, EV) applied the form to all studies. No study included a fatal flaw that precluded its use in this systematic review. Although none of the studies was a randomized control trial, and all of the studies contained flaws, the inclusion of all studies allows for the most comprehensive systematic review possible.

After data extraction and quality appraisal, final inclusion and exclusion decisions were made by two reviewers (SF, EV) and mutual agreement was reached. The literature search was summarized to make it easier to understand (Fig. 1). The data then were put in tabular format to allow readers to easily compare each study and to assess each study's relevance to their patient population (Tables 1, 2; Appendices 1, 2, 3).

None of the eight studies reviewing MUA could be classified as Level I by the system described by Wright et al. [31]. We identified one Level II study [9]. Two studies qualified as Level III [6, 14]. The remaining five studies were Level IV retrospective case series [10, 16, 20, 24, 33]. All 12 of the studies included in this review evaluating arthroscopy to treat the stiff TKA are Level IV [2, 4, 8, 11, 13, 21, 24, 26, 28–30, 33]. Two of the studies were case reports [21, 26]. All three of the articles that reviewed open arthrolysis to treat the stiff TKA are Level IV [1, 19, 33].

Many of the studies in this review did not report the average age of the patients and the number of male and female patients (Appendix 1) [1, 2, 4, 8, 10, 13, 16, 24, 29, 33]. In particular, in the arthroscopy and open groups, this is because patients with arthrofibrosis after TKA represent only one subset of patients in the presented articles and demographic data were presented for all groups of patients in the article as a whole [1, 2, 4, 8, 13, 24, 29, 33].

Most authors used knee motion less than 90° as their indication to perform MUA (Appendix 2) [10, 14, 16, 20, 24]. In the MUA group, authors had different time cutoffs as an indication for the procedure, as early as 2 weeks after surgery and as late as 3 months after initial surgery. Most studies did not report the time from index TKA or ROM used to indicate patients for arthroscopic or open lysis of adhesions [1, 2, 4, 8, 11, 13, 19, 21, 26, 28–30, 33]. Many studies report indications for these procedures as patients with arthrofibrosis after TKA who had failed PT, continuous passive motion, and/or failed MUA (Appendix 2) [2, 4, 8, 11, 24, 26, 33].

The most common technique for MUA was general anesthetic, muscle relaxants, and flexion of the hip and knee to achieve 90° knee flexion (Appendix 3). In the arthroscopy group, all authors used the standard technique of arthroscopic débridement of the suprapatellar pouch, medial and lateral gutters, and intercondylar notch [2, 4, 8, 11, 13, 21, 24, 26, 28–30, 33]. Many authors advocate the use of lateral release when performing arthroscopic lysis of adhesions [4, 11, 21, 26, 28, 29]. In three studies, patients had the PCL released with a resulting increase in ROM of 31° to 33° (Appendix 3) [24, 28, 30].

Two of the 12 studies did not report if MUA was used when the arthroscopy was performed [13, 33]. Only one study specifically stated MUA was not performed [11]. The gain in flexion for patients in that study was 34°, which is comparable to the increase in motion reported for patients in the other 11 articles. The other nine studies reported MUA was performed during the arthroscopic procedure (Appendix 3) [2, 4, 8, 21, 24, 26, 28–30]. This means it is more accurate to state this systematic review examines arthroscopy combined with MUA to treat the stiff TKA, not arthroscopy alone.

In the open lysis of adhesions group, authors used similar techniques to remove scar tissue from the knee, whereas only Babis et al. [1] reported using lateral release. Babis et al. [1] downsized the tibial inserts to allow for better extension, whereas Mont et al. [19] increased the insert size to account for instability after removal of scar tissue (Appendix 3).

The mean gain in ROM in the MUA group was between 30° and 47° (Table 1). Four studies reported motion in knee flexion [6, 9, 10, 14], whereas three studies reported motion as increase in ROM [20, 24, 33]. In one article, it was unclear if the degrees of knee motion referred to flexion or ROM [16].

The gain in ROM for patients included in the 12 articles evaluating arthroscopic lysis of adhesions for the stiff TKA ranges from 18.5° to 60° (Table 1) [2, 4, 8, 11, 13, 21, 24, 26, 28–30, 33]. The final increase in knee flexion was reported in nine of 12 articles and ranged from 5° to 58.4° [2, 11, 13, 21, 26, 28–30, 33]. In seven of eight articles that

Table 1. Gains in knee ROM, timing of procedure, and final followup

Study	Number of knees (number of patients)	Final increase in ROM (mean)	Final increase in flexion (mean)	Final increase in extension (mean)	Timing of procedure (mean in months)	Followup (mean in months)
MUA group						
Daluga et al. [6]	94 (60)	—	42°	—	—	34.8
Esler et al. [9]	47 (42)	—	35°	—	3	24
Fox and Poss [10]	76 (—)	—	30°	—	0.5	12
Keating et al. [14]	113 (90)	—	35°	—	2.5	55
Maloney [16]	24 (—)	47°*	—	—	1.5	—
Pariente et al. [20]	65 (60)	32°	—	—	1.5	21.3
Scranton [24]	19 (19)	42°	—	—	1.5–15	≥ 12
Yercan et al. [33]	46 (46)	47°	—	—	1	31
Arthroscopy group						
Bae et al. [2]	13 (11)	42°	45°	−3°	20	12
Campbell [4]	7 (7)	18.5°	—	—	11.6	≥ 12
Diduch et al. [8]	8 (8)	26.3°	—	—	7.4	—
Jerosch and Aldawoudy [11]	32 (32)	—	34°	23°†	8.5	28
Johnson et al. [13]	2 (2)	—	30°	—	—	—
Parisien [21]	1 (1)	50°	45°	5°	3	10
Scranton [24]	7 (7)	31°	—	—	—	≥ 12
Sprague et al. [26]	1 (1)	23°	5°	18°	12	3
Teng et al. [28]	11 (11)	30.8°	29°	1.8°	13	3
Wasilewski and Frankl [29]	6 (6)	34°	26°	8°	30	30
Williams et al. [30]	10 (9)	33°	30.5°	2.5°	29	20
Yercan et al. [33]	3 (3)	60°	58.4°	1.6°	—	—
Open group						
Babis et al. [1]	5 (5)	19°	—	—	—	—
Mont et al. [19]	18 (17)	31°	—	—	31	30
Yercan et al. [33]	3 (3)	21°	—	—	—	—

* Study did not clearly report motion in ROM or flexion; †data only for eight of 32 patients who had an extension lag (mean, 27°; range, 10°–35°); — = data were not presented or not clearly presented; MUA = manipulation under anesthesia.

reported on knee extension, the increase in motion was from 1.6° to 23° [11, 21, 26, 28–30, 33]. One article reported a loss of 3° extension after arthroscopy [2].

The final gain in ROM ranged from 19° to 31° in patients in the studies treating the stiff TKA with open lysis of adhesions (Table 1) [1, 19, 33]. The article by Mont et al. [19] was the only article that commented on timing. Mont et al. [19] reported slightly better results in the patients treated less than 1 year from the original TKA; however, no data were reported in the results section [19].

The complications in the MUA group included three hemarthroses, two fatal pulmonary emboli, one wound dehiscence, one subdural hematoma, and one supracondylar fracture (Table 2) [10, 14, 20]. There were 347 knees included in this part of the review. One study reported heterotopic ossification in 17 of 60 patients [6], but the authors reported this was clinically unimportant. The arthroscopy group had one complication, which was a superficial wound infection [28]. Three papers reported no complications in a total of 58 knees (Table 2) [4, 8, 11]. In the article by Williams et al., one patient who had revision TKA with PCL release reported subjective instability [30]. This is not included in the review because the article did not contain a section clearly stating all complications. The complications cited in another article also were not included in this review because they were not clearly described in the patients who had arthroscopy for arthrofibrosis (Table 2) [13]. The two complications were one infection and one case of instrument breakage [13]. Babis et al. [1] reported two late revisions that could not be directly attributed to open lysis of adhesions so they were not included in this review. The other two studies in the open group did not clearly report complications (Table 2) [19, 33].

Table 2. Clinically significant complications

Study	Number of complications/number of knees
MUA group	
Daluga et al. [6]	—
Esler et al. [9]	0/47
Fox and Poss [10]	5 of 76 (3 hemarthroses, 1 fatal PE, 1 wound dehiscence)
Keating et al. [14]	1/113 (supracondylar fracture)
Maloney [16]	—
Pariente et al. [20]	2/65 (1 subdural hematoma, 1 fatal PE)
Scranton [24]	—
Yercan et al. [33]	0/46
Arthroscopy group	
Bae et al. [2]	—
Campbell [4]	0/7
Diduch et al. [8]	0/8
Jerosch and Aldawoudy [11]	0/32
Johnson et al. [13]	—
Parisien [21]	—
Scranton [24]	—
Sprague et al. [26]	—
Teng et al. [28]	1/11 (1 superficial wound infection)
Wasilewski and Frankl [29]	—
Williams et al. [30]	—
Yercan et al. [33]	—
Open group	
Babis et al. [1]	—
Mont et al. [19]	—
Yercan et al. [33]	—

MUA = manipulation under anesthesia; PE = pulmonary embolism; — = data were not presented or not clearly presented.

Results

MUA and arthroscopy (with or without MUA) result in similar gains in ROM in patients with arthrofibrosis after TKA. Open arthrolysis to treat arthrofibrosis after TKA seems to have inferior results when compared with MUA or arthroscopy (with or without MUA). In the eight articles reviewed, MUA alone resulted in a mean gain in knee motion of 30° to 47° [6, 9, 10, 14, 16, 20, 24, 33]. In the 12 articles using arthroscopy to treat arthrofibrosis of the stiff TKA, ROM increased between 18.5° to 60° [2, 4, 8, 11, 13, 21, 24, 26, 28–30, 33]. At least nine of these articles reported MUA was performed in addition to arthroscopy. Therefore, this review more accurately reviews arthroscopy combined with MUA and not arthroscopy alone to treat the stiff TKA [2, 4, 8, 21, 24, 26, 28–30].

The timing of MUA seems to influence the gain in ROM in patients with a stiff TKA. The data suggest late MUA will achieve gains in knee flexion but may not be as effective as early MUA. Three articles support early manipulation [6, 9, 33]. However, the exact timing is unclear. One article states that patients who had manipulation less than 3 weeks from the index procedure had better final ROM than patients who had manipulation after 3 months from the index procedure [33]. Daluga et al. [6] support using MUA less than 3 months from the index procedure. Esler et al. [9] suggest MUA helps motion more when performed before 4 months but reported patients also had noteworthy gains in knee flexion after 4 months [9]. Scranton [24] suggested the group of patients who had manipulation before 12 weeks had a similar average gain in ROM as patients who had manipulation after 12 weeks (36° vs. 35°). However, in the early group only one of 12 patients underwent revision surgery, whereas in the late group three of seven patients had revision surgery [24]. Keating et al. reported no major difference in final knee flexion before or after 3 months [14]. The timing of arthroscopy does not seem to affect the gain in ROM for patients with a stiff TKA. Only one article examined timing of arthroscopy [2]. In an article by Bae et al., three patients treated before 6 months did better than patients treated after 6 months [2]. In the four articles in which arthroscopy was performed 1 year after the index procedure, the gains in motion were 30.8°, 33°, 34°, and 42° [2, 28–30] (Table 1). These results are comparable to the gains in ROM reported in the studies in the arthroscopy group when the arthroscopy was performed within 1 year of the index procedure [4, 8, 11, 21]. In the articles examining open arthrolysis to treat the stiff TKA, timing of surgery was poorly reported [1, 19, 33]. One article [1] stated patients had better ROM if performed within 1 year of the index procedure, but no data were reported in the article to evaluate.

The number of clinically important complications after MUA and arthroscopy were similar. There were eight complications in the MUA group. There was one complication in the arthroscopy group. There were 347 patients in the MUA group and 58 patients in the arthroscopy group. Complications were poorly reported in the articles that evaluated open arthrolysis to treat the stiff TKA (Table 2) [1, 19, 33].

Discussion

Stiffness after TKA is a common problem that does not have a well-defined treatment algorithm. The goal of this systematic review was to address three questions: (1) are there differences in the gains in ROM after MUA,

arthroscopic lysis of adhesions, and open arthrolysis in patients with arthrofibrosis after TKA; (2) does the timing of each procedure influence the gain in ROM; and (3) do the numbers of clinically important complications differ between the various procedures?

After performing this evidence-based review, it is clear that although there has been important clinical research on these modalities to improve motion in knees with arthrofibrosis after arthroplasty, the literature is incomplete. Unfortunately, there are no Level I studies on the topic and only one Level II study [9]. Without high-level studies, it is difficult to make informed treatment recommendations and we currently rely mainly on Level IV studies for our decision-making. Limitations in the current studies include poor reporting of demographic data and considerable variability in the indications for each procedure because there are no agreed-on criteria for what ROM and what time from index TKA substantiates the need for intervention (Appendices 1, 2). The techniques for performing the procedures were similar in each treatment group; however, there was considerable variability in the anesthesia used and adjunctive therapy, which may have affected results (Appendix 3). It also is difficult to tell the true value of arthroscopy to treat the stiff TKA because arthroscopy without MUA was performed in patients in only one study [11]. Furthermore, final increase in knee arc of motion was reported in flexion in some studies and ROM in some studies. For example, in the MUA group, four of the articles reported results in knee flexion, whereas three studies reported results in knee ROM (Table 1) [6, 9, 10, 14, 20, 24, 33]. In one article, it was unclear if the degrees of knee motion referred to flexion or ROM [16]. In addition, complications often were not reported or not reported clearly and failures were inconsistently defined (Table 2). In this review, we did not distinguish major from minor complications but we did list each complication for the reader to review (Table 2). Another limitation of our study is the selection bias from restricting our searches to the English language. Finally, the studies span 25 years and surgical techniques evolve and improve with time, which can affect results.

A limitation of our systematic review was the quality appraisal. We created quality appraisal forms and evaluated each study. A quantitative score was not used because of the possible flaws with this type of system. Instead we used a modified checklist. The goals of the checklist were to ensure that each study minimized methodologic error and had acceptable generalizability [18, 32]. Because we did not strictly evaluate studies by quality scores it is possible that we included studies with poor quality that would influence our results.

The final increases in knee ROM after MUA and arthroscopy (with or without MUA) are similar in patients with arthrofibrosis after TKA. Open arthrolysis provides inferior results. Arthroscopy combined with MUA may be particularly beneficial to treat flexion contracture after TKA. A flexion contracture after TKA can cause anterior knee pain and altered gait. Under normal conditions, the quadriceps muscle does not need to have sustained contraction when full extension is achieved. However, for a patient with a flexion contracture, the quadriceps must work harder. Gait analysis shows the percentage of maximum quadriceps force to achieve stability increases from 22% to 51% as a flexion contracture increases from 15° to 30° [22].

MUA to treat the stiff TKA seems to give better results when performed less than 3 months from the index procedure, although one study reported a similar increase in ROM before and after 3 months [14]. Arthroscopy (with or without MUA) seems to provide substantial increases in ROM even when performed 1 year after the index procedure. Histologic examination of tissue in arthrofibrosis shows collagen-producing fibroblastic tissue with various degrees of cellularity and vascularization. One study showed adhesive tissue matures with time by losing cells and vascularity and gaining collagen content and that most adhesive tissue organizes during the first 6 months [17]. However, the degree of loss of motion is not related to the maturity of the tissue; instead, it is related to the amount of tissue and the location of the tissue [17]. With this knowledge, it is possible that MUA is more effective during the first few months because there is less adhesive tissue in the knee. In addition, Mariani et al. postulated the less mature tissue is easier to overcome with manipulation [17]. This also may explain why arthroscopy is effective late. During arthroscopy, the surgeon is able to locate the exact tissue that is the cause of the stiffness and can lower the overall load of adhesive tissue instead of simply breaking it up with force like in MUA.

Complications from MUA often are related to the force used to manipulate the knee resulting in fracture or wound dehiscence. These complications were not seen in the arthroscopy group that had manipulation. It is possible the sample size of knees was too small to see these uncommon complications. It also is possible that the use of arthroscopy in conjunction with MUA allowed the surgeons to use less force to manipulate the knee resulting in fewer traumatic complications. Moreover, there were three hematomas in the MUA group and none in the arthroscopy group. This again could be the result of the low numbers of patients enrolled in the studies. It also could be because arthroscopy allows for hemostasis after MUA and because many authors use a drain after arthroscopy to treat arthrofibrosis of the knee. Performing arthroscopy at the time of MUA adds the potential risks of an invasive procedure such as infection and component damage. Arthroscopic PCL release also can result in knee instability [30]. Moreover,

performing arthroscopy increases anesthesia time and can be technically demanding.

The best available data provided by this review suggest that the gains in ROM after MUA and arthroscopy with or without MUA are similar in patients with arthrofibrosis after TKA. Open arthrolysis seems to provide inferior results. MUA appears more effective when performed early but still may be valuable when performed late. Arthroscopy combined with MUA seems to provide adequate improvements in ROM even when performed 1 year after the index TKA. The number of clinically important complications after MUA alone and arthroscopy with or without MUA appears similar. The optimal timing and complication rate of open arthrolysis to treat the stiff TKA is difficult to evaluate owing to limited data. High-quality randomized control trials are needed to confirm the results found in this systematic review.

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Appendix 1. Demographic data

Study	Year	Average age (years)	Male/female (number)
MUA group			
Daluga et al. [6]	1991	66	15/45
Esler et al. [9]	1999	67	18/24
Fox and Poss [10]	1981	—	—
Keating et al. [14]	2007	65	35/55
Maloney [16]	2002	—	—
Pariente et al. [20]	2006	58	14/46
Scranton [24]	2001	—	—
Yercan et al. [33]	2006	—	—
Arthroscopy group			
Bae et al. [2]	1995	—	—
Campbell [4]	1987	—	—
Diduch et al. [8]	1997	—	—
Jerosch and Aldawoudy [11]	2007	71	10/22
Johnson et al. [13]	1990	—	—
Parisien [21]	1988	60	0/1
Scranton [24]	2001	—	—
Sprague et al. [26]	1982	50	1/0
Teng et al. [28]	2002	66.3	6/5
Wasilewski and Frankl [29]	1989	—	—
Williams et al. [30]	1996	64	4/5
Yercan et al. [33]	2006	—	—
Open group			
Babis et al. [1]	2001	—	—
Mont et al. [19]	2006	56	11/6
Yercan et al. [33]	2006	—	—

MUA = manipulation under anesthesia; — data not presented or not presented clearly.

Appendix 2. Indications for each procedure

Study	Indications for procedure
MUA group	
Daluga et al. [6]	Early group (0–21 days): if patient did not achieve at least 70° flexion by the time of discharge or did not progress at satisfactory rate
	Intermediate group (22–90 days): patients discharged with 65°–75° flexion but subsequently progression stopped or had regression
	Late group (> 90 days): patients unable to achieve 80°–85° by 3 months after discharge

Appendix 2. continued

Study	Indications for procedure
Esler et al. [9]	Patients in whom maximum flexion remained less than 80° despite intensive physical therapy
Fox and Poss [10]	Patients who did not achieve 90° of comfortable active flexion by the end of second postoperative week
Keating et al. [14]	Patients who did not achieve greater than 90° flexion by 2 months postoperatively
Maloney [16]	Patients with less than 90° motion 6 weeks after index TKA
Pariente et al. [20]	Patients who had less than 90° ROM 6 weeks after TKA; patients also had previous standard manipulation under GA that failed followed by CPM in PACU and same-day discharge
Scranton [24]	Patient's progress in PT plateaued at < 90°
Yercan et al. [33]	Patients did not achieve knee flexion of 75° at the end of 10 days and/or 95° within 3 months postoperatively
Arthroscopy group	
Bae et al. [2]	Diagnosis of arthrofibrosis and failure of PT
Campbell [4]	Arthrofibrosis after TKA and PT, MUA, and CPM failed
Diduch et al. [8]	Arthrofibrosis without component malposition and not responding to PT, especially if > 3 months after TKA
Jerosch and Aldawoudy [11]	Arthrofibrosis without component malposition and not responding to PT
Johnson et al. [13]	Limited ROM after TKA
Parisien [21]	Arthrofibrosis 3 months after TKA
Scranton [24]	Patient's progress in PT plateaued at < 90°, and the patient presented > 10 weeks postoperatively; or if the manipulated knee "seemed stiff or springy"
Sprague et al. [26]	Patient who had TKA with knee flexion < 90° and PT failed
Teng et al. [28]	Painful limitation of ROM after TKA
Wasilewski and Frankl [29]	Diagnosis of arthrofibrosis without component malposition
Williams et al. [30]	Stiff and painful posterior cruciate-retaining TKA with appropriate mechanical alignment
Yercan et al. [33]	Arthroscopy performed in patients who did not respond to MUA (indications for MUA: patients did not achieve knee flexion of 75° at the end of 10 days and/or 95° within 3 months postoperatively)
Open group	
Babis et al. [1]	Severe knee stiffness after TKA; no infection and no mechanical problem with TKA
Mont et al. [19]	Stiffness (< 90° knee flexion) after TKA without malalignment or infection
Yercan et al. [33]	Patients who did not respond to MUA with no malalignment or infection (indications for MUA: patients did not achieve knee flexion of 75° at the end of 10 days and/or 95° within 3 months postoperatively)

MUA = manipulation under anesthesia; ROM = range of motion; GA = general anesthesia; CPM = continuous passive motion; PACU = postanesthesia care unit, PT = physical therapy.

Appendix 3. Technique-related variables

Study	Technique	Anesthesia	PCL release	MUA	Adjunctive therapy
MUA group					
Daluga et al. [6]	After muscle relaxation with succinylcholine, hip and knee flexed to goal of at least 100° knee flexion	GA	—	Y	CPM for 24 hours, Ice, PT
Esler et al. [9]	After stabilizing the thigh and lower leg, a steady force was applied to the proximal tibia to a goal of at least 90° knee flexion	GA	—	Y	CPM for 24 hours
Fox and Poss [10]	After muscle relaxation with succinylcholine, the hip is flexed to 90°, then the knee is flexed to a goal of the final intraoperative flexion gained at the initial TKA	GA	—	Y	PT, ice

Appendix 3. continued

Study	Technique	Anesthesia	PCL release	MUA	Adjunctive therapy
Keating et al. [14]	The patient's hip is flexed to 90°, then the knee is manipulated into flexion until audible and palpable lysis of adhesions is complete	GA	—	Y	PT, ice, epidural catheter for 24 hours (22 patients)
Maloney [16]	The patient's hip is flexed and steady pressure is applied to the tibia until a firm end point is reached	GA	—	Y	CPM, PT, intraarticular bupivacaine
Pariente et al. [20]	Patient given epidural anesthesia, manipulation is performed; epidural is continued for CPM and PT as inpatient for up to 3 days	Epi	—	Y	Continuous epidural anesthesia, CPM, PT, intraarticular anesthesia
Scranton [24]	After muscle relaxation with succinylcholine, hip and knee flexed to goal 120°	GA	—	Y	CPM, PT, intraarticular Marcaine and Depo-Medrol
Yercan et al. [33]	—	—	—	Y	Splint at 90°, CPM, PT
Arthroscopy group					
Bae et al. [2]	Standard technique; authors also used 5- and 8-mm blunt metal bars to aid in adhesiolysis	GA or SA	—	Y	100° flexion splint postoperative, PT
Campbell [4]	Standard technique; arthroscopic lateral release	GA	—	Y	CPM
Diduch et al. [8]	Standard technique	—	PS	Y	—
Jerosch and Aldawoudy [11]	Standard technique; arthroscopic medial and / or lateral release if patellar malalignment	GA with femoral nerve catheter	—	N	Postoperative femoral catheter, CPM, PT
Johnson et al. [13]	Standard technique	GA or RA	—	—	CPM, PT
Parisien [21]	Standard technique; arthroscopic lateral release	GA	—	Y	CPM, PT, ice
Scranton [24]	Standard technique with 5.5-mm shaver	—	Y	Y	CPM, PT, intraarticular bupivacaine and cortisone
Sprague et al. [26]	Standard technique; arthroscopic lateral release	GA or RA	—	Y	PT
Teng et al. [28]	Standard technique; arthroscopic lateral release if patellar malalignment	SA or GA	Y	Y	CPM, PT
Wasilewski and Frankl [29]	Standard technique; arthroscopic lateral release	—	—	Y	CPM, PT
Williams et al. [30]	Standard technique	—	Y	Y	PT
Yercan et al. [33]	Standard technique	—	PS	—	—
Open group					
Babis et al. [1]	Synovectomy, removal of scar tissue, lateral retinacular release; liner exchange	Epi	—	—	Epidural catheter for 48 hours, PT, CPM
Mont et al. [19]	Synovectomy, contracture release, excision of scar tissue, lysis of adhesions. Liner exchange in 10/18.	—	—	—	CPM, ice, aggressive PT, CKD, ES

Appendix 3. continued

Study	Technique	Anesthesia	PCL release	MUA	Adjunctive therapy
Yercan et al. [33]	Removal of scar tissue preventing motion between the femur and quadriceps mechanism; recreation of medial and lateral gutters and evacuation of the posterior capsule	—	—	—	—

PCL = posterior cruciate ligament; MUA = manipulation under anesthesia; GA = general anesthesia; Y = yes; CPM = continuous passive motion; PT = physical therapy; Epi = epidural anesthesia; SA = spinal anesthesia; PS = posterior cruciate-sacrificing knees were used at initial TKA; N = no; RA = regional anesthesia; CKD = customized knee device (a knee brace that forces the knee into flexion or extension); ES = electrical stimulation; — = data were not presented or not clearly presented.

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