Review

Why Determining the Native Length Change Pattern of Medial Patellofemoral Ligament Is Still a Challenge: State-of-the-Art Review of Potential Sources of Heterogeneity within Studies Evaluating Isometry of MPFL

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Abstract: **Background:** In the literature there are divergent results as to the native MPFL length change pattern. The reason for such divergent results may be the heterogeneity of design of studies analyzing MPFL isometry. The hypothesis of this review was that studies assessing MPFL length change pattern are highly heterogeneous. The aim was to present a state-of-the-art review of sources of this heterogeneity. **Materials and Methods:** A total of 816 records were identified through the initial search of MEDLINE and Scopus databases. After eligibility assessment, 10 original articles and five reviews were included. In the included studies, the following 15 potential sources of heterogeneity were assessed: number of patients/cadavers, age, males to females ratio (demographics), identification of measured fibers, measurement method, measurement precision, quadriceps muscle activity, iliotibial band activity, hamstrings activity (study design), patellar height, trochlear or patellar dysplasia, femoral anteversion, mechanical axis of the limb, tibial tubercle–trochlear groove distance, and condylar anteroposterior dimensions (morphology). Each variable was graded in every included article with 1 point if reported precisely and not introducing bias; or with 0 points if reported not precisely, introducing bias, or not reported at all. **Results:** Within original articles, the highest achieved score was 10 out of 15 possible points with mean score of 6.7, SD = 2.37, and minimum score of just 3 out of 15 points. In the demographics section, mean score was 2.4, SD = 0.8 (80% of maximum possible score of 3); in the study design section it was 3.1, SD = 1.87 (52% of maximum possible score of 6); and in the morphology section it was 1.5, SD = 1.43 (25% of maximum possible score of 6). **Conclusions:** There is high heterogeneity and incomplete reporting of potential sources of bias in studies assessing native MPFL length change pattern. Future investigators should be aware of the presented factors and their potential impact on MPFL isometry. All methodologic factors should be meticulously reported. Detailed description of demographic data is already a standard; however, authors should more extensively report variables concerning study design and morphology of patients' patellofemoral joint. Furthermore, future studies should try to meticulously simulate the real-life working environment of MPFL and ensure usage of proper measurement methods.

Keywords: medial patellofemoral ligament; length change pattern; isometry; heterogeneity; studies design; anisometry

1. Introduction

The role of the medial patellofemoral ligament (MPFL) is to prevent lateralization and lateral dislocation of the patella [1–4]. It is located in the second layer of soft tissues on the medial side of the knee with reported average length varying between 43 mm to 72 mm [1,5–8]. The femoral insertion is located between the medial epicondyle of the femur, adductor tubercle, and gastrocnemius tubercle; the patellar insertion is located on the upper-medial half of the patella [1,5–8].

In case of recurrent patellar instability, surgical reconstruction of this ligament is often necessary. Multiple techniques for MPFL reconstruction are described and the goal of most of them is to provide isometry throughout the whole arc of motion [9–11]. However, some authors suggested that length change pattern of native, non-reconstructed MPFL is not isometry, even though most of the techniques for MPFL reconstruction try to produce isometric graft [12–14]. Due to discrepancy in results, it is unclear what length change pattern should be restored by MPFL reconstruction in patients after MPFL injury in order to best recreate native biomechanics [12–14]. It is possible that the biomechanics that we routinely try to restore during MPFL reconstruction are not the same as exhibited by native, non-reconstructed MPFL [12–14].

While there are numerous literature reviews of MPFL anatomy, biomechanics, injury patterns, and reconstruction outcomes, due to authors' knowledge there is no review concerning sources of heterogeneity within studies evaluating MPFL isometry [15–18]. The hypothesis of this review was that studies assessing MPFL length change pattern are highly heterogeneous. The aim was to present a state-of-the-art review of sources of this heterogeneity and to provide future investigators with an approachable “to-report list” of potential sources of bias, as well as with suggestions and considerations for future research.

2. Materials and Methods

State-of-the-art review methodology was chosen as specified by Grant et al. in their typology of the reviews [19]. As stated by the authors, such review “may offer new perspectives on an issue or highlight an area in need of further research” [19].

2.1. Search Methods and Exclusion Criteria

Three independent reviewers (M.M., K.K., and K.R.) searched MEDLINE and Scopus electronic databases for original studies and reviews assessing native MPFL length change pattern or factors influencing it. The search was performed in February 2021, with no time limits set. The following search term was used: ((Medial Patellofemoral Ligament) OR (MPFL)) AND ((isometry) OR (biomechanics) OR (kinematics) OR (mechanics) OR (length changes)). Inclusion criteria were original research article or review article (any type); healthy study subjects; assessment of MPFL length change pattern; English language. Excluded were studies assessing MPFL length change pattern in patients with patellar instability, after lateral patellar dislocation and after MPFL reconstruction; studies assessing other aspects of MPFL biomechanics (i.e., strain or influence on patellofemoral kinematics such as on the tilt of patella). Three reviewers (M.M., K.K., and K.R.) independently decided whether the study was eligible for inclusion. When there were discrepancies, consensus was reached by discussion.

2.2. Results of the Query

A total of 816 records were identified through initial query (MEDLINE, $n = 392$; Scopus, $n = 424$). After screening of titles and abstracts, 45 articles were assessed in full text. A total of 15 papers were included in the final analysis: 10 original research articles and five reviews. The process of study selection is presented in Figure 1.

Figure 1. Flowchart of study selection.

2.3. Data Extraction Process

In the included studies the following potential sources of heterogeneity were assessed:

- (1) Demographics: age, number of patients/cadavers, male to female ratio.
- (2) Study design:
  - (a) How was measured fibers identified? How was MPFL length measured and what was the precision of measurements (3D vs. 2D; magnetic resonance imaging [MRI] vs. computed tomography [CT] vs. caliper vs. suture vs. other; straight line vs. convex line; precision in mm)?
  - (b) What was the activity of quadriceps muscle, iliotibial band (ITB), and hamstrings (in study assessing patients: contracted/resting/not contracted; in study assessing cadavers: simulated/simulation of resting tension/not simulated)?
- (3) Morphology of patellofemoral joints:
  - (a) What was the patellar height (reported vs. not reported; if reported, normal vs. stratified vs. abnormal)?
  - (b) Whether there was trochlear or patellar dysplasia (as above).
  - (c) Femoral anteversion (as above).

- (d) Mechanical axis of the limb (as above).
- (e) Tibial tubercle–trochlear groove (TT–TG) distance (as above).
- (f) Condylar anteroposterior dimensions (as above).

For review articles, the possible categories for abovementioned variables were investigated/mentioned/not investigated.

2.4. Summarizing the Extracted Data

Extracted data were summarized narratively, with tabular accompaniment [19]. Included articles were graded as to presence of 15 abovementioned potential sources of bias. Afterwards, total sum of achieved “clarity of reporting points” was calculated for each study and results were narratively described. No formal quality assessment or formal synthesis of extracted data was performed [19].

3. Demographics as the Source of Heterogeneity

While it is not clear whether demographics influence biomechanics of MPFL, it was reported to influence the biomechanics of other ligaments, potentially making it important to precisely report number, age, and sex of patients/cadavers [16,20]. Within original studies included in this review, all 10 articles reported number of patients/cadavers [7,14,21–28]; however, only seven studies specified the age of patients/cadavers [7,14,22–26], and also seven studies reported the sex of patients/cadavers [7,14,21–25]. Within included review articles, only one of them investigated number of patients/cadavers and their age as potential factors influencing MPFL length change pattern [16]. None of the five reviews investigated sex [15–18,29] (Table 1).

Table 1. Demographics within included articles.

	Authors	Year	Patients/Cadavers	n of Subjects	Age, Years	Sex
Original articles	Steensen et al.	2004	Cadavers	11	“Elderly”	7M; 4F
	Victor et al.	2009	Cadavers	12	78–87 at the time of death	8M; 4F
	Higuchi et al.	2010	Patients	20	Mean 32 (range, 26–38)	10M; 10F
	Stephen et al.	2013	Cadavers	8	Mean 73.5 (range, 46–88)	5M; 3F
	Graf et al.	2014	Patients	10	Mean 35 (range, 25–42)	10M; 0F
	Song et al.	2015	Patients	11	Mean 32.0 ± 3.9 (range, 27–39)	11M; 0F
	Decante et al.	2019	Cadavers	8	Mean 85.25	Not reported
	Kernkamp et al.	2019	Patients	15	Mean 25.1 ± 5.2	9M; 6F
	Huddleston et al.	2020	Cadavers	8	Below 65	Not reported
	Yanke et al.	2020	Cadavers	8	Below 65	Not reported
Reviews	Amis et al.	2003	-	Not investigated	Not investigated	Not investigated
	Bicos et al.	2006	-	Not investigated	Not investigated	Not investigated
	Zaffagnini et al.	2013	-	Not investigated	Not investigated	Not investigated
	Chahla et al.	2019	-	Not investigated	Not investigated	Not investigated
	Huber et al.	2020	-	Investigated	Investigated	Not investigated

M—males; F—females.

4. Study Design as the Source of Heterogeneity

4.1. Identification of Measured Fibers and Measurement Methods

Proper identification of measured MPFL fibers connecting femoral and patellar insertions is of great importance when measuring MPFL isometry. However, different authors adopted different measures to properly mark them. For example, femoral attachment of MPFL was reported to be identified either by using Schöttle’s point [25,27] or midway between adductor tubercle and medial epicondyle [14,23]. On the patellar attachment, authors reported identifying different insertions such as “at 20%, 40%, and 60% of the patellar length from the proximal tip” [22] or “20% (point 20), 30% (point 30), 40% (point 40), 50% (point 50), and 60% (point 60) from the superior pole of the patella” [25]. Furthermore, recent literature suggests that some of the measurement methods used in the previous studies assessing MPFL length change pattern may be inaccurate. Higuchi et al. and Arai

et al. described that MPFL fibers do not run straight between insertions but, according to the degree of knee flexion, they “travel” through positions named A, B, to C from extension to flexion [7,30]. The type A was present at 0° and 30° of flexion, meaning “convex course toward the side of the patellofemoral joint surface”; type B was present in the majority of participants at 60° of flexion, meaning straight fibers; type C was present in 90° and 120° of flexion, meaning “a convex course toward the extra-articular side” [7,30]. If these reports are accurate, measurements made by calipers or navigation systems assessing the distance in a straight line can be biased both in initial and final degrees of flexion [21,22]. In addition, measurements made by sutures attached to linear variable displacement transducers may be biased if they were not threaded along MPFL fibers [31,32]. Furthermore, MPFL is a 3D structure; however, in some studies it was measured on a single 2D MRI slice [7,30].

From 10 original articles included in this review, nine studies identified multiple fibers of MPFL for assessment of length change [7,14,21,22,24–28] and one study assessed only a single fiber [23]. Various femoral and patellar attachments were analyzed, as specified in Table 2. Nine studies performed measurements in 3D [14,21–28]; however, only in four was MPFL measured with respect to its convexity [7,14,24,25]. CT was utilized in four studies [14,22,24,25], caliper in two studies [21,27], MRI in one study [7], suture in one study [23], and other measurement methods in two studies [26,28]. Only five out of 10 studies reported precision of measurements [14,21,23,24,27]. Within included review articles, just one study investigated whether the methodology of identification of measured fibers had an impact on observed MPFL length change pattern [29]. In addition, only one review study investigated the impact of measurement method as a potential source of heterogeneity [16]. Not a single review article investigated the impact of measurement precision (Table 2).

4.2. Muscular Activity

Numerous authors described the merging of the oblique part of the vastus medialis muscle (VMO) with MPFL [1,5,8,15] as well as the important role of quadriceps muscle contraction in patellar movement [1,14,15,33,34]. In 2006, Panagiotopoulos et al. suggested the dynamizing role of VMO in MPFL mechanics, a so-called “pull and guide” mechanism, according to which MPFL tensioned by VMO guides the patella to the intercondylar groove during initial flexion [1]. Besides quadriceps muscle, various authors described iliotibial band to connect to the patella by separate ligament or by fascia lata [35,36]. These connections mean that inaccurate simulation of ITB tension may be another potential source of bias. Hamstrings tension may also introduce heterogeneity due to anterior translation of the tibia in case of inaccurate simulation. Such anterior translation could influence patellar kinematics through patellar ligament tension, similar to the patellar height [27,28].

Out of 10 original articles included in this review, six of them assessed cadavers [21–23,26–28] and four assessed patients [7,14,24,25]. In cadaveric studies, two out of six simulated high tension of quadriceps muscle [22,23], two simulated resting tension [27,28], one simulated quadriceps tension with unspecified load [21], and one did not simulate quadriceps tension at all [26]. Only one cadaveric study simulated high load activity of ITB [23] or hamstrings [22], with all other cadaveric studies not simulating any tension. In patients studies, two articles reported contraction of lower limb muscles (i.e., by performing a lunge) [14,24] and in the remaining two, patients were assessed with relaxed limbs [7,25]. Within five included review articles, one study investigated the impact of quadriceps tension on MPFL length change pattern [16] and two others mentioned it briefly [15,17]. None of the five reviews investigated ITB or hamstrings tension [15–18,29] (Table 3).

Table 2. Identification of measured fibers and measurement methods used in included articles.

	Authors	Year	Patients/Cadavers	Identification of Measured Fibers	Measurement Method	Measurement Precision
Original articles	Steensen et al.	2004	C	Multiple fibers, connecting most superior edge, midpoint, and inferior edge of the ligament at its patellar and femoral insertions.	3D caliper straight line	Rounded to the nearest mm
	Victor et al.	2009	C	Multiple fibers, connecting single femoral attachment (“bony depression proximal/posterior to the medial epicondyle and anterior/distal to the adductor tubercle”) with three patellar attachments (“at 20%, 40%, and 60% of the patellar length from the proximal tip”).	3D CT straight line	Not reported
	Higuchi et al.	2010	P	Two fibers, measured on the most proximal and distal slice among slices in which “the entire length of the fiber bundle connecting the patella and the adductor tubercle could be observed in one cross-section”. Their values were averaged, resulting in combined single fiber value.	2D MRI convex line	Not reported
	Stephen et al.	2013	C	Single fiber, connecting single femoral attachment (midway between the adductor tubercle and the medial epicondyle) with single patellar attachment (“on the superomedial border of the patella, halfway between the uppermost medial border and the mid patellar body”).	3D suture	Between 0 ± 0 mm and 1.4 ± 0.5 mm
	Graf et al.	2014	P	Two fibers, connecting “one femoral (i.e., at the adductor tubercle) and two patellar insertion points lying on the medial patellar border (i.e., the most proximal point and a distal point in the proximal third)”.	3D CT convex line	0.01 mm
	Song et al.	2015	P	Multiple fibers, connecting single femoral attachment (Schöttle) and five patellar attachments: “20% (point 20), 30% (point 30), 40% (point 40), 50% (point 50), and 60% (point 60) from the superior pole of the patella”.	3D CT convex line	Not reported
	Decante et al.	2019	C	Multiple fibers, connecting single femoral attachment (“on the medial femoral epicondyle, immediately behind the femoral insertion of the MCL in 80% of the cases, remaining below and in front, at a distance from the adductor tubercle; [. . .] on the femoral insertion of the MCL in 14% of cases, in front of the femoral insertion of the MCL in 6% of cases”) and two patellar attachments (upper and lower border of dissected MPFL).	3D, probably straight line, no convexity reported	Not reported

Table 2. Cont.

	Authors	Year	Patients/Cadavers	Identification of Measured Fibers	Measurement Method	Measurement Precision
	Kernkamp et al.	2019	P	Multiple fibers, connecting 185 points on the medial femoral epicondyle, including five “anatomic” attachments of MPFL (proximal, central, distal, posterior, and anterior within the dimple between the adductor tubercle and the medial femoral epicondyle) and three patellar attachments (proximal, central, and distal).	3D CT convex line	0.3 ± 0.1 mm
	Huddleston et al.	2020	C	Multiple fibers, connecting single femoral attachment (identified “visually”) and four patellar attachments of MPFC: midpoint patella, MPFC osseous footprint center, superior medial pole of the patella at the level of the quadriceps insertion, and “the proximal extent of the MPFC along the quadriceps tendon”.	3D caliper straight line	0.051 mm
	Yanke et al.	2020	C	Multiple fibers, connecting single femoral attachment (established by means of palpating “the sulcus between the medial epicondyle and abductor tubercle”) and four patellar attachments the same as in the study of Huddleston et al.	3D straight line	Not reported
Reviews	Amis et al.	2003	-	Mentioned: “it often seems to have two functional bands of fibers, that run along the proximal and distal edges”.	not investigated	Not investigated
	Bicos et al.	2006	-	Not investigated	not investigated	Not investigated
	Zaffagnini et al.	2013	-	Investigated	not investigated	Not investigated
	Chahla et al.	2019	-	Not investigated	not investigated	Not investigated
	Huber et al.	2020	-	Mentioned: “investigations into the influence of the patellar attachment sites on the elongation behavior of the ligament have suggested that the superior fibers are strained differently from the inferior fibers, hence plausibly indicating that 2 functionally independent regions of the structure exist”.	investigated	Not investigated

C—cadavers; P—patients; CT—computed tomography; MRI—magnetic resonance imaging; MPFC—medial patellofemoral complex.

Table 3. Muscular activity within included articles.

	Authors	Year	Patients/Cadavers	Quadriceps Muscle	Iliotibial Band	Hamstrings
Original articles	Steensen et al.	2004	Cadavers	Simulated, load not reported	Not simulated	Not simulated
	Victor et al.	2009	Cadavers	Simulated, high load	Not simulated	Simulated, high load
	Higuchi et al.	2010	Patients	Resting	Resting	Resting
	Stephen et al.	2013	Cadavers	Simulated, high load	Simulated, high load	Not simulated
	Graf et al.	2014	Patients	Contracted	Contracted	Contracted
	Song et al.	2015	Patients	Resting	Resting	Resting
	Decante et al.	2019	Cadavers	Not simulated	Not simulated	Not simulated
	Kernkamp et al.	2019	Patients	Contracted	Contracted	Contracted
	Huddleston et al.	2020	Cadavers	Resting tension simulated	Not simulated	Not simulated
Reviews	Yanke et al.	2020	Cadavers	Resting tension simulated	Not simulated	Not simulated
	Amis et al.	2003	-	Mentioned	Not investigated	Not investigated
	Bicos et al.	2006	-	Not investigated	Not investigated	Not investigated
	Zaffagnini et al.	2013	-	Not investigated	Not investigated	Not investigated
	Chahla et al.	2019	-	Mentioned	Not investigated	Not investigated
	Huber et al.	2020	-	Investigated	Not investigated	Not investigated

5. Morphology of Participants' Patellofemoral Joints as the Source of Heterogeneity

While the biomechanics of the patellofemoral joint are not yet fully elucidated [15,16,37], it was reported that MPFL length change pattern can be influenced by patellar height [28,38,39], trochlear or patellar dysplasia [14,16,29], femoral anteversion [29,39,40], mechanical axis of the limb [39,40], and tibial tubercle–trochlear groove (TT–TG) distance [13,14,40]. Other recently reported potential factors influencing MPFL length change pattern are anteroposterior dimensions of femoral condyles [14,41]. While influence of condylar dimensions on MPFL isometry has not been assessed yet, the short posterior part of the lateral condyle was reported to be associated with higher risk of lateral patellar dislocation [41], and the long lateral condyle seems to be associated with higher risk of ACL injury [42–44], highlighting the importance of distal femur bony morphology.

From 10 original articles included in this review, five reported the patellar height and presence of trochlear or patellar dysplasia explicitly [7,23,25,27,28], and one reported it implicitly in the limitations section [14]. Three studies reported TT–TG distance [14,25,28], two reported precise angular values of mechanical axis of the limb [7,25], and one study reported exclusion of severe varus or valgus deformities [26]. Not a single study reported precisely on femoral anteversion or femoral condylar dimensions [7,14,21,22,24–28]; however, one study in the limitations section implicitly reported the femoral condylar dimensions to be normal [14]. As to the included review articles, two studies mentioned trochlear or patellar dysplasia as a potential factor influencing MPFL length change pattern [16,18]. The same number of studies mentioned mechanical axis of the limb [18,29] and femoral anteversion [18,29]. Only one review article mentioned TT–TG distance in the context of influencing MPFL isometry [18]. Not a single review study investigated the potential impact of patellar height or femoral condylar dimensions on MPFL length [15–18,29] (Table 4).

Table 4. Morphology of participants' patellofemoral joints in included articles.

	Authors	Year	Patients/Cadavers	Patellar Height	Trochlear or Patellar Dysplasia	TT-TG Distance	Mechanical Axis of the Limb	Femoral Anteversion	Femoral Condylar Dimensions
Original articles	Steensen et al.	2004	Cadavers	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported
	Victor et al.	2009	Cadavers	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported
	Higuchi et al.	2010	Patients	Reported, normal	Reported, normal	Not reported	Mean Q-angle 14°	Not reported	Not reported
	Stephen et al.	2013	Cadavers	Reported, normal	Reported, normal	Not reported	Not reported	Not reported	Not reported
	Graf et al.	2014	Patients	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported
	Song et al.	2015	Patients	Reported, normal	Reported, normal	Reported, normal	Reported, normal	Not reported	Not reported
	Decante et al.	2019	Cadavers	Not reported	Not reported	Not reported	Severe def. excluded	Not reported	Not reported
	Kernkamp et al.	2019	Patients	Implicitly reported to be normal	Implicitly reported to be normal	Reported, normal	Not reported	Not reported	Implicitly reported to be normal
	Huddleston et al.	2020	Cadavers	Reported, normal	Reported, normal	Not reported	Not reported	Not reported	Not reported
	Yanke et al.	2020	Cadavers	Tested variable	Reported, normal	Reported, normal	Not reported	Not reported	Not reported
Reviews	Amis et al.	2003	-	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated
	Bicos et al.	2006	-	Not investigated	Mentioned	Mentioned	Mentioned	Mentioned	Not investigated
	Zaffagnini et al.	2013	-	Not investigated	Not investigated	Not investigated	Mentioned	Mentioned	Not investigated
	Chahla et al.	2019	-	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated
	Huber et al.	2020	-	Not investigated	Mentioned	Not investigated	Not investigated	Not investigated	Not investigated

TT-TG—tibial tubercle–trochlear groove; def.—deformations.

6. Summary of the Review

In this state-of-the-art review, 15 potential sources of heterogeneity within articles assessing native MPFL length change pattern were reviewed. These sources were: number of patients/cadavers, age, male to female ratio, identification of measured fibers, measurement method, measurement precision, quadriceps muscle activity, ITB activity, hamstrings activity, patellar height, trochlear or patellar dysplasia, femoral anteversion, mechanical axis of the limb, TT–TG distance, and condylar anteroposterior dimensions. Each variable was graded in every included article into one of the following categories. For original articles: (1) reported precisely; (2) reported but not precisely, or reported precisely but introducing potential bias (i.e., resting muscles or measurement method other than 3D convex line); (3) not reported. For reviews: (1) investigated; (2) mentioned; (3) not investigated. Afterwards, total sum of points for clarity of reporting was calculated. Category “reported precisely”/“investigated” was counted as 1 point and other categories were counted as 0 points (Table 5).

Within original articles, the highest achieved score was 10 out of 15 points for “clarity of reporting” of the factors potentially influencing MPFL length change pattern [14,23]. Mean score was 6.7, SD = 2.37 with minimum of just 3 out of 15 points [26]. In the demographics section, mean score was 2.4, SD = 0.8 (80% of maximum possible score of 3); in the study design section it was 3.1, SD = 1.87 (52% of maximum possible score of 6); and in the morphology section it was 1.5, SD = 1.43 (25% of maximum possible score of 6). Such results confirm the hypothesis of this review—studies assessing MPFL length change pattern are highly heterogeneous (Table 5).

For review articles, only two articles investigated any of 15 factors, achieving 3 out of 15 points [16] and 1 out of 15 points [29]. Mean score was 0.8, SD = 1.17 (Table 5). However, it may be impossible to review the influence of given factors on MPFL isometry if there are no original studies assessing it.

7. Limitations

The first limitation of this review is that despite analyzing 15 different potential sources of heterogeneity, it was impossible to assess which variable influenced results to the greatest extent. Heterogeneity between studies was too high to compare one study to the others in a way that they differed with just one variable. Due to the fact that raw datasheets containing the data of included articles were not available online, we also could not analyze the impact of given potential variables statistically. Our personal opinion is that the most important factors may be identification of measured fibers, measurement method, and muscular activity. However, this is just personal opinion, unsupported by properly designed research. The second limitation is that, while there are studies reporting the impact of potential sources of heterogeneity, it is hard to compare their outcomes with other studies due to heterogeneity in other variables. Therefore, the literature does not allow us to conclude whether studies with similar experimental approaches would have similar results. For example, Yanke et al. [28] showed that patellar height influences MPFL isometry. However, in this study only the resting tension of quadriceps muscle was simulated and tension of ITB and hamstrings was not simulated at all. Furthermore, MPFL length was measured using straight line measurement [28]. Therefore, we considered it inappropriate to compare their results, i.e., with the study of Kernkamp et al. [14], in which quadriceps, ITB, and hamstrings were contracted and MPFL length was measured with convex line measurement.

Table 5. Summary of which sources of heterogeneity were reported in included articles.

Authors	Original Articles										Reviews				
	Steensen et al.	Victor et al.	Higuchi et al.	Stephen et al.	Graf et al.	Song et al.	Decante et al.	Kernkamp et al.	Huddleston et al.	Yanke et al.	Amis et al.	Bicos et al.	Zaffagnini et al.	Chahla et al.	Huber et al.
Year	2004	2009	2010	2013	2014	2015	2019	2019	2020	2020	2003	2006	2013	2019	2020
Patients/cadavers	C	C	P	C	P	P	C	P	C	C	-	-	-	-	-
Number	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	✓
Age	~	✓	✓	✓	✓	✓	✓	✓	~	~	x	x	x	x	x
M:F ratio	✓	✓	✓	✓	✓	✓	x	✓	x	x	x	x	x	x	x
Demographics (max 3)	2	3	3	3	3	3	2	3	1	1	0	0	0	0	1
Identification of measured fibers	✓ MF	✓ MF	✓ MF	✓ SF	~ MF	✓ MF	✓ MF	✓ MF	✓ MF	✓ MF	~	x	✓	x	~
Measurement method	~ 3DSL	~ 3DSL	~ 2D CL	✓ 3DCL	✓ 3DCL	✓ 3DCL	~ 3DSL	✓ 3DCL	~ 3DSL	~ 3DSL	x	x	x	x	✓
Measurement precision	✓	x	x	✓	✓	x	x	✓	✓	x	x	x	x	x	x
Quadriceps	~	✓ Co	~ R	✓ Co	✓ Co	~ R	x	✓ Co	~ R	~ R	~	x	x	~	✓
ITB	x	x	~ R	✓ Co	✓ Co	~ R	x	✓	x	x	x	x	x	x	x
Hamstrings	x	✓ Co	~ R	x	✓ Co	~ R	x	✓ Co	x	x	x	x	x	x	x
Study design (max 6)	2	3	1	5	5	5	1	6	2	1	0	0	1	0	2
Patellar height	x	x	✓	✓	x	✓	x	~	✓	✓	x	x	x	x	x
Trochlear or patellar dysplasia	x	x	✓	✓	x	✓	x	~	✓	✓	x	~	x	x	~
TT-TG distance	x	x	x	x	x	✓	x	✓	x	✓	x	~	x	x	x
Mechanical axis of the limb	x	x	✓	x	x	✓	~	x	x	x	x	~	~	x	x
Femoral anteversion	x	x	x	x	x	x	x	x	x	x	x	~	~	x	x
Femoral condylar dimensions	x	x	x	x	x	x	x	~	x	x	x	x	x	x	x
Morphology (max 6)	0	0	3	2	0	4	0	1	2	3	0	0	0	0	0
Total (max 15)	4	6	7	10	8	9	3	10	5	5	0	0	1	0	3

It was summarized whether included studies reported on potential sources of heterogeneity influencing MPFL length change pattern. The following categories were given: for original articles: ✓—reported precisely; ~—reported but not precisely, or reported precisely but introducing potential bias (i.e., resting muscles or measurement method other than 3D convex line); x—not reported. For reviews: ✓—investigated; ~—mentioned; x—not investigated. Afterwards, total sum of points for clarity of reporting was calculated. Category “investigated” was counted as 1 point and categories “mentioned” and “not investigated” were counted as 0 points. C—cadavers; P—patients; M—males; F—females; SF—single fiber; MF—multiple fibers; Co—contraction/simulation of contraction; R—resting/simulation of resting tension; ITB—iliotibial band; SL—straight line measurement; CL—convex line measurement; TT-TG—tibial tubercle–trochlear groove.

8. Considerations for Future Research

We hope that the “to-report list” of potential sources of bias presented in this review will be of use to the future investigators interested in MPFL length change pattern. Controlling each of these factors (and potentially some more that were not identified) may be hardly feasible. However, it may not be possible to determine what the native length change pattern of MPFL is without controlling this heterogeneity in the future research. Therefore, below we provide our conclusions about how to design an experiment to properly evaluate the MPFL isometry.

Up to date, it is not clear which sources of heterogeneity may influence the measurements the most; however, trying to simulate the real-life working environment of the MPFL seems to be the first crucial issue. We lobby for patients-based studies with quadriceps, ITB, and hamstrings contraction, preferably in real-life situations such as squatting or lunges. The second crucial issue, in our opinion, is proper identification of MPFL femoral and patellar insertions. Ideally, this identification should be made two times by two or more independent researchers with experience in MPFL dissection and imaging. Afterwards, intra- and interrater agreement in identification of insertions should be calculated. The third crucial issue, in our opinion, is measurement methods and their precision. 3D measurements taking into account the convexity of MPFL with high and meticulously reported precision (i.e., 3D CT or MRI models) seem mandatory for proper assessment of MPFL isometry. The fourth consideration is that “apples should not be compared to oranges”—patients of different genders and from different age groups should be assessed separately. The fifth point is to exclude participants with variations in patellofemoral joint anatomy (i.e., patella alta, highly valgus knee, dysplastic knees) or to perform a subgroup analysis. Some anatomical variations (patellar height, trochlear or patellar dysplasia, TT-TG distance and femoral condylar dimensions) are relatively easy to assess on knee CT or MRI which are performed either way to evaluate MPFL isometry. However, precise assessment of mechanical axis of the limb or femoral anteversion requires performing additional imaging studies. We acknowledge this as a practical problem. Therefore, properly powered and designed study analyzing whether mechanical axis of the limb and femoral anteversion has an impact on MPFL isometry is needed. The sixth issue is that ideally MPFL length should be measured and reported in 10-degree or, even better, 5-degree intervals. Such a high “resolution” of available MPFL lengths in given knee flexion angles would prevent the inability to compare the results with other studies. However, we are aware that achieving such a detailed “map” of MPFL length changes according to the flexion angle can only be achieved with the use of a 3D model. We are also aware that 3D modelling is always another potential source of bias. Therefore, as an alternative approach, we propose that before designing the study one should review what flexion angles were analyzed in the studies that one wants to compare the results with. The last advice from the authors of this review is that future researchers should meticulously report methodology of their studies, namely demographics, study design, and morphology of participants’ patellofemoral joint. As stated in the limitations section, raw datasheets containing the data should be made available online by the authors. Such availability would potentially allow future authors to perform a meta-analysis with subgroup analysis of the impact of given variables, i.e., by the means of linear regression model or other statistical tools.

9. Conclusions

There is high heterogeneity and incomplete reporting of potential sources of bias in studies assessing native MPFL length change pattern. Future investigators should be aware of the presented factors and their potential impact on MPFL isometry. All methodologic factors should be meticulously reported. Detailed description of demographic data is already a standard; however, authors should more extensively report variables concerning study design and morphology of participants’ patellofemoral joints. Furthermore, future studies should try to meticulously simulate the real-life working environment of the MPFL and ensure usage of proper measurement methods.

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