The Knee 26 (2019) 1171–1181

Contents lists available at ScienceDirect

The Knee

Review

Current concepts in the surgical management of patellar instability

Peter Thompson *, Andrew J. Metcalfe

University Hospital of Coventry and Warwickshire NHS Trust, Clifford Bridge Road, Coventry, CV2 2DX, United Kingdom

ARTICLE INFO

Article history:
Received 25 October 2019
Received in revised form 11 November 2019
Accepted 12 November 2019

Keywords:
Patellar dislocation
Patellar instability
Knee surgery

ABSTRACT

Background: Patellar instability is a common condition, and recurrent instability can be highly disabling. It is important to understand the patho-anatomy of patellar instability in order to treat it effectively, with the trochlear shape, patellar height and the integrity of the medial retinaculum being the most important factors in determining the risk of ongoing instability.

Clinical Assessment and Radiographic Assessment: Clinical assessment is based around correct diagnosis of instability, identification of at risk features and an assessment of neuromuscular control and factors that may affect the potential for rehabilitation before or after surgery. Radiology is important to assess features predisposing to instability and to determine the best treatment plan for each individual.

Treatment: There are a range of surgical options for the treatment of patellar instability and these should be chosen based on an each patients individual patho-anatomy. Lateral release is not recommended as a treatment for patellar instability. Medial patello-femoral ligament reconstruction, tibial tubercle distalisation, trochleoplasty or occasionally tibial or femoral osteotomies for correction of rotational or coronal plane mal-alignment may all be used either individually or in combination. High quality physiotherapy is an essential part of post-operative management and should address the whole of the kinetic chain, working on strength and control of the lower limbs to optimise balance and movement patterns in order to achieve the best results.

Contents

* Corresponding author.
E-mail addresses: peter.thompson@uhcw.nhs.uk, (P. Thompson), a.metcalfe@warwick.ac.uk. (A.J. Metcalfe).

https://doi.org/10.1016/j.knee.2019.11.007
0968-0160/

1. Introduction

Patellar instability is a common problem seen by orthopaedic surgeons and physiotherapists with an overall incidence of five to seven per 100,000, but in the 10–17-year old age group is as high as 29 per 100,000 [1–3]. There is a 15–44% chance of recurrence after a first patellar dislocation and at least a 50% chance, if not greater, of further recurrence after a second dislocation [4]. Even without recurrent instability, there is a fairly high incidence of on-going mechanical symptoms from the patello-femoral joint, approximately 50% of patients do not get back to their previous level of sporting activities, and over 70% have some form of limitation [5,6].

Patellar instability is a multi-factorial problem and there is large variation in surgical treatment that occurs globally. The aim of this article is to outline the anatomical abnormalities seen in patients with patellar instability, describe their clinical assessment, outline the necessary investigations and discuss the best practice in surgical decision making. This is supported by the work of the British Patellofemoral Society and the BASK Patellofemoral working group.

1.1. Patello-femoral anatomy and kinematics

The patella has a tendency to dislocate laterally due to the Q angle with the resultant lateral force vector on the patella. The optimal anatomy for functional patellar stability is a deep trochlea groove with early engagement of the patella as the knee starts to flex from a fully extended position. This requires the lower part of the patella to be situated over the proximal part of the trochlear groove with the knee in full extension. The patella engages the groove laterally and is guided slightly medially into the trochlea groove as the knee is flexed. The contact point on the patella progresses from distal to proximal as the knee flexes. In the absence of patella alta or patella infera the patella should be located at the distal end of the femur when the knee is flexed to 90°.

Senavongse and Amis have shown the most important factor affecting stability of the patella is the shape of the trochlea [7,8]. In a cadaveric experiment that flattened the trochlear groove by performing an osteotomy of the lateral facet of the trochlea, effectively mimicking trochlear dysplasia, a reduction in the force required to displace the patella by 10 mm was seen throughout the range of flexion from 0 to 90°, but this was most significant at 30 degrees of flexion where a 70% reduction in force was seen [8]. Patients with significant patella alta will see a marked reduction in lateral patellar stability in early flexion, even in the presence of a well-formed trochlea groove, as the patella will not engage with the trochlea until deeper flexion angles.

Patella alta has been increasingly recognised in recent years as a major factor in patients with patellar instability and also causes soft tissue impingement/conflict of the lateral proximal patellar tendon and adjacent retinaculum/fat pad as those anatomical parts rub over the lateral side of the trochlea. Patella alta also results in articular cartilage wear of the lower part of the patella due to increased loading.

The next most important factor resisting lateral translation of the patella is the medial retinaculum [9,10]. The medial retinaculum is composed of various condensations of fibres with the medial patello-femoral ligament (MPFL) being the most important. The other components are the transverse fibres of the medial retinaculum (TMR), the medial patella meniscal ligament (MPML) and the medial patella tibial ligament (MPTL). The relative contributions to restraint to lateral subluxation of the patella are shown in Table 1.

Table 1
Medial retinacular structures and their resistance to lateral patella translation [9,10].

Anatomical structure	Restraint to lateral patella translation
MPFL	53–72%
TMR	11%
MPML	13–22%
MPTL	5%
LR	10%

The lateral retinaculum (LR) acts as a restraint to lateral subluxation by preventing the lateral edge of the patella being displaced anteriorly over the prominence of the lateral facet of the trochlea. Lateral release therefore reduces lateral stability rather than improves it.

The MPFL acts in early flexion to limit the lateral displacement of the patella, effectively guiding it into the trochlea groove during the first 20–30 degrees of knee flexion at which point the bony anatomy becomes increasingly important. A sectioning study has shown a 49% reduction in resistance to lateral displacement of the patella by 10 mm in full extension [8]. Various other sectioning studies have confirmed the importance of the MPFL [11–13].

Anatomically, the MPFL consists of a condensation of fibres within layer two of the medial side of the knee. Its average length is 55 mm (range 47–70 mm) with a width of 15–17 mm. It inserts into the supra-medial border of the patella and inserts close to the medial femoral epicondyle [14]. There is a variable insertion from the VMO muscle giving some dynamic effect through the MPFL. The tensile strength is 208 Newtons and the elongation to failure is 25.8 mm [15].

The patellar tendon insertion at the tibial tuberosity affects the Q angle, with a more lateral position on the tibia increasing the lateral force vector on the patella. Valgus limb alignment will also increase the Q angle and generalised hyperlaxity has an additional negative effect on patella stability. Rotational mal-alignment is considered as a contributing cause, but in practice it is rare to need to correct this surgically.

These patho-anatomical features are commonly referred to as ‘risky anatomy’ and are listed in Table 2. Of these factors, the trochlea shape and depth, the patellar height and the continuity of the medial retinaculum are the most important.

Additional chondral or osteochondral damage may occur to the patello-femoral joint surfaces and these intra-articular injuries most commonly affect the medial facet of the patella and the lateral side of the trochlea. They usually occur in deeper flexion angles due to the higher loads necessary to dislocate the patella in this position.

1.2. Clinical assessment

Patellar instability is usually fairly easy established from the history but occasionally can be confused with other causes of knee instability such as cruciate and collateral ligament injury. It is important to differentiate between pain and instability when taking the history, and the presence of continuous pain in-between dislocations may indicate underlying chondral damage. Crepitus and recurrent effusions within the knee may also indicate the presence of chondral damage.

A first dislocation occurring under the age of 12 years is highly likely to indicate underlying trochlear dysplasia. It is important to establish any instability symptoms from other joints that may indicate hypermobility being a significant factor.

The history should also explore previous treatment such as physiotherapy and previous surgery. It is important to crosscheck the type of physiotherapy rehabilitation that has taken place, as this is not always optimal and may remain a treatment option, even if prior physiotherapy has been tried.

Clinical examination of patients with a history of patellar instability is aimed at identifying the risky anatomy outlined in Table 2. Initial inspection should focus on coronal and rotational lower limb alignment, muscle bulk and movement patterns including assessing functional movements such as single leg mini dips that commonly identify a weakness in the proximal core muscles and hip abductors. Screening for joint hyperlaxity is also recommended.

Patella height is assessed with the knee flexed to 90° over the side of the examination couch and tuberosity position should also be evaluated with the knee flexed. Patella tracking is assessed by asking the patient to extend their knee and observing and palpating any lateral movement of the patella as the knee moves into full extension. Lateral tracking of the patella is due to patella alta, trochlear dysplasia and by a laterally placed tibial tuberosity. Dramatic J tracking where the patella jumps/clunks laterally out of the trochlea is pathognomonic of severe trochlear dysplasia.

Medial and lateral patella glide tests with the knee flexed approximately 20° can be used to assess the laxity or tightness of the retinaculum with movement described in quadrants. Apprehension to lateral patellar glide is strongly associated with patellar instability. Palpation of crepitus and the presence of a joint effusion suggest underlying chondral damage.

Table 2
The patho-anatomy of patella instability.

Trochlea shape and depth
Patella height
Medial retinaculum continuity
Valgus limb alignment
Tibial tuberosity offset
Generalised hyperlaxity

2. Radiological assessment

2.1. Plain radiographs

All patients with recurrent patellar instability should have plain radiographs consisting of an AP view, a true lateral taken in slight flexion with the posterior femoral condyles perfectly overlapping and a single skyline view taken in 20–30 degrees of knee flexion with the beam as parallel to the femur as possible. Additional skyline views at 60 and 90 degrees of knee flexion are unhelpful.

The lateral view allows identification of Dejour's crossing sign and a supra-trochlear spur that is seen in patients with trochlear dysplasia [16]. The insall-Salvati [17], Blackburn-Peel [18] and Caton-Deschamps [19] ratios are well described methods of measuring patella height with normal values shown in Table 3.

Of these methods, the Caton Deschamps ratio (Figure 1) is the most easily used, but all three methods have their limitations as they measure patella height relative to the tibia rather than the femur. A patient may have a normal radiographic ratio, yet have functional patella alta if the trochlea groove is short resulting in the patella tracking out of the groove as the knee extends. The skyline view is useful in identifying osteochondral fractures and patello-femoral osteoarthritis. Historical measurements of the sulcus congruence and patello-femoral angles are unhelpful.

2.2. MRI

A more logical assessment of patella height can be measured from the sagittal MRI scans using the patella-trochlea index as described by Biedert and Albrecht (Figure 2) [20]. This measures the percentage overlap of the inferior patella articular surface with the proximal trochlea articular surface with measurements less than 12.5% indicating patella alta, and measurements more than 50% indicating patella infera. It must be noted that this measurement also has its limitations as there is great variation in the exact position of knee flexion when MRI scans are performed and a dynamic scan performed with a quadriceps contraction will significantly alter the overlap of the patella with the trochlea. It must be conceded that we are yet to establish the ideal way of assessing patella height, but a combination of clinical assessment, radiographic and MRI measurements seems most sensible.

The axial sections of MRI scans show trochlea anatomy best. They show trochlear dysplasia, osteochondral fractures, MPFL avulsion fractures and osteoarthritis. The axial sections can also be used to measure trochlea groove - tibial tuberosity offset (TGTT), patella shape and tilt as well as medial retinacular injury. Trochlear dysplasia has been classified by Dejour et al. [21] but surgeons debate the usefulness of this classification and many describe mild, moderate or severe trochlear dysplasia depending on whether the trochlea is shallow, flat or domed.

The normal value for TGTT offset on an MRI scan is less than that on a CT scan with values in patients without patella instability being 7.5 ± 3.5 mm, and values in patients with patellar instability measuring 13.5 ± 4.1 mm [22].

2.3. CT Scans

CT scans show the bony anatomy well and are a more reliable way of measuring the TGTT with the normal value being 12.7 ± 3.4 mm, and values in instability patients being 19.8 ± 1.6 mm [16]. However, the clinical value of measuring TGTT has been questioned in recent years and procedures to only medialise the tibial tuberosity are less commonly performed by experienced patellar instability surgeons within the UK in favour of tibial tuberosity distalisation to correct patella alta and combined with slight medialisation when necessary.

CT scans can also be used to assess the rotational profile of patients who have extreme femoral anteversion and tibial torsion from their clinical assessment. Scans are performed through the hip, knee and ankle joints to allow assessment of the rotational profile.

2.4. Long leg alignment X-rays

These are reserved for patients who clinically have significant coronal plane mal-alignment, as occasional distal femoral osteotomy to correct valgus may be necessary when treating patients with patellar instability.

Table 3
Radiographic measurements of patella height.

Method	Value
Insal-Salvati	<1
Blackburne-Peel	0.54–1.06
Caton-Deschamps	0.8–1.2

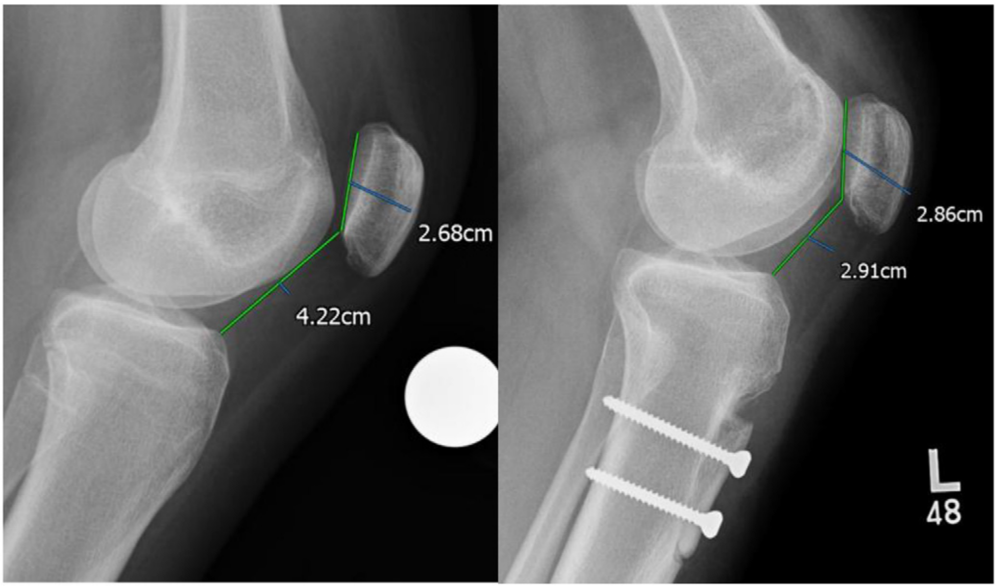

Figure 1. Caton–Deschamps Ratio pre (4.2 ÷ 2.7 = 1.55) and post (2.9 ÷ 2.9 = 1) tibial tuberosity Distalisation:

3. Surgical management of patella instability

Surgical management of patellar instability involves three key procedures: MPFL reconstruction, tibial tuberosity realignment and trochleoplasty. Patients may require a combination of these procedures and rarely may require osteotomy surgery to correct abnormal valgus or rotation.

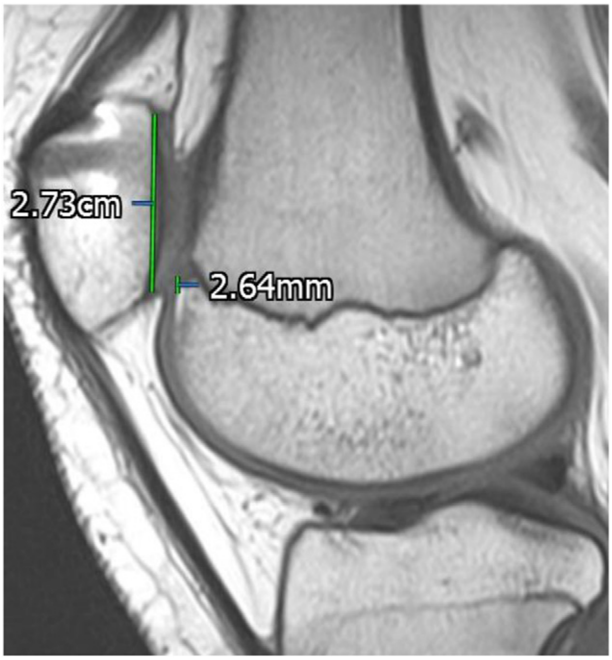

Figure 2. Biedert–Patellotrochlear Index: 2.6 ÷ 27.3 × 100 = 9.5%.

3.1. Lateral release

Isolated lateral release is an anatomically illogical procedure for treating patients with patellar instability and should not be performed. Several anatomical studies have shown lateral release results in a reduction in the force required to displace/dislocate the patella laterally as it becomes easier for the patella to ride-up and over the lateral side of the trochlea [23,24]. Patients undergoing trochleoplasty surgery commonly require a lateral retinacular lengthening procedure, but isolated lateral release should be regarded as a historical procedure.

3.2. MPFL reconstruction

Reconstruction of the medial patello-femoral ligament has become one of the most common ways of treating patellar instability. Numerous techniques have been described with the most popular techniques using a free gracilis tendon or a quadriceps tendon turn-down graft. Although a free semi-tendinosis graft is an option, it must be noted that this graft is much stronger

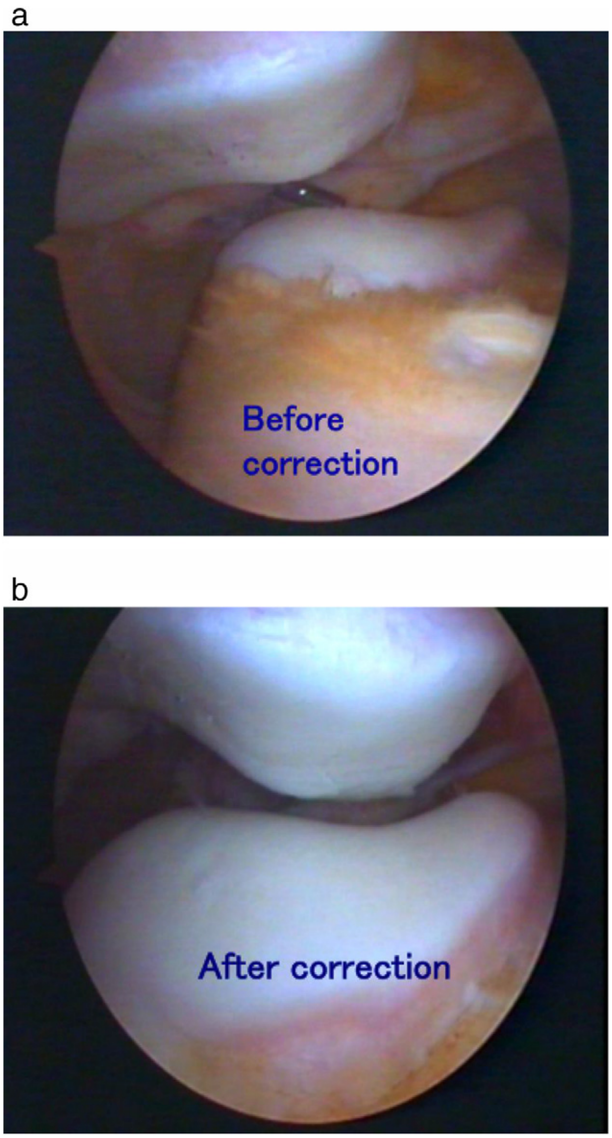

Figure 3. a) Arthroscopic photo prior to MPFL reconstruction demonstrating a typical appearance of a laterally lying patella whose pole lies at the lateral-most edge of the trochlea, well lateral to the groove. b) Arthroscopic photo after MPFL reconstruction demonstrating that the patella is now central in the groove but not excessively medialised or compressed against the trochlea, implying that tension is optimal.

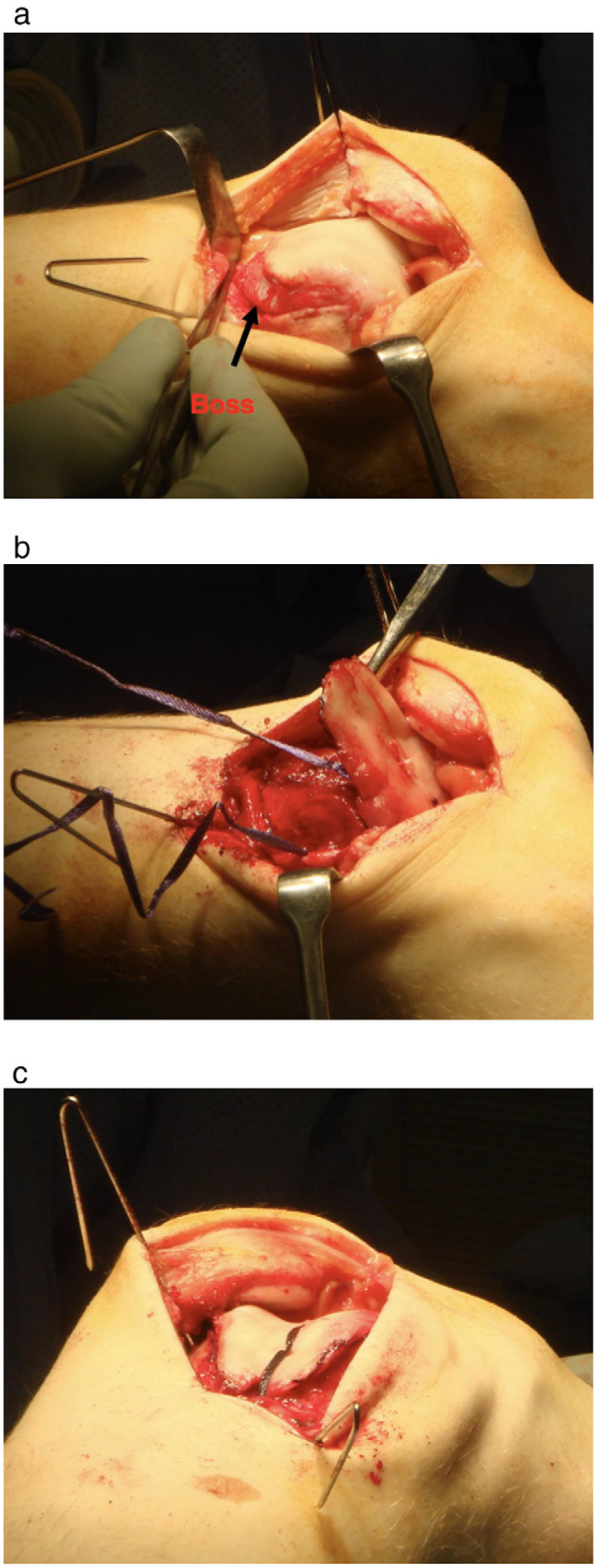

Figure 4. a) Exposure for trochleoplasty, showing evidence of trochlea dysplasia b) A thin flap has been raised, a new groove made in the subchondral bone, and vicryl tape inserted into bone holes c) The flap has been closed and moulded into the new groove, and secured with the vicryl tape.

and stiffer than the native MPFL and may risk overloading the medial side of the patello-femoral joint. Similarly, synthetic grafts risk the development of medial sided patello-femoral wear.

MPFL reconstruction techniques should focus on accurate placement of the femoral tunnel, as this is the major factor that dictates graft tension. More proximal femoral tunnel positions risk overload of the medial side of the patello-femoral joint, and result in stretching and the recurrence of instability symptoms. The radiographic landmarks for femoral tunnel position have been described by Schöttle et al. [25], Wijdicks et al. [26] and Barnett et al. [27]. It is worth noting that these radiographic landmarks were identified in the normal population who did not have patellar instability and many surgeons advocate intraoperative isometric testing of graft placement prior to drilling the femoral tunnel.

Equally, numerous techniques for graft fixation to the patella have been described with the presence of transverse tunnels being associated with a higher risk of patella fracture [28–30]. The importance of checking patella position arthroscopically during final fixation of the MPFL graft is considered highly important by many experienced MPFL surgeons (Figure 3).

3.3. Trochleoplasty

Trochleoplasty procedures are used to correct trochlear dysplasia. The first trochleoplasty was actually described in 1890 by Pollard and several other techniques have been described since. Trochleoplasty is the only operative procedure that addresses the bony abnormality seen in trochlear dysplasia. There are three well-known trochleoplasty procedures, the Albee, Dejour and Bereiter types [31–33]. The Albee trochleoplasty consists of an osteotomy that elevates the lateral side of the trochlea and is illogical, as it does not correct the abnormality of the domed central part of the trochlea.

The Dejour and Bereiter trochleoplasties both create a central trochlea groove and are now the favoured techniques. The Dejour trochleoplasty creates a gap beneath the trochlea surface before the trochlea is split longitudinally and the two flaps collapsed into the gap and held with staples, screws or sutures. Dejour described this technique in 1987 as a modification of the Masse trochleoplasty published in 1978 [34].

The Bereiter trochleoplasty [33] involves elevating an osteochondral flap, which is thinned and then moulded into a groove in the underlying bone that is created with osteotomes and a burr (Figure 4). Arthroscopic techniques are also described. Patients requiring trochleoplasty surgery always have a lax medial retinaculum that requires addressing either with reefing/double

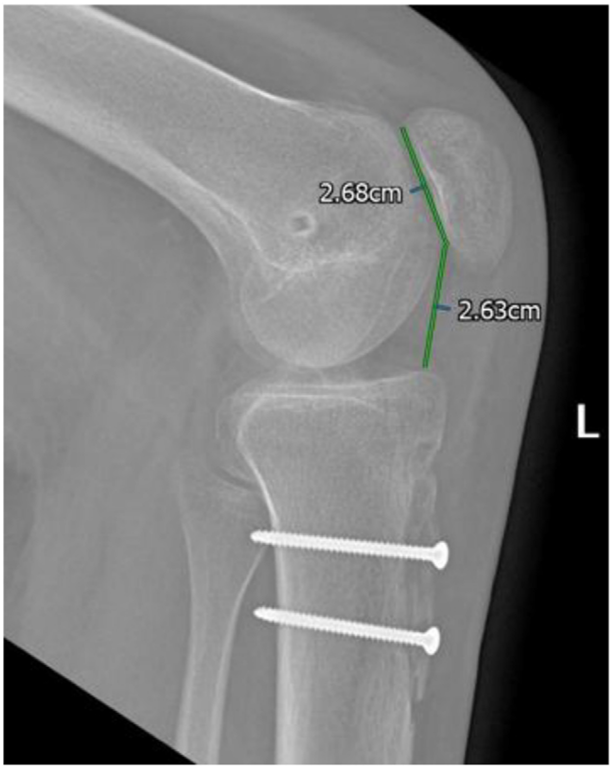

Figure 5. X-ray showing combined TT distalisation + MPFL Reconstruction.

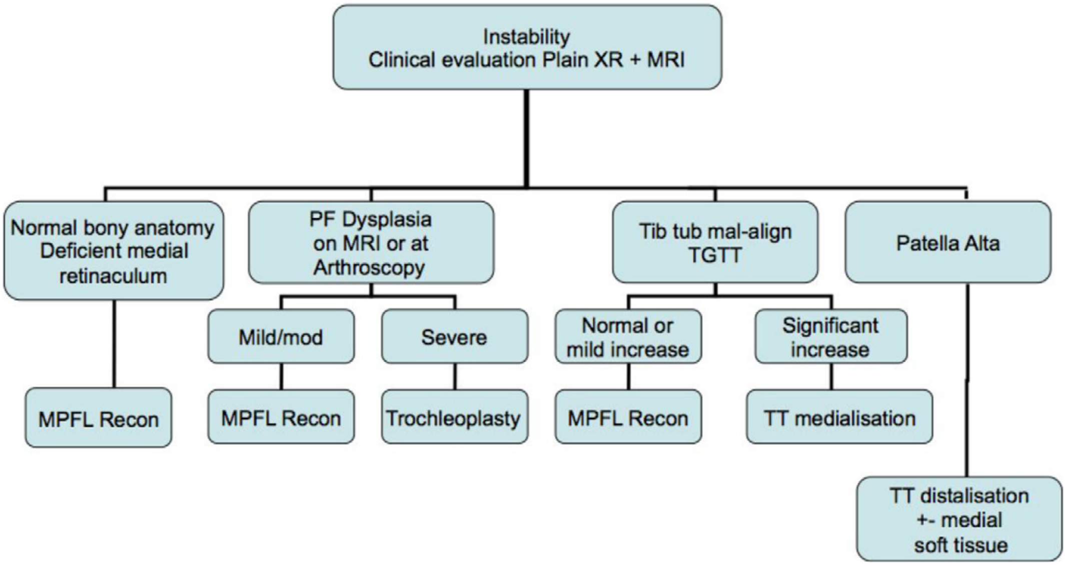

Figure 6. Algorithm for surgical management of patellar instability.

breasting techniques, or by formal MPFL reconstruction [35]. Trochleoplasty surgery may require combining with tuberosity realignment to correct patella alta or an extremely laterally positioned tuberosity.

3.4. Tibial tuberosity realignment

Distal realignment of the tibial tuberosity has been performed for a number of decades to treat patellar instability. Antero-medialisation of the tuberosity was popularised by Fulkerson [36] in the United States and direct medialisation by Elmslie and Trillat in Europe [37]. Historically, isolated medialisation of the tibial tuberosity was commonly performed, but as the effect of patella alta on patellar stability has been increasingly recognised, many UK surgeons have moved to performing distalisation of the tibial tuberosity, which also produces a small medialisation effect. The effect of tibial tuberosity medialisation and lateralisation on patello-femoral joint kinematics, contact mechanics and stability has been investigated by Stephen et al. [38] with an excessively lateralised tuberosity increasing lateral patello-femoral contact pressures and reducing patella stability. Progressive medialisation was shown to correct the abnormal mechanics, but some long-term clinical studies have raised concerns regarding the development of medial sided patello-femoral osteoarthritis after tuberosity medialisation with osteoarthritis rates ranging from 30 to 75% [39–41].

Tuberosity distalisation to correct patella alta combined with MPFL reconstruction is the most commonly performed combination procedure (Figure 5).

Figure 6 shows a surgical algorithm to help with decision making when planning surgical treatment for patients with patello-femoral joint instability. There is no absolute consensus regarding values for each of anatomical measurements but the algorithm can help focus decision making on the relevant anatomical features.

3.5. Post-operative physiotherapy

Post-operative physiotherapy should be overseen by an experienced lower limb physiotherapist and address the whole kinetic chain. There should be a focus on core and gluteal strengthening exercises, combined with improving balance and movement patterns. Appropriate early restrictions on range of motion and extensor mechanism loading must be put in place following tuberosity surgery to reduce the risk of non-union/detachment of the repositioned tuberosity.

4. Summary

Successful surgical treatment of patello-femoral instability requires accurate clinical and radiological assessment of patients to identify the most abnormal anatomy that is contributing to the instability. Patients should be assessed radiologically using a mixture of plain X-rays and MRI scans with CT scan and long leg alignment X-rays being reserved for patients with more extreme valgus and rotational mal-alignment. It is important to recognise the limitations of radiographical measurements, but surgery should target the most abnormal anatomy.

Medial patello-femoral ligament reconstruction, tibial tuberosity realignment and trochleoplasty are the most commonly indicated procedures and some patients may be best treated by combination procedures. Osteotomy to correct valgus or rotational alignment is occasionally indicated and lateral release should be avoided.

Declaration of competing interest

We have no financial conflicts of interest to declare. Mr. Metcalfe is secretary of the British Patello-Femoral Society and Mr. Thompson is one of its founder committee members.

Acknowledgement

We would like to thank the NIHR Clinical Research Network for their pump-priming funding which helped us deliver the surgical consensus for the PIPS (Patella Instability: Physiotherapy or Surgery) feasibility study, which has partially informed this paper.

References

[1] Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias Da, et al. Epidemiology and natural history of acute patellar dislocation. The American journal of sports medicine.32: 1114–21.
[2] Atkin DM, Fithian DC, Marangi KS, Stone ML, Dobson BE, Mendelsohn C, et al. Characteristics of patients with primary acute lateral patellar dislocation and their recovery within the first 6 months of injury, vol. 28; 2000; 472–9.
[3] Nietosvaara Y, Aalto K, Kallio PE. Acute patellar dislocation in children: incidence and associated osteochondral fractures. J Pediatr Orthop 1994;14:513–5.
[4] Stefancin JJ, Parker RD. First-time traumatic patellar dislocation: a systematic review. Clin Orthop Relat Res 2007;455:93–101.
[5] Magnussen RA, Verlage M, Stock E, Zurek L, Flanigan DC, Tompkins M, et al. Primary patellar dislocations without surgical stabilization or recurrence: how well are these patients really doing? Knee Surg Sports Traumatol Arthrosc 2015:2–6.
[6] Hawkins RJ, Bell RH, Anisette G. Acute patellar dislocations. The natural history The American journal of sports medicine 1986;14:117–20.
[7] Amis A, Oguz C, Bull MJ, Senavongse W, Dejour D. The effect of trochleoplasty on patellar stability and kinematics: a biomechanical study in vitro. J Bone Joint Surg 2008;90:864–9.
[8] Senavongse W, Amis A. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. J Bone Joint Surg Br 2005;87:577–82.
[9] Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med 1998;26:59–65.
[10] Philippot R, Boyer B, Testa R, Farizon F, Moyen B. The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc 2012;20:331–6.
[11] Hautamaa PV, Fithian DC, Kaufman KR, Daniel DM, Pohlmeyer AM. Medial soft tissue restraints in lateral patellar instability and repair. Clin Orthop Relat Res 1998:174–82.
[12] Nomura E, Inoue M, Osada N. Anatomical analysis of the medial patellofemoral ligament of the knee, especially the femoral attachment. Knee Surg Sports Traumatol Arthrosc 2005;13:510–5.
[13] Zaffagnini S, Colle F, Lopomo N, Sharma B, Bignozzi S, Dejour D, et al. The influence of medial patellofemoral ligament on patellofemoral joint kinematics and patellar stability. Knee Surg Sports Traumatol Arthrosc 2013;21:2164–71.
[14] LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. J Bone Joint Surg Am 2007;89:2000–10.
[15] Amis AA, Firer P, Mountney J, Senavongse W, Thomas NP. Anatomy and biomechanics of the medial patellofemoral ligament. Knee 2003:215–20.
[16] Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2:19–26.
[17] Insall J, Salvati E. Patella position in the normal knee joint. Radiology 1971;101:101–4.
[18] Blackburne JS, Peel TE. A new method of measuring patellar height. J Bone Joint Surg Br 1977;59:241–2.
[19] Caton J. Method of measuring the height of the patella. Acta Orthop Belg 1989;55:385–6.
[20] Biedert R, Albrecht S. The patellotrochlear index: a new index for assessing patellar height. Knee Surg Sports Traumatol Arthrosc 2006;14:707–12.
[21] Dejour H, Walch G, Nevret P, Adeleine P. Dysplasia of the femoral trochlea. Rev Chir Orthop Reparatrice Appar Mot 1990;76:45–54 [in French].
[22] Hingelbaum S, Best R, Huth J, Wagner D, Bauer G, Mauch F. The TT-TG Index: a new knee size adjusted measure method to determine the TT-TG distance. Knee Surg Sports Traumatol Arthrosc 2014;22:2388–95.
[23] Bedi H, Marzo J. The biomechanics of medial patellofemoral ligament repair followed by lateral retinacular release. Am J Sports Med 2010;38:1462–7.
[24] Christoforakis J, Bull AM, Strachan RK, Shymkiw R, Senavongse W, Amis AA. Effects of lateral retinacular release on the lateral stability of the patella. Knee Surg Sports Traumatol Arthrosc 2006;14:273–7.
[25] Schottle PB, Schmeling A, Rosenstiel N, Weiler A. Radiographic landmarks for femoral tunnel placement in medial patellofemoral ligament reconstruction. Am J Sports Med 2007;35:801–4.
[26] Wijdicks CA, Griffith CJ, LaPrade RF, Johansen S, Sunderland A, Arendt EA, et al. Radiographic identification of the primary medial knee structures. J Bone Joint Surg Am 2009;91:521–9.
[27] Barnett AJ, Howells NR, Burston BJ, Ansari A, Clark D, Eldridge JD. Radiographic landmarks for tunnel placement in reconstruction of the medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc 2012;20:2380–4.
[28] Parikh SN, Nathan ST, Wall EJ, Eismann EA. Complications of medial patellofemoral ligament reconstruction in young patients. Am J Sports Med 2013;41:1030–8.
[29] Tanaka MJ, Bollier MJ, Andrish JT, Fulkerson JP, Cosgarea AJ. Complications of medial patellofemoral ligament reconstruction: common technical errors and factors for success: AAOS exhibit selection. J Bone Joint Surg Am 2012;94:e87.
[30] Shah JNH, Jennifer S, Flanigan David C, Brophy Robert H, Carey James L, Lattermann Christian. A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med 2013;40:1916–23.
[31] Albee F. The bone graft wedge in the treatment of habitual dislocation of the patella. Med Rec 1915;88:257–9.
[32] Dejour D. Summary A. deepening trochleoplasty for treatment of recurrent dislocation of the patella: indications, surgical technique, results; 2012; 1–12.
[33] Bereiter H, Gautier E. Die Trochleaplastik als Chirurgische Therapie der Rezidivierenden Patellaluxation bei Trochleadysplasie. Arthroskopie 1994;7:281–6.
[34] Masse Y. Trochleoplasty: restoration of the intercondylar groove in subluxations and dislocations of the patella. Rev Chir Orthop Reparatrice Appar Mot 1978;64: 3–17 [in French].
[35] Metcalfe AJ, Clark DA, Kemp M, Eldridge J. The Bristol experience of the bereiter trochleoplasty: indications and technique. Operative Techniques in Sports MedicineS 2015;23:123–8.
[36] Fulkerson JP, Shea KP. Disorders of patellofemoral alignment. The Journal of Bone and Joint Surgery American 1990;72(9):1424–9.

[37] Naranja Jr RJ, Reilly PJ, Kuhlman JR, Haut E, Torg JS. Long-term evaluation of the Elmslie-Trillat-Maquet procedure for patellofemoral dysfunction. Am J Sports Med 1996;24:779–84.
[38] Stephen JM, Lumpaopong P, Dodds AL, Williams A, Aa Amis. The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. The American journal of sports medicine 2015;43:186–94.
[39] Arnbjörnsson A, Egund N, Rydling O, Stockerup R, Ryd L. The natural history of recurrent dislocation of the patella. Long-term results of conservative and operative treatment. J Bone Joint Surg 1992;74:140–2.
[40] Naveed MA, Ackroyd CE, Porteous AJ. Long-term (ten- to 15-year) outcome of arthroscopically assisted Elmslie-Trillat tibial tubercle osteotomy. Bone and Joint Journal 2013;95(B):478–85.
[41] Tigchelaar S, Van Essen P, Bénard M, Koëter S, Wymenga A. A self-centring osteotomy of the tibial tubercle for patellar maltracking or instability: Results with ten-years' follow-up. Bone and Joint Journal 2015;97-B:329–36.