Lack of evidence to support present medial release methods in total knee arthroplasty

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Abstract

Purpose   The aim of this review was to identify a reliable sequential medial release protocol for restoration of soft tissue balance in total knee arthroplasty of the varus osteoarthritic knee and to allow for improved intraoperative decision-making.

Method   Current medial release sequences and applicability based upon pre-operative deformity have been reviewed. Furthermore, risks associated with over release, and the necessity of medial release, are discussed.

Results   The different medial release sequences are discussed in relation to pre-operative deformity, along with potential complications associated with medial release. It was found that release sequences may include the deep and superficial components of the medial collateral ligament, the posteromedial capsule, the posterior oblique ligament, the pes anserinus (pes A), and tendons of the semi-membranosus and medial gastrocnemius muscle. The sequences described were found to vary substantially between studies, and very few studies had systematically quantified the effect of each release on balance.

Conclusion   While medial release is the standard intraoperative mode of balancing, there is a lack of evidence to support current methods. The correct method for defining intraoperatively the sequence, extent and magnitude of releases required remains ill-defined. It could be argued that the classic extensive medial release may be unnecessary and may be associated with iatrogenic injury to the pes A and saphenous nerve, instability and abnormal knee kinematics. Minimal medial release may allow for improved soft tissue balancing leading ultimately to improved functional outcome.

Level of evidence   V (expert opinion).

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Introduction

Total knee arthroplasty (TKA) is the standard treatment for symptomatic late-stage osteoarthritis (OA) [57]. In varus OA knees, TKA often involves the release of the medial structures in order to realign the leg and also achieve balance [13, 14, 45, 46]. Correct soft tissue balance is essential to the success of TKA surgery [59, 63].

A knee can be described as 'balanced' when the normal motion of the knee is not hindered by the soft tissue constraint, so that normal knee motion (kinematics) is allowed by the soft tissue envelope [29, 62]. Sufficient tension should be present to provide stability, while excessive compression of

Fig. 1 Posteromedial view of a right knee, demonstrating the medial attachments of **a** muscles and **b** ligamentous tissues. *pes A* pes anserinus, the insertion point of the tendons on the tibia of the sartorius, gracilis and semitendinosus (SemiT) muscles. *SemiM* semimembranosus muscle, *sMCL* superficial medial collateral ligament, *dMCL* deep medial collateral ligament, *POL* posterior oblique ligament, *PMC* posteromedial capsule
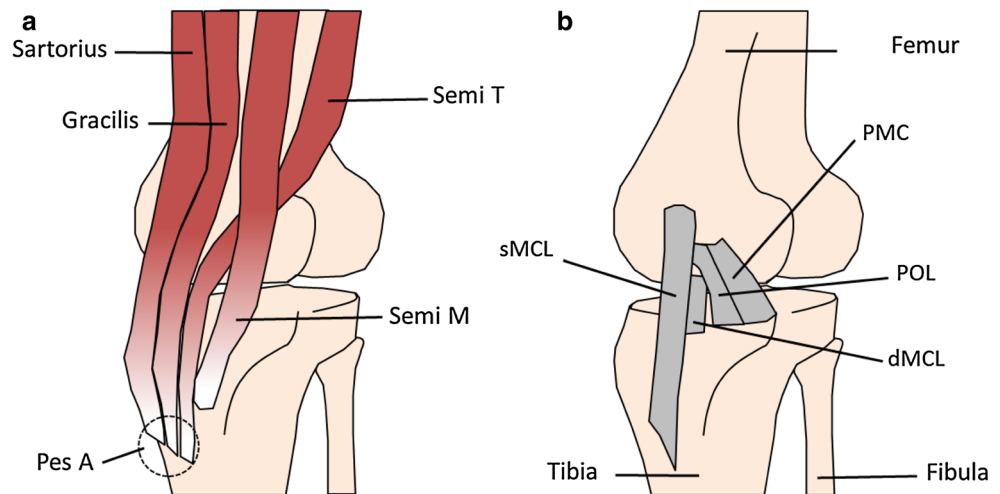
the polyethylene component is avoided [56]. Incorrect soft tissue balancing can result in a number of complications, including instability, abnormal polyethylene wear, aseptic loosening, altered patellofemoral biomechanics and pain [6, 7, 32]. While medial release is the standard intraoperative mode of balancing, its frequency, sequence and extent is often not reported, but according to studies by Aunan et al. [6], Whiteside et al. [63] and Griffin et al. [23], it is necessary in 78, 76 and 88 % of OA varus knees, respectively.

The medial stabilising structures include the deep and superficial components of the medial collateral ligament (dMCL and sMCL), semimembranosus (SemiM), pes anserinus (pes A), posteromedial capsule (PMC) and the posterior oblique ligament (POL). Many cadaveric dissections showing the anatomy of these structures have been published, for example [17, 36, 52, 58]. In Fig. 1, the locations of medial stabilising structures are outlined. The biomechanical importance of these structures has been discussed in a number of studies [5, 24, 26, 52, 58, 65].

The purpose of this literature review was to identify a reliable method to ensure appropriate medial release for varus OA knees. In doing so, current concepts of surgical sequence and techniques based upon pre-operative deformity are reflected on. Potential complications associated with medial releases are also discussed.

The aim of this review was to allow for improved intraoperative decision-making in primary resurfacing of OA varus knees so that soft tissue balance is achieved. A minimal medial release should contribute to optimised knee kinematics with improved clinical outcome.

Materials and methods

A literature review of different methods for medial release in primary TKA surgery for OA knees was

conducted. The search terms included 'total knee arthroplasty' and 'total knee replacement' along with 'balance', 'medial release', 'soft tissue release', 'ligament balancing', 'varus' and 'osteoarthritis'. The articles included were those involving primary total knee arthroplasties, published in English from 1999 to 2013 based on either biomechanical or clinical studies. Pub-Med, Science Direct, and Web of Knowledge databases were used. To prevent publication bias, search engines Google and Google Scholar were also used to find any additional articles that may have been missed out on during the search. Initially, all abstracts that discussed medial release/balancing in primary total knee replacement were identified. Accumulated articles were scrutinised by the authors. Certain studies were then rejected based on reporting insufficient data, non-standardised scoring systems and lack of precise methods. The reference lists of the articles that had been included were then hand searched to retrieve citations to articles that may have been missed by the search to add to the database, and those articles were then subjected to assessment under the same inclusion criteria. In total, 30 publications were identified.

Results

Quantification of release

The methods employed to assess the effect of medial releases on the balance of the knee were very variable. Only six studies were found in which the impact of each release step had been quantified sequentially [13, 18, 37, 39, 63, 66] (Table 1). Of these studies, four were cadaveric [18, 37, 39, 63] and two were clinical [13, 66]. Four studies assessed balance according to medial and lateral joint gaps

Table 1 Studies assessing balance intraoperatively after each release step

Studies	Balance assessment technique	Measurement device	Sample size (knees)	Cadaveric/clinical	Angles of flexion considered (°)
Chen et al. [13]	Joint gap measurement	Knee balancer	100	Clinical	0, 90
Yagishita et al. [66]		Laminar spreader-like device with torque meter	45		
Luring et al. [37]		Navigation and tensor device	10	Cadaveric	
Matsueda et al. [39]		Callipers	8		
Crottet et al. [18]	Contact forces	Force-sensing device	6		0, 30, 60, 90
Whiteside et al. [63]	Valgus and rotational laxity	Custom testing device	8		

in flexion and extension [13, 37, 39, 66], whereas the remaining two cadaveric studies assessed balance at 0°, 30°, 60° and 90° flexion using either a force-sensing device to assess changes in medial contact forces [18] or a custom testing device in order to assess the effect of each release on valgus and rotational laxities [63].

Most studies assessed the overall effect of the employed number of releases deemed appropriate according to the final alignment or flexion and extension gaps, as summarised in Table 2. All studies shown in Table 2 were clinical and involved between 30 [42] and 359 knees [61]. Ten studies assessed balance according to post-operative alignment [8, 20, 27, 33, 43, 45, 46, 49, 51, 61]. In five of these studies, the overall effect of releases was reported which did not allow for the effect of individual release stages to be determined. Verdonk et al. [61], however, reported alignment changes according to releases performed, allowing the effect of different releases to be determined. Koh and Yong [33] showed the overall effect of releases on the change in alignment for all knees grouped together, but also demonstrated the effect of the semiM release individually according to the change in medial and lateral joint gaps at 0°, 45° and 90° flexion so that the impact of this step could be determined.

Two studies reported final alignment as determined by navigation intraoperatively [27, 51]. Picard et al. [51] showed the change in knee alignment according to the extent of release performed, allowing effects of different releases to be determined to some extent, whereas the study by Hakki et al. [27] only reported improvement in alignment for all knees grouped together, so the effect of each release cannot be determined.

The effectiveness of medial release sequences were determined by assessing final joint gaps in six studies [2, 14, 23, 33, 40–42]. In most instances, this was determined intraoperatively [27, 51], whereas one study made the assessment post-operatively using radiology [2]. In all of these studies, knees were not grouped according to the extent of release performed, so the effect of different steps cannot be determined.

Comparison of medial release sequences

Cadaveric biomechanical studies

In total, four cadaveric biomechanical studies were found in which the effect of medial release on soft tissue balance after TKA implantation was determined. The release sequences examined in these studies are summarised in Table 3.

The release sequences employed by Luring [37] and Matsueda [39] were identical (Table 3), showing the effect of increasing the anteriomedial sleeve, releasing the PMC and semiM then the MCL and both partial and full release of the PCL on the joint gaps at 0° and 90° flexion in a total of 18 cadaveric knees with CR-TKAs. A stepwise release of the sMCL starting at the tibial joint line (as is described in most methodologies) was extended distally by subperiosteal elevation to eventually completely release the sMCL. The procedure was performed on unloaded cadavers with no evidence of arthritis, and therefore, only static constraints to medial stability were assessed in normal tissues. With a valgus moment applied, complete sMCL release resulted in a 12° change in knee alignment, 9 mm increase in the medial gap and no change in the lateral gap. Adding an entire release of the PCL added only 2° more valgus. Although releases of these structures are employed clinically, this specific sequence has not been employed.

Crottet et al. [18] assessed balance using a force-sensing device placed within the six knees at 0°, 30°, 60° and 90° flexion after release of a third of the MCL attachment and then two-thirds of the MCL attachment. Minor and major MCL releases were found, on average, to reduce medial contact force by 20 and 46 %, respectively, at full extension. Releases had greater effects on medial contact force reduction at 0° and 90° flexion, compared with 30° and 60°. The authors also found large variation among specimens, reflecting the difficulty of ligament release.

Whiteside et al. [64] assessed the effect of each release on both valgus and rotational laxity at 0°, 30°, 60° and 90° flexion in eight knees with CR-TKAs. They released either

Table 2 Studies assessing balance after final release; intra- or post-operatively

Studies	Balance assessment technique	Measurement device	Sample size (knees)	Angles of flexion considered (°)
Mullaji et al. [46]	Post-operative alignment	Radiography	117	0
Moon et al. [45]			143	
Bellemans et al. [8]			35	
Engh and Ammeen [20]			70	
Verdonk et al. [61]			359	
Orban et al. [49]			60	
Meftah et al. [43]			31	
Picard et al. [51]	Intraoperative alignment	Navigation	81	0
Hakki et al. [27]			66	
Koh and Yong [33]	Final joint gaps and post-operative alignment	Distractor device and radiology	104	0, 45, 90
Griffin et al. [23]	Final joint gaps	Ruler	63	0, 90
Chon et al. [14]		Knee balancer	72	90
Ahn and Back [2]		Radiography	40	0, 90, 130
Matsumoto et al. [41]		Tensor device and navigation	120	0, 90
Matsumoto et al. [42]			30	
Matsumoto et al. [40]		Tensor device	60	0, 10, 45, 90, 135

All studies were clinical

the anterior or posterior fibres of the MCL first, followed by the posterior capsule. Release of the oblique portion of the MCL (performed in four knees) caused a significant increase in valgus laxity at full extension (3.4°) and 30° flexion (3.6°) but not 60° and 90° flexion. Rotational laxity increased significantly only at 0° and 30° flexion, by 1.2° and 4.4°, respectively. Subsequent additional release of the anterior portion of the MCL significantly increased valgus laxity at all angles; however, the increase was more pronounced at 60° and 90° (7.9° and 7.2°, respectively) than at 0° and 30° flexion (2.4° and 2.6°, respectively), and rotational laxity was significantly increased at all angles, by 3.7°–5.5°. In the remaining four knees, the anterior portion of the MCL was released first, which was seen to significantly increase valgus laxity at 60° and 90° flexion (6.4° and 7.7°, respectively) but not at 0° and 30°. Rotational laxity was only significantly increased at 60° and 90° flexion, by 11.6° and 15.2°, respectively. In these four knees, the posterior oblique portion of the MCL was subsequently released, which significantly increased valgus laxity throughout the flexion arc, with increases of 5.1°, 8.2°, 5.7° and 5.0° at 0°, 30°, 60° and 90° flexion, respectively. Rotational laxity was also significantly increased throughout 0°–90° flexion, by 2.3°–5.2°. Additional release of the posterior capsule significantly increased valgus laxity by 5°–8.2° and rotational laxity by 2.8°–5° throughout 0°–90° flexion. PCL release significantly increased valgus laxity at all angles of flexion, although more so at 60° and 90° than at 0° and 30° flexion.

PCL resection also significantly increased rotational laxity by 8.7°, 5.6°, 10.5° and 12.1° at 0°, 30°, 60° and 90° flexion, respectively.

Clinically applied medial release sequences

Table 4 includes medial releases sequences which have been reported for clinical application. Three commonly described releases which are employed by the authors (DJD and LML) are illustrated in Fig. 2. These are the elevation of the pes A (a), release of the dMCL (c) and sMCL (e) from the tibial attachments. The step at which these releases are used, and the number of other releases used within sequences, however, can vary, as illustrated in Table 4. Table 4 also illustrates the variable level of detail provided by authors on the release procedure.

Sequences described by Engh [21], Burke and O'Flynn [12] and Bottros et al. [10] were not based on experimental data presented within these papers, but can be assumed to be based on previous work conducted by the authors. All other protocols presented in Table 4 were demonstrated in clinical studies involving OA varus knees.

Chon et al. [14] described a minimal release involving only the PMC, dMCL and a portion of the sMCL. This clinical study involved 72 knees, of which 61 had OA. The pre-operative varus alignment and the correction achieved were not given, but the authors stated that 'severe' deformities had been excluded. The authors indicated that positioning of implants according to size could eliminate the need for more

Table 3 Summary of soft tissue release sequences investigated in cadaveric biomechanical studies

Studies	Soft tissue release sequence
Crottet et al. [18]	1. 1 of 3 of MCL bone attachment released
	2. 2 of 3 of MCL bone attachment released
Whiteside et al. [63]	*CR-TKA*
	1. sMCL (tibial insertion)—(a) anterior fibres 1st if knee tight in flexion, or (b) posterior fibres 1st if knee tight in extension
	2. Posterior capsule
Matsueda et al. [39], Luring et al. [37]	*CR-TKA*
	1. Anteromedial tibial sleeve 2 cm below the joint line (in horizontal direction posteriorly to the popliteus muscle)
	2. PMC and semiM (tibial attachment)
	3. Anteromedial tibial sleeve 4 cm below joint line
	4. Anteromedial tibial sleeve 6 cm below joint line
	5. MCL—from tibia then femoral attachment
	6. PCL—medial half (tibial attachment)
	7. PCL excised (tibial attachment)

ACL excision always first so therefore not included. Bone cuts and removal of osteophytes and meniscus omitted for simplicity

extensive medial releases to achieve balanced medial and lateral flexion gaps. To achieve a perfect rectangular space in flexion for pre-existent OA deformity, the authors found that the femoral component should be externally rotated an additional 2° referencing from Whiteside's line. This effect was less with larger femoral components.

Yagishita et al. [66] described a more extensive serial release protocol than Chon et al. [14] with the addition of a PCL resection prior to medial releases for PS-TKA, or a partial release at the end when a CR-TKA was used, with additional release of the semiM and medial capsule along with the PMC and dMCL, and subsequent more extensive releases of the MCL. These releases were applied to 45 varus OA knees, of which 28 had 'mild' varus deformity (<10°), and 17 'severe' (10°–18° varus). The magnitude of effect between different steps was very variable, both within mildly and severely varus knees and between the two groups. PMC release had a greater effect on severely than mildly varus knees, whereas PCL release affected mildly varus knees more. Furthermore, the differential effects of different structures in flexion and extension were highlighted. The PCL had a greater effect in flexion, and the MCL release significantly affected the medial gap in both extension and flexion. Balance was assessed by comparing medial and lateral gaps in flexion and extension. Poor balance (a difference of >5 mm) was reported in

7–29 % of knees, depending on the comparison that was made, with the greatest difference being seen between medial and lateral gaps in extension (29 %) [66]. No details of post-operative follow-up were reported to help understand method effectiveness.

Moon et al. [45] described a fairly conservative medial release sequence which was applied to 143 varus OA knees undergoing PS-TKA surgery, with varus deformity of 5°–28.1°. The PCL was resected, then the dMCL released prior to either sMCL or semiM release. This contrasts with the method of Yagishita et al. [66] whereby the semiM was always released prior to any sMCL release. An intraoperative mechanical axis alignment within ±3° of neutral alignment was achieved. In these knees, the pre-operative alignment, range of motion (ROM) and contracture were 5°–28.1°, 95°–150° and 0°–25°, respectively. They reported that the degree of pre-operative deformity influenced the reducibility of varus deformity, and that correct component positioning can minimise medial release requirement, in agreement with other studies [14].

Matsumoto et al. reported the use of the same medial release sequence, involving release of the PMC followed by MCL, then semiM and finally the pes A in three different studies [40–42] published in 2009, 2011 and 2013 involving 30, 60 and 120 knees, respectively, where a CR- or PS-TKA was used. For PS-TKA, the PCL was released prior to any medial releases, in agreement with Yagishita et al. [66] and Moon et al. [45]. In the 2013 study [41], with the largest sample number, the method was applied to knees with pre-operative varus deformity of $10.9 \pm 4.8°$ in the CR group and $9.3 \pm 7.8°$ in the PS group. The joint component gaps and ligament balance were measured at 0°, 10°, 30°, 60°, 90° and 120° flexion. The authors found 68.7 % of CR-TKAs (55/80) and only 30 % of PS-TKAs (12/40) had equalised rectangular gaps at extension and flexion, defined as having differences within ±3 mm between extension and flexion gap and within ±3° ligament balance at extension and flexion. Post-operative follow-up was not included, so the long-term impact of imperfect flexion gaps cannot be discerned. The frequency with which each release step was required was not stated in any of these three studies [40–42].

Mullaji et al. [46] reported an extensive medial release sequence which they applied to 173 severely varus knees (15°–62° varus), of which 155 had OA. This protocol allowed for the improvement of mean tibiofemoral (TF) angle from 23° varus pre-operatively (range 15°–62°) to 5° valgus (range 2°–9°) post-operatively, with 86 % of patients considered to have an acceptable alignment of 4°–10° valgus, with 25 patients remaining in 'slight' varus. Mean Knee Society score (KSS) improved from 23 (range 0–64) to 91 (range 52–99), and functional score (FS) from 23 (range 0–64) to 72 (range 5–100) at 2.6 years (range

Table 4 Summary of soft tissue release sequences described in the literature which have been employed in clinical practice for medial release in primary TKA of the osteoarthritic knee

Publication	Details of release sequences
Burke and O'Flynn [12]	*CR- and PS-TKA*
	1. dMCL—subperiosteally
	2. sMCL
	3. Pes A
	4. PMC
	5. Medial gastrocnemius muscle origin
Bottros et al. [10]	*CR- and PS-TKA*
	Moderate varus
	MCL only
	Severe varus
	1. Pes A
	2. dMCL (tibial insertion)
	3. PMC
	4. PCL excised (if PS-TKA)
	5. sMCL—medially and posteriorly, subperiosteally
Chon et al. [14]	*TKA type not defined*
	sMCL, dMCL and PMC
Yagishita et al. [66]	*CR- and PS-TKA*
	1. PCL sacrificed (if PS-TKA)
	2. PMC, medial capsule, dMCL, and semiM
	3. sMCL—tibial insertion at 8–10 cm distal to medial joint (scalpel)
	4. MCL—gradual transverse cut of tight portion at joint line (electrode)
	5. PCL—partial release (if CR-TKA)
Moon et al. [46]	*PS-TKA*
	1. PCL sacrificed
	2. dMCL
	3. (a) sMCL—subperiosteal (using periosteal elevator), or (b) semiM (tibial insertion)
Matsumoto et al. [40–42]	*CR- and PS-TKA*
	1. PCL sacrificed (if PS-TKA)
	2. PMC
	3. MCL
	4. SemiM
	5. Pes A
Mullaji et al. [46]	*PS-TKA (varus of >20°)*
	1. PCL sacrificed
	2. dMCL, PMC, and semiM—subperiosteally to midline posteriorly along upper tibia
	3. sMCL—subperiosteally
	4. Pes A (detailed description given)
Whiteside et al. [63, 64]	*CR-TKA*
	1. sMCL (tibial insertion)—(a) anterior fibres 1st if knee tight in flexion, or (b) posterior fibres 1st if knee tight in extension
	2. Posterior capsule
Engh 2003 [21]	*CR- and PS-TKA (severe varus)*
	sMCL and dMCL—progressive release of tight fibres at joint line (using cautery)

Table 4 continued

Publication	Details of release sequences
Chen et al. [13]	*PS-TKA*
	1. PCL sacrificed
	2. dMCL and PMC
	3. sMCL—according to Whiteside [64]
	4. Pes A
	5. SemiM
Hakki et al. [27]	*Deep-dish TKA (for use in PCL presence and absence)*
	1. (a) Tight in extension: (i) PMC then (ii) MCL posterior fibres or (b) tight in flexion: MCL anterior fibres
	2. PCL sacrificed
Griffin et al. [23]	*PS-TKA*
	SemiM and MCL—by medial subperiosteal peel from tibia (according to Insall [29])
Picard et al. [51]	*CR- or PS-TKA*
	Moderate releases
	1. dMCL, sMCL pes A—by medial tibial subperiosteal elevation
	2. SemiM—from posterior medial corner and deep fascia of soleus
	Extensive releases
	3. PCL sacrificed (if PS-TKA)
	4. Capsule—subperiosteal elevation increased posteriorly and distally
	5. Posterior capsule further released—subperiosteally from femur and tibia
	(according to Krackow and Insall [32, 51, 62])
Engh [21]	*CR- and PS-TKA (severe varus)*
	1. sMCL—subperiosteal elevation to Pes A insertion
	2. Medial capsule—subperiosteal elevation increased anteriorly and distally
	3. sMCL—detached completely from tibia
	4. Pes A—subperiosteally from tibial
	5. SemiM—subperiosteally from tibial
	6. Posterior capsule—from top of tibia
	7. Posterior capsule—from back of the femur
Bellemans et al. [9]	*PS-TKA*
	1. PCL sacrificed
	2. dMCL and sMCL—needle punctures (19-gauge needle) in tensed MCL every 3–5 mm, proximodistal and anteroposterior
Verdonk et al. [61]	*PS-TKA*
	1. PCL sacrificed
	2. dMCL
	3. (a) sMCL—by 'pie-crusting' or (b) periosteally distal to the joint line (knife or periosteal elevator used)
Meftah et al. [43]	*PS/semi-constrained TKA*
	1. PCL sacrificed
	2. PMC released (by electrocautery) at the level of the tibial cut, to the posterior margin of the sMCL
	3. sMCL—incised tight bands of in a 'pie-crust' manner
Koh and Yong [33]	*PS-TKA*
	1. PCL sacrificed
	2. dMCL
	3. semiM
	4. sMCL—'pie-crusting'

Table 4 continued

Publication	Details of release sequences
Engh and Ammeen [20]; Engh [21]; Orban et al. [49]	*CR- and PS-TKA*
	MCL—osteotomy of the femoral attachment
Ahn and Back [2]	*PS-TKA (≥10° varus)*
	All
	1. Subperiosteal layer 1 cm distally and posteromedially from capsular tibial insertion
	Group 1
	2. Extended release ≥1 cm distally
	3. (a) If tight at 0°: dMCL and PMC or (b) if tight at 90°: sMCL and the anteromedial capsule
	Group 2
	4. Osteotomy of proximal medial tibia in 2 mm increments

ACL excision always first so therefore was not included. Standard bone cuts to remove the femoral and tibial surfaces to allow resurfacing and removal of osteophytes and meniscus were also omitted for simplicity

Pes A pes anserinus, *SemiM* semimembranosus, *sMCL/dMCL* superficial/deep medial collateral ligament, *PMC* posteromedial capsule, *PCL* posterior cruciate ligament, *CR/PS-TKA* cruciate retaining/posterior stabilising total knee arthroplasty

2–9 years). As would be expected in such severely deformed knees, some complications were observed, including three cases of varus recurrence with tibial component loosening, and two cases of post-operative patellar fracture. The release sequence used [46] was similar to Yagishita et al. [66] from PCL to sMCL release for PS-TKAs. However, after release of the sMCL, the pes A was released by Mullaji et al. [46] whereas Yagishita et al. [66] never released the pes A.

Whiteside et al. [63] reported successfully using the release of either the anterior or posterior fibres of the MCL first, according to whether flexion or extension contracture existed, followed by the release of the posterior capsule as demonstrated in their cadaveric study [63] (Tables 1, 2) to balance 62 patients' knees in which a CR-TKA was used; 22 knees required release of the posterior oblique portion of the MCL alone to correct balance, 31 required release of only the anterior portion of the MCL and nine knees required complete release of the MCL. The remaining three knees required additional release of the posterior capsule to correct balance and 17 required PCL release to prevent excessive femoral rollback. No measurements of balance for the clinical cases were, however, reported.

Whiteside's MCL releases [63, 64] were also employed by Chen et al. [13] in 100 knees receiving PS-TKAs, as part of a more extensive protocol. MCL releases were performed after resection of the PCL and partial releases of the dMCL and PMC. The pes A followed by the semiM was then released if balance had not been achieved. The authors found release of the pes A to be necessary in 27 % of the knees and the subsequent release of the semiM in only 8 % of the knees. Chen et al. [13] reported the effect of each release step on joint gaps at 0° and 90° knee flexion. The authors highlighted the significantly different
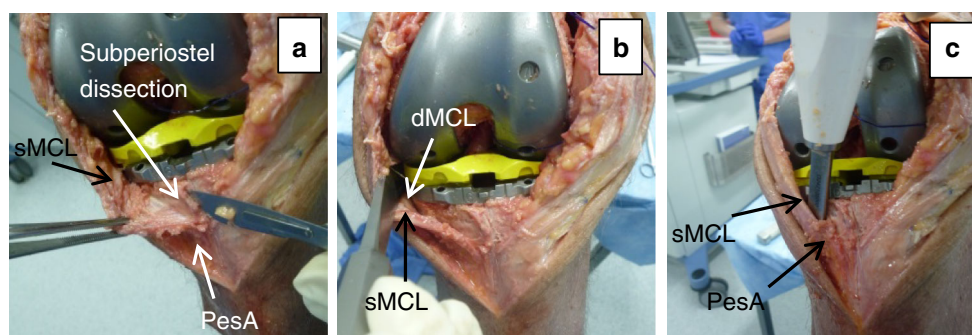
Fig. 2 Commonly employed medial releases (shown on a left knee). **a** Elevation of the anterior superior window of the Pes A from the tibia starting at the midline and working medially. **b** Release of the deep component of the MCL (dMCL) with a Cobb elevator to a depth of 1–2 cm from the joint line (which can be extended posteriorly to as far as the insertion of the semimembranosus tendon). **c** Release to a depth of 10–12 cm (as per Whiteside et al. [63]) with a straight elevator of the superficial MCL (sMCL) while preserving the tibial attachments of the semitendinosus and gracilis tendons

effects that each of their medial releases had between flexion and extension, with the total effect of medial soft tissue releases being significantly larger in flexion than in extension ($4.9° \pm 3.2°$ vs. $3.0° \pm 2.0°$), with the exception of the posterior fibres of the sMCL. Following this protocol, the authors changed the mean joint alignment from $5.1°$ varus to $4.4°$ valgus.

Hakki et al. [27] also released the MCL according to Whiteside's method [59, 60]. However, in contrast to Chen et al. [13], the PMC was released after the MCL, and the PCL was excised only if PMC and MCL releases were insufficient to correct imbalance, rather than as the first release [13] since a deep-dished TKA suitable for use in knees with and without a PCL was used [27]. Only 10 of 66 knees with pre-operative varus of $\leq 18°$ required MCL release, with bone resection and prosthesis placement and PMC release being sufficient to gain a mechanical axis within $0° \pm 2°$ in the remaining 56 knees. No details regarding post-operative follow-up were reported to help understand method effectiveness.

Engh [21] also described a protocol in which tight portions of the dMCL and sMCL were selectively released, but in contrast to Whiteside et al. [63, 64], this was done only in extension and usually only involved the central third of the MCL. Engh [21] also emphasised that using this method, the POL and PMC must be preserved to provide residual stability to the medial side of the knee, whereas Whiteside et al. [63, 64] included release of the posterior capsule and Chen et al. [13] and Hakki et al. [27] included release of the PMC.

Griffin et al. [23] described the use of the 'subperiosteal peel' which was extended to the required magnitude, as originally described by Insall [30] to be a progressive skeletonisation to the insertion of the pes A tendon distally and beyond dMCL and semiM insertions posteriorly [31]. The authors used the method on 63 OA varus knees ($2°$–$12°$ varus) within a cohort of 104 knees undergoing PS-TKA surgery. Medial release was considered necessary in 56 of 63 varus knees. Clinically, all knees appeared to be perfectly balanced intraoperatively, but measurement of medial and lateral gaps under maximal tension at $0°$ and $90°$ flexion revealed only 4 of 63 pre-operatively varus knees were perfectly balanced. Rectangular flexion and extension gaps within 1 mm were obtained in >80 % of knees, and none of the extension gaps were >3 mm from being perfectly rectangular, and the lateral gap was usually larger than the medial gap. Equality of the flexion and extension gaps (≤ 1 mm) was only observed in ~ 50 % of knees and cases of >3 mm differences were frequently observed. Extension gaps were generally larger than flexion gaps, which the authors suggest can help prevent at least flexion contracture and flexion instability post-operatively.

Medial release by subperiosteal peel [55, 67] has also been employed by Engh [21] and Picard et al. [51]. Picard et al. [51] described using the method to perform either 'moderate' or 'extensive' releases involving the dMCL, sMCL, pes A and semiM, followed by the release of the PCL and/or the further skeletonisation of the tibia and femur. The authors firstly analysed the final alignment achieved intraoperatively in 46 OA knees after primary CR-TKA, according to pre-operative alignment and releases performed. From this, they developed an algorithm which was validated on a further OA knees, whereby a deformity of $\leq 2°$ required no release (only standard medial approach [3, 47]), $2°$–$5°$ required moderate medial release and $>5°$ required extensive medial release.

Most medial release sequences involve MCL release from the tibial attachment [10, 12, 23, 51]. A few studies did, however, employ other techniques, including osteotomy of the femoral or tibial attachments of the MCL [2, 20, 21, 49] and 'pie-crusting [33, 61] or needle-puncturing [9] the MCL.

A 'pie-crusting' technique has been used by Neyret's group [61] to release the sMCL, whereby multiple small horizontal incisions are made in the sMCL, with selective release of anterior or posterior fibres according to tightness in flexion or extension, respectively, according to Whiteside et al. [63, 64]. This procedure was used in a stepwise medial release, following PCL resection and dMCL release and prior to complete release of the sMCL from its distal attachment, depending on the alignment correction required, with means of $6°$, $8°$ and $11°$. Out of 359 patients, 255 required only capsular and dMCL releases, 87 had pie-crusting of the sMCL and 17 required full distal release of the MCL; the authors found no significant differences in the final alignment. Meftah et al. [43] also demonstrated the potential effectiveness of sMCL pie-crusting in 34 knees with $>15°$ varus and flexion contracture of $>5°$ using either a PS- or semi-constrained TKA. The sMCL was released after PCL sacrifice and PMC release to correct flexion contracture. Post-operative follow-up up to 4.9 years showed coronal alignment improved from $21.1° \pm 4°$ varus to $4.5° \pm 1.6°$ valgus, mean ROM improved from $103.3° \pm 14.1°$ to $119.1° \pm 8°$, mean KSS pain subscore improved from 39.5 ± 12.6 to 93.2 ± 10.5 and the FS improved from 47.1 ± 17.8 to 78.5 ± 21.9. No evidence of implant loosening or osteolysis, over release of the MCL or instability was observed. Meftah et al. did not, however, include a control group for comparison.

'Pie-crusting' of the sMCL was also used by Koh and Yong [33]. Stepwise release of PCL, dMLC, semiM was applied prior to sMCL release to 104 OA knees with a mean pre-operative varus deformity of $4.6°$ (range $0°$–$19.3°$ varus), receiving a PS-TKA. Compared with the study by Verdonk et al. [61], an additional semiM release

prior to pie-crusting of the sMCL was applied. Out of 104 knees (70.2 %), 73 were balanced after dMCL release and bone cutting alone. Out of 104 knees (29.8 %), 31 had residual medial tightness after dMCL release of which 24 knees were balanced after the semiM release, and the remaining 7 of 104 (6.7 %) required sMCL release. All medial releases were needed to balance the most severely varus knee with a post-operative varus of 19.3° varus. However, semiM release was needed in knees with as little as 0.1° pre-operative varus and additional sMCL release in as little as 3.2° pre-operative varus. The authors were particularly interested in the effect of the semiM release, which was found to significantly increase medial gaps at 0°, 45° and 90° flexion, by 1.5 ± 1.60, 2.00 ± 1.6 and 2.3 ± 1.3 mm, respectively. The lateral gaps were also significantly increased after semiM release except in full extension, whereby gaps increased by 0.5 ± 1.8, 1.1 ± 2.1 and 1.4 ± 1.6 mm, respectively. Patients' outcomes up to 12 months post-operative were reported. All patients showed valgus knee alignment on standing AP radiographs (mean; 6.1° valgus, range; 0.1°–12.7° valgus). The mean KSS improved from 39 (range 20–60) pre-operatively to 93 (range 57–100), mean KSS FS from 53 (range 25–70) pre-operatively to 89 (range 45–100) and ROM improved from 120.8° (range 65°–150°) pre-operatively to 130.1° (87°–150°) at final follow-up. Stress radiographs taken at full extension showed the mean medial joint line opening of patients who had dMCL and semiM releases was 2.3 mm (range 1.1–3.7 mm) and the mean medial joint line opening of patients who received the additional sMCL release was 3.7 mm (range 2.6–4.7 mm). No clinical complications or signs of instability, loosening or osteolysis were observed.

Although 'pie-crusting' is commonly used for releasing the lateral structures in valgus knees [1, 15], it is generally avoided for the release of the MCL due to the risk of iatrogenic transection and subsequent instability [9, 44].

Bellemans et al. [9] proposed a technique that may be potentially safer, whereby multiple needle punctures are made in the MCL. The procedure was considered successful when 2–4 mm mediolateral joint line opening was obtained in extension and 2–6 mm in flexion. In 34 of 35 cases, this was achieved, with over release of the MCL only seen in 1 of 35 knees. No instability or complications were seen on follow-up up to 2 years post-operatively, although one patient required manipulation under anaesthesia due to insufficient flexion. However, this study did not involve a control group for comparison, so the relative suitability of this MCL release technique is as yet unclear and, as stated by the authors, it is probably not suitable for severe varus deformities.

Engh and Ammeen [20] used medial epicondylar osteotomy (MEO) of the femoral attachment of the MCL to correct varus deformity. Their rationale for such a

technique was that it allowed for no damage to be inflicted on the MCL. In this study of 70 knees, the alignment changed from a mean of 6° varus pre-operation to 7° valgus at 4 years post-surgery. An average KSS of 93 was achieved, with no reported instability. This technique has also been suggested to be suitable for use in more severe varus knees (15°–40° varus) [21, 49]. However, although Engh and Ammeen [20] reported that bone union only occurred in 54 % of the knees, no associations were seen with symptoms such as focal tenderness or restricted motion [20]. Orban et al. [49] did not consider bone union to be necessary, given the lack of statistically different outcomes between patients with presence or lack of bone union. The natural MCL femoral attachment is isometric in the normal knee in order to maintain MCL tension across the range of knee motion. Isometry must be re-established, if the articular geometry changes when the femoral component is positioned to correct a varus misalignment, by fixing the epicondylar fragment elsewhere.

Ahn and Back [2] describe using osteotomy of the proximal medial tibia in 2 mm increments to correct varus contracture in OA knees with ≥10° varus deformity. The authors compared this release with a more 'standard' release of the dMCL and PMC or sMCL, following an initial release of the subperiosteal layer. The authors also found no significant difference in post-operative ROM, Hospital for Special Surgery score, and TF medial–lateral gap ratio in 0° and 90° flexion. Additionally, the TF medial–lateral gap ratio was found to be significantly lower at 130° flexion post-operatively after tibial osteotomy compared with the 'standard' medial release (1.02 vs. 1.14). Post-operative assessments up to 6 months only were reported, so long-term outcome was not determined.

Within the clinically applied methods, agreement of the release techniques was sought so that a common stepwise release protocol could be determined. In all cases, the ACL is sacrificed prior to release of any medial tissues or the PCL, and therefore was not included in Table 4. When the PCL is to be sacrificed for use of a PS-TKA this is usually performed prior to the release of any medial stabilisers [9, 13, 33, 43, 45, 61, 66]. However, Picard et al. [51] only released the PCL after release of the dMCL, sMCL, pes A and SemiM; Bottros et al. [10] sacrificed the PCL after pes A, dMCL and PMC releases had been performed, while Hakki et al. [27] sacrificed the PCL after PMC and/or MCL releases. The release sequences described for medial stabilisers were highly inconsistent between studies, and therefore, an overall common sequence could not be identified. For example, the pes A was included in the release sequence of 8 of 20 studies. Bottros et al. [10] and Picard et al. [51] described releasing the pes A as part of the first medial release step, whereas Mullaji et al. [46] and Matsumoto et al. [40–42] released the pes A in the final step and

Burke and O'Flynn [12] released the pes A in the third step after release of the dMCL and sMCL. Likewise, a release of the PMC was described in a number of studies within the first medial release step [13, 40–42, 46, 66], whereas other studies described releasing the PMC after other releases [2, 10, 11]. These variations were true of other medial stabilisers too, including the SemiM, dMCL and sMCL, which were commonly released to achieve balance [10, 12, 63, 66]. The way in which medial stabilisers were released was also highly variable. For example, a number of studies described releasing the MCL according to Whiteside's method [13, 27, 63, 64], but the MCL could also be released via methods including subperiosteal elevation, pie-crusting, needle-puncturing or osteotomy [2, 8, 21, 34, 56]. Additionally, in many instances, the exact manner in which medial structures had been released was not defined.

Discussion

The major finding of this review was that there is a lack of evidence to support extensive medial release for routine varus knee replacement. Surgical methods can vary between surgeons and the level of detail provided in published articles is often very limited. There remains a lack of consensus for quantification of such releases on the medial side, so interpretation of surgical procedures remains difficult. Furthermore, the description of the method and also the subjective approach normally adopted to assess the stability of the joint by 'feel' [6, 25] can make it difficult for relatively inexperienced surgeons to achieve balance confidently and accurately.

Medial release should be performed sequentially, to an extent that depends on the degree of varus deformity that is to be corrected [16, 33, 37, 39]. It can involve the release of the MCL, PMC, semiM and pes A tendons [12, 33, 37]. The MCL is always released to some extent during the initial anteromedial arthrotomy. Release of the dMCL and PMC alone is usually sufficient to correct mild varus deformity [10, 33, 60]. The sMCL is then often released to correct any residual varus deformity [40–42]. Release of the semiM and pes A [16, 33, 39, 46] appears to be less frequently employed, even in cases where varus deformity is severe. Release of these structures is often avoided except in the most severe fixed varus deformities.

The need for, and details of, a soft tissue release depend on whether a CR- or PS-TKA implant is used. Release of the PCL results in a greater increase in flexion gap compared with extension gap can result in increased valgus laxity in flexion [31, 66]. Similarly, if the semiM tendon is released in a PS-TKA, this will cause both an increase in flexion and extension gaps and can alter the laxity pattern of the knee towards unwanted instability [13].

It is important to note that extensive medial releases also increase lateral gaps, although to a lesser amount than medially [42, 66]. Extensive releases generally result in loss of medial constraint, and that mandates the need for a more-constrained prosthesis. Excessive medial release results in gross instability of the TF joint [7, 14, 16] ultimately resulting in the need for a more costly, and functionally restrictive, hinged TKA [10, 46].

Other risks associated with medial release are the possibilities of neurovascular damage [5] and delayed rupture [11, 35]. Furthermore, incorrect balancing can result in abnormal and increased loading leading to excessive polyethylene wear, osteolysis and loosening of the implant. Increased strain on other soft tissues of the knee can also result in pain [5, 53].

Most methods advocate that surgeons should check for rectangular gaps at full extension and 90° of flexion [13, 14, 23]. Cadaveric studies have shown that it is also important to look at mid-flexion, because the MCL has its greatest effect at mid-flexion angles [10]. The need for checking mid-flexion in the clinical setting has been recognised by some authors [10, 33]. Koh and Yong [33] measured the gaps with a distractor at 45° flexion as well as at extension and 90° in a clinical study of medial release in 104 varus knees, and Matsumoto et al. [40] checked gaps using navigation and a tensor device at 0°, 10°, 45°, 90°, 135° flexion in their clinical study. Use of tibial trial inserts containing pressure sensors [18, 25, 66] and computer navigation [22, 41, 48, 54] may possibly prove an efficient way of doing this quantitatively per operatively.

It has traditionally been taught that medial release should aim to achieve TF alignment within 3° of neutral [40, 61]. This has been made more controversial in recent years with the emerging concept of 'constitutionally varus' alignment—meaning that the knee has had a varus alignment since skeletal maturity [8], and that it should be this pre-arthritic natural 'anatomical' alignment that is restored [8, 19, 28, 29]. There has been little work done concerning restoration of constitutional varus, although the few preliminary studies have suggested that there is no increased adverse effects of this compared with the neutral alignment, at least in the short term [19, 38] and suggests that there may even be some benefits of restoring varus alignment up to 6° varus, when compared to 'neutral' alignment (±3°), such as increased flexion, more natural kinematics, better clinical scores, and better functional outcome scores [19, 60]. Furthermore, a 10-year follow-up of 846 TKAs showed that revision was not increased in >3° axis misalignment [4] and a 15 year study indicated that there had been no impact of the mechanical axis on long-term implant survivorship [50]. The restoration of natural pre-arthritic alignment cannot, however, be performed using available surgical navigation equipment or standard

available TKAs, but rather must be performed using patient-specific TKAs and cutting guides to achieve custom-fit positioning [28]. This aspect of TKA surgery is developing rapidly and will affect decisions about soft tissue releases and knee realignment. An overriding principle could be that the extent of medial soft tissue release, except in the most severe cases of >15° varus [46, 49], should be as conservative as possible.

The limitations of this study are that it is based on review of the literature rather than experimental data, that there may be subtle discordance in nomenclature of surgical procedures since several papers were used, and that only articles published in English were included. It is possible that some medial release methodologies may not have been identified.

Standardisation of the nomenclature of surgical release and promotion of minimal medial release may allow for improved soft tissue balancing.

Conclusion

To date, a lack of data exists with regard to the rates and extent of medial release in TKA surgery of varus OA knees. The literature supports a stepwise, conservative approach. Accurate bony cuts and femoral rotation seem to minimise release required, even with significant deformity. Emerging technology and current concepts in native limb alignment may help guide the surgeon to perform this intervention more effectively.

Conflict of interest None.

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