Total knee arthroplasty in the varus knee: tips and tricks

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INTRODUCTION

Varus deformity of the knee is the most common angular deformity in total knee arthroplasty (TKA) [1]. It is typically characterized by a mechanical axis of less than 180° at the long-leg x-rays, with a medial joint line narrowing and a proximal tibial deformity. In some cases, there may be an associated flexion and a medial soft tissue contracture with lateral soft tissue elongation. In less than 10% of the cases a severe varus deformity is present, with medial subluxation of the femur on the tibia, requiring more complex reconstruction [2].

The varus arthritic knee can be characterized by both bone and soft tissue deformity. As recently demonstrated by Thienpont et al, varus deformity are often correlated to medial tibial disease and lateral joint distraction, with a Joint Line Congruency Angle (JLCA) of about 3° (Fig.1). If varus deformity is more substantial, and measured deformity is more important than the measured intra-articular angles, an extra-articular deformity must be suspected. In the varus knee, the most common extra-articular deformity is a femoral bowing or varus proximal tibia [3]. Soft tissues are also involved in varus knee, and it can be divided into static stabilizers (i.e. ligament) or dynamic stabilizers (i.e. tendon). The most important static stabilizers involved in varus knees are the superficial medial collateral ligament (sMCL) and the posterior oblique ligament (POL). The dynamic stabilizer involved in varus knees is the semimembranosus. It is important to underline that the release of anterior structures (i.e. sMCL) tends to increase the flexion gap more than the extension gap. Conversely, release of more posterior structures (i.e. POL or Semimembranosus) will increase the extension gap more than the flexion one. Furthermore, as previously described, varus knee is often associated to flexion contracture. The sacrifice of Posterior Cruciate Ligament (PCL) in Postero-stabilized (PS) implants further increase the flexion gap [4].

Different authors recently introduced the "constitutional varus", defined as a physiologic mechanical alignment of 3° varus or more. Particularly, Bellemans et al found that in healthy population 32% of male had a constitutional varus [5]. Different authors speculated that in these patients, correction to a neutral alignment potentially decrease patient satisfaction due to biomechanical changes [6]**.**

Recently, few studies described a relationship between knee varus deformity and compensatory valgus changes in the ankle and subtalar joints [7, 8]. Correction of varus knee may lead to valgus hindfoot correction. However, some studies reported than in more than 80% of the patients with rigid ankle and foot deformity, the valgus hindfoot and midfoot alignment is not affected by TKA alignment correction [9].

There are different classifications of knee deformities. De Muylder et al classified them according to the degree of the deformity into well aligned knees (0°-3° deviation), common deformities (4°-10° deviation), substantial deformities (11°-20° deviation), important deformities (21°-30° deviation) and extreme deformities (greater than 30° deviation) [10]. The same authors, similarly to others, observed that important and extreme deformities (greater than 20°) are difficult to correct to neutral alignment with conventional surgical technique, and are often related to extra-articular deformities such as femoral bowing or proximal tibial varus deformities [11].

Thienpont and Parvizi [12] recently proposed a new classification mainly based on deformity location. Intra-articular deformities (Type IA) can be divided according to the degree of reducibility into four group. Group 1 included reducible antero-medial osteoarthritis (AMOA) with intact Anterior Cruciate Ligament (ACL), in which there is a Kellegren-Lawrence (KL) type 4 OA with bone on bone contact, and the antero-medial wear can be confirmed with Magnetic Resonance Imaging (MRI) or Computer Tomography (CT) scans. Group 2 included reducible postero-medial OA (PMOA) with a deficient ACL, in which there is a bone on bone medial OA and the postero-medial wear can be observed on x-rays and confirmed with MRI or CT scans. Group 3 included fixed varus deformities without lateral laxity and group 4 included fixed varus deformities with lateral laxity. The second type are the metaphyseal deformity (Type M), located within 5 cm of joint line, and can be at the femoral (F) or tibial (T) side. These deformities can be further divided into 2 groups: Metaphyseal involvement because of wear or metaphyseal involvement because of changed joint line obliquity. The last type is the diaphyseal deformity (Type D), located at least 5 cm away from joint line. These deformities are further divided into 3 groups: 1) Deformity at the tibial level; 2) Deformity at the femoral level; 3) Combined femoral and tibial deformity. Table 1 summarized this classification.

Once the varus knee has been classified, a careful pre-operative planning should be performed. Different surgical technique can be performed for TKA in the varus knee. In this manuscript, the preoperative planning and implant selection, as well as surgical techniques and outcomes of TKA in the varus knee will be discussed.

PRE-OPERATIVE PLANNING AND IMPLANT SELECTION

Radiographic planning

In our experience a complete radiographic pre-operative planning is mandatory, and it includes weight bearing long-leg, antero-posterior, lateral, Rosenberg and Merchant views [13].

In the antero-posterior (AP) view, attention should be focused to the overall lower limb alignment and to the joint line obliquity. In the lateral view, presence of posterior osteophytes should be noted. Furthermore, in advanced deformities the worn medial tibial plateau develops a concave “pagoda-like” shape. This deformity should be pre-operatively evaluated on lateral x-rays because it may be difficult to dislocate the tibia during the surgery, and it may require posterior tibial plateau osteophytes resection with osteotomes prior to tibial dislocation. Furthermore, in the lateral view, patellar height should be evaluated using Caton-Deshamps or Insall-Salvati index [14].

In the AP view the planning for both femoral and tibial cuts can be performed. Usually an intramedullary guide is used at the femoral side. Presence of extra-articular deformity or excessive femoral bowing should be carefully evaluated because they can interfere with the entry point of intra-medullary guide [14]. The valgus correction angle (VCA) or angle of resection of the distal femur is conventionally set between 5° to 7° in varus knees. However, Mullaji et al demonstrated that the VCA can vary from 2° to 12° depending on the severity of the deformity. The authors suggested that VCA should be individualized for each patient based on the Hip-Knee angle (HKA) measured on the long-leg x-rays [15]. Furthermore, also the amount of distal femoral and proximal tibial resection can be planned on the pre-operative x-rays, and they should be individualized based on the severity of the deformity and the presence of medio-lateral soft tissue imbalance. Different authors suggested that both femoral and tibial resection should be less than 8 mm if there is a severe deformity, tibial subluxation indicating severe medio-lateral instability or in case of recurvatum deformity [15, 16]. Finally, pre-operative evaluation of femoral and tibial size may also be performed on AP and lateral x-rays, as well as plan for posterior osteophytes removal, which can affect the flexion gap, particularly in cases where a flexion contracture is present [17].

Knee evaluation

Careful knee evaluation is mandatory in TKA pre-operative planning. The overall limb alignment should be assessed both in supine and weight-bearing position. Any sagittal deformity, such as recurvatum or flexion deformity, should be evaluated. If a flexion deformity is associated to the varus knee, a Posterior Cruciate Ligament (PCL) sacrificing implant should be considered, because a correct balancing of the PCL may be very difficult [18].

Similarly to valgus deformity, the knee should be evaluated for anteroposterior laxity, range of motion (ROM), coronal and sagittal deformity, and mediolateral instability [13].

It is crucial to evaluate the gait pattern of the patients. As previously described by Noyes et al, most of all in varus knees associated to ACL injuries, three types of varus can be recognized: single varus, double varus (varus alignment and ACL injury) or triple varus (varus alignment, ACL injury and postero-lateral deficiency) [19]. Some patients with a varus knee associated to ACL deficiency may be develop overtime a postero-lateral soft tissue deficiency, demonstrating a varus thrust when ambulating. These patients may need of some sort of constrain when a TKA is performed. Similarly to valgus deformity [13], and as described by Thienpont and Parvizi in their new classification [12] it is mandatory to evaluate the reducibility of the deformity. Severe and not reducible deformities may require more extensive soft tissue release, so constrained implant may be considered, as previously described for valgus knees [13].

Selection of the implant

The impact of the deformity on the mechanical alignment, and the possibility to correct it with intra-articular procedures should be evaluated pre-operatively. Furthermore, the varus effect of extra-articular deformity can be calculated at his apex and then multiplied by the distance to the joint line. For example, a deformity at the middle of the femur (50%) has a 0.5 impact of the varus alignment. It means that the closer the deformity is to the joint line, the bigger is its influence on the coronal alignment. Furthermore, if the angle is smaller than the osteotomy needed through the lateral distal condyle, without risk for collateral ligament insertion injury, an intra-articular correction can be performed [12]. In severe varus knee, exceeding 15° of coronal deformity, soft tissue release may not be sufficient, and a tibial reduction osteotomy may be considered after proper soft tissue release. In these cases, a 2 mm osteotomy corrects 1° of the deformity [11]. Finally, need for extra-articular osteotomies should be carefully evaluated pre-operatively. As described by Mullaji et al [20], if the deformity is close to the joint, or it is greater than 20° in the coronal plane or if the plane of the distal cut compromised the attachment of the lateral collateral ligament on the lateral epicondyle, a corrective extra-articular osteotomy may be indicated and carefully planned.

Implant selection should be carried out pre-operatively based on radiological and clinical evaluation. In mild varus knee (<10° deformity) with no flexion contracture, a Cruciate Retaining (CR), Postero-stabilized (PS), Medial Congruence (MC) or Medial Pivoting (MP) implant may be used. In these cases, the deformity is normally reducible, and there is no need for further constrain.

If the varus knee is associated to flexion contracture, the PCL is part of the deformity, and it needs to be released. Some authors described and increased revision rate, together with a decreased ROM and survivorship if a CR implant is performed compared to PS implant in severe varus deformities associated to flexion contracture. In these cases, a PS implant is indicated over a CR implant [18, 21].

Condylar constrained implants are normally not necessary in varus deformity. However, in presence of a severe, not reducible, varus deformity associated or not to flexion contracture, an extensive soft tissue release may be necessary. In these cases, it may be useful a semi-constrained implant, such as a condylar constrained one, if a good ligamentous balance cannot be achieved without destabilizing the knee [22]. Semi-constrained implants may also be necessary in cases of varus deformity associated to previous multi-ligament knee surgery [23]. Furthermore, semi-constrained implants may also be used also in severe flexion deformity, if the knee cannot be correctly balanced throughout the ROM [24].

In presence of extra-articular deformity greater than 20° or 30° and close to the knee joint, a corrective osteotomy may be useful. In these cases, a stem extension and increasing the level of constrain may be indicated [2].

Recently different companies introduced the midlevel constraint (MLC) bearings, characterized by a wider post to provide increased varus/valgus and rotational stability. Considered the higher constrained with these inserts, it is suggested to use them in association to short tibial stem extension, to avoid early loosening on tibial side [25]**.** These MLC implants can be useful in severe varus deformity, particularly in the cases in which a varus thrust is present and a certain amount of instability is observed after soft tissue balancing. However, the lower level of constrain possible should always be preferred in total knee arthroplasty to decrease stresses on bone-prosthesis interface and potentially increase the longevity of the implant.

SURGICAL TECHNIQUE

Approach

The approach most commonly used in varus knees is the medial parapatellar approach exposing the tibia down to the anterior tibial tubercle. The patellar tendon is mobilized, and the medial plateau is exposed to the posterior midline. Cruciate ligaments have to be excised according to the type of implant chosen (CR or PS). Menisci have then to be completely excised. The knee is gradually flexed, and the tibia externally rotated till it is dislocated anteriorly. The foot is externally rotated, medial collateral ligaments released from the first 15-20 mm from proximal tibia and the posterior border of the medial plateau is exposed in the so-called Ransall manoeuvre.

Soft Tissue balancing

Releasing procedure has been described in different articles [26-30], by the way Mullaji et al. [31] proposed a sequence based on the analysis of the releases performed under computer assisted surgery control (Table 2). The first release is made removing osteophytes by the medial border of the plateau and femoral condyle with a rongeur. This procedure permits to reduce the bow-string effect on the medial collateral ligament and open the gap medially reducing the deformity. In most of the cases, this is enough to obtain a well-balanced knee.

The next step is the elevation of the deep part of the MCL using a Cobb elevator to the postero-medial section of the tibial plateau.

Sometimes the release of the semimembranosus tendon is required to increase the gap both in extension and flexion. To correctly expose the semimembranosus tendon the knee has to be placed in the “figure-of-four” position and the foot has to be externally rotated (Ransall manoeuver). While rotating the foot, the release is checked and gradually performed.

At this time, gap symmetry can be grossly checked in order to decide the need for further releases. Posterior osteophytes can influence the extension gap and the removal has always to be performed.

Additional releases are the superficial MCL elevation and pes anserinus release. The superficial MCL has to be elevated posteriorly to the pes anserinus using a Cobb elevator gradually from anterior to posterior. Superficial MCL should be carried out carefully, because a complete release or a mid-substance lesion can be hardly managed, and the risk is to obtain an overcorrection and medial instability in flexion or mid-flexion. Pes anserinus is released cutting tendons at 90°, starting from proximal and going distally checking the amount of the release during all the procedure. If the flexion gap is severely affected by the pes anserinus release it can be reattached with a staple with the knee at 90 degrees of flexion.

Bone cuts

Bone cuts have to be performed in a standard manner. Historically, tibial proximal has been performed perpendicular to the long tibial axis. The amount of bone to be resected has to be evaluated on the lateral side (8-10 mm according to the prosthetic design). When the medial plateau has a large bone defect it is possible to increase the tibial bone cut of 2 mm reducing the dimension of the bone defect.

In the last years the dogma of 90° tibial resection is under discussion; to reproduce the flexion–extension axis of the pre-arthritic knee and maintain the original collateral ligament balance and joint line the principle of the kinematic alignment has been presented [32].

The anatomical 3° of varus is restored and the cylindrical axis for femoral rotation results as a line equidistant from the articular surface of each femoral condyle [33, 34].

Varus alignment of the tibial component is historically related to aseptic loosening [35, 36] but kinematically aligned knees are perceived to be a good clinical surrogate for medial loading of the joint in patients with medial knee osteoarthritis [37-39].

Some studies demonstrated that a kinematic alignment does not unbalances the medial and lateral compartments because the frontal plane is not the only one that influences the joint [40].

In addition a study by Vanlommel et al. [41] showed better clinical outcome scores in varus aligned tibial plateaus (3°–6° varus) in a varus osteoarthritic population.

New implant designs are developing following these principles and new alignment philosophy.

Femoral distal cut has to be performed using the normal instrumentation and the normal valgus alignment. Has previously described, VCA should be individualized based on HKA angle [15].

Uncontained defects of the medial tibial plateau have to be addressed using the same procedure used in revision: cement fill, bone grafting or wedges. If the defect is less than 5 mm deep it is possible to manage it using bone cement only, when the defect is bigger has to be filled using cement reinforced with screws, bone grafts (using a step-cut technique) usually derived by the notch osteotomy, or metal augments and wedges according to surgeon’s attitude.

Other procedures

TIBIAL REDUCTION OSTEOTOMY

Varus deformities with medial contracture are usually associated with prominent osteophytes and proximal tibia remodelling [42, 43].

Osteophytes removal results in relaxation of the medial contracture, if this procedure is not enough to completely reduce the deformity, a reduction tibial osteotomy can be performed [31, 44-46] .The purpose of this procedure is to equalize medial and lateral gaps. The amount of medial tibial resection has to be planned according to the severity of the deformity, Mullaji et al. [11] considering that a correction of 1 degree requires a 2 mm reduction of the medial plateau.

The bone is regularized medially by downsizing the tibial plate that should be lateralized as much as possible moving the femoral shell laterally also to be centred on the tibial component.

SLIDING MEDIAL COLLATERAL LIGAMENT OSTEOTOMY

The indication for sliding medial collateral ligament osteotomy is a recalcitrant unbalanced varus deformity. It is performed when the normal balancing procedures have failed and in substitution of pes anserinus and superficial medial collateral ligament releases. This procedure can be used for both flexion and extension contracture. The medial femoral condyle has to be osteotomized and can be moved distally or posteriorly.

Moving the ligament origin distally increases the extension gap, while moving it posteriorly releases the flexion gap; the bone chip is then secured using a screw. The amount of release needed for a complete release without instability is difficult to obtain and it may require a computer assisted approach to precisely evaluate the needed translation. Mullaji et al. described this procedure achieving well balanced knees, high patient satisfaction and no need for constrain increase in implants[47].

RESULTS

Different authors described the outcomes of TKA in varus deformities [1, 44-46, 48-56]. Most of these studies are focused on deformities greater than 10°. The reported outcomes are good, with a survivorship ranging between 92% and 98% at ten years follow-up. The most relevant and recent articles are summarized in **Table 2**.

OUR TECHNIQUE

Pre-operative radiographs are extremely useful to access the canal in the correct position and avoid frontal malalignment.

In author's technique a medial para-patellar approach is performed, the anterior horn of the medial meniscus is cut and the deep fibers of the MCL are elevated by sub-periosteal dissection from the first 15-20 mm of tibia.

The medial borders of the tibial plateau and medial femoral condyle are exposed, and the postero-medial corner is exposed also using the so-called Ransall-maneuvre.

All osteophytes are removed on both sides of the joint; if not enough, the semimembranosus tendon is then gradually released keeping the knee in a "position-of-four". Tibial proximal and femoral distal cuts are then performed using the normal references (0° for the tibia and 5° of valgus on the femoral side).

After bone cuts, the extension gap is checked with the 10 mm spacer block. A contracted medial gap at this time of the surgery can be tolerated, especially if there are posterior osteophytes stretching the capsule. The next step is to assess dimension and rotation of the femoral component, taking care to completely remove the posterior condyles and all osteophytes in the posterior aspect of the joint, especially on medial side. With regard to antero-posterior cuts, we triple-check the posterior condylar reference cutting block position with both Whiteside line and transepicondylar axis; moreover, with the cutting blocks in site, we further check the balancing in flexion before performing the cuts.

Flexion and extension gaps are now checked again. When distal femoral and proximal tibial cuts are performed, the osteophytes are removed and the PCL is sacrificed, the knee is kept in extension with lamina spreaders to evaluate the extension gap.

If the balancing is not perfect, a reduction tibial osteotomy is performed when possible, and the tibial baseplate is reduced of one size lateralizing the femoral component (Fig. 2).

If soft tissue balancing is still not adequate the pie-crusting of the MCL under continuous distraction obtained with lamina spreader can be performed. MCL release is carefully checked throughout the range of motion to achieve good balancing and knee stability. No additional releases have never been used in the author's experience in obtaining a complete reduction of the deformity in all patients.

Standard PS implant has been used in most of the cases in author's experience. Semi-constrained implants have been rarely used, but it can be useful if varus deformity is associated to severe flexion deformity. MLC implants have been recently introduced. In the author's experience, they can be used in presence of severe deformity with pre-operative varus thrust or in case of mild medial instability after soft tissue balancing. If a MLC insert is used, a short tibial stem should be implanted to avoid risk of early loosening.

CONCLUSION

Varus knee is the most common deformity. Adequate soft tissue balancing and deformity correction is mandatory to obtain good outcomes. Particularly, soft tissue balancing is a step-wise approach, and it should be carried out only after osteophytes removal.

If varus deformity cannot be corrected with sequential soft tissue balancing, other procedures may be performed, such as tibial reduction osteotomy or medial epicondyle sliding osteotomy. These procedures should be reserved to severe deformity correction.

In conclusion, TKA in varus knees is a highly effective surgery with good results and patients satisfaction, I f an adequate soft tissue balancing, stability, alignment and fixation are obtained.

CONFLICT OF INTEREST

R. Rossi is a teaching consultant for Zimmer Biomet ®, Smith and Nephew ®, Depuy Mitek ®. The other authors have nothing to declare

FIGURES AND TABLES

Table 1. Varus Deformity Classification According to "Thienpont and Parvizi." (AMOA=anterior medial osteoarthritis, PMOA posterior medial osteoarthritis)

Table 2. Sequence of releases proposed by Mullaji et al

Table 3. Outcome of total knee arthroplasty in varus deformity (N/A=not applicable, TKA= Total Knee Arthroplasty, PS=postero-stabilized, CR=Cruciate Retaining, UC=Ultracongruent, CCK=Condylar Constrained Knee, ROM= Range Of Motion)

Figure 1. X-rays demonstrating a varus knee deformity

Figure 2. Intra-operative picture demonstrating a tibial reduction osteotomy

REFERENCES

1. Verdonk PC, Pernin J, Pinaroli A, Ait Si Selmi T, Neyret P (2009) Soft tissue balancing in varus total knee arthroplasty: an algorithmic approach. Knee Surg Sports Traumatol Arthrosc 17:660-666. DOI 10.1007/s00167-009-0755-7

2. Mullaji A, Marawar S, Sharma A (2007) Correcting varus deformity. J Arthroplasty 22:15-19. DOI 10.1016/j.arth.2007.01.017

3. Thienpont E, Schwab PE, Cornu O, Bellemans J, Victor J (2017) Bone morphotypes of the varus and valgus knee. Arch Orthop Trauma Surg 137:393-400. DOI 10.1007/s00402-017-2626-x

4. Mihalko WM, Saleh KJ, Krackow KA, Whiteside LA (2009) Soft-tissue balancing during total knee arthroplasty in the varus knee. J Am Acad Orthop Surg 17:766-774

5. Bellemans J, Colyn W, Vandenneucker H, Victor J (2012) The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 470:45-53. DOI 10.1007/s11999-011-1936-5

6. Vandekerckhove PTK, Matlovich N, Teeter MG, MacDonald SJ, Howard JL, Lanting BA (2017) The relationship between constitutional alignment and varus osteoarthritis of the knee. Knee Surg Sports Traumatol Arthrosc 25:2873-2879. DOI 10.1007/s00167-016-3994-4

7. Gao F, Ma J, Sun W, Guo W, Li Z, Wang W (2016) The influence of knee malalignment on the ankle alignment in varus and valgus gonarthrosis based on radiographic measurement. Eur J Radiol 85:228-232. DOI 10.1016/j.ejrad.2015.11.021

8. Norton AA, Callaghan JJ, Amendola A, Phisitkul P, Wongsak S, Liu SS, Fruehling-Wall C (2015) Correlation of knee and hindfoot deformities in advanced knee OA: compensatory hindfoot alignment and where it occurs. Clin Orthop Relat Res 473:166-174. DOI 10.1007/s11999-014-3801-9

9. Mullaji A, Shetty GM (2011) Persistent hindfoot valgus causes lateral deviation of weightbearing axis after total knee arthroplasty. Clin Orthop Relat Res 469:1154-1160. DOI 10.1007/s11999-010-1703-z

10. De Muylder J, Victor J, Cornu O, Kaminski L, Thienpont E (2015) Total knee arthroplasty in patients with substantial deformities using primary knee components. Knee Surg Sports Traumatol Arthrosc 23:3653-3659. DOI 10.1007/s00167-014-3269-x

11. Mullaji AB, Shetty GM (2014) Correction of varus deformity during TKA with reduction osteotomy. Clin Orthop Relat Res 472:126-132. DOI 10.1007/s11999-013-3077-5

12. Thienpont E, Parvizi J (2016) A New Classification for the Varus Knee. J Arthroplasty 31:2156-2160. DOI 10.1016/j.arth.2016.03.034

13. Rossi R, Rosso F, Cottino U, Dettoni F, Bonasia DE, Bruzzone M (2014) Total knee arthroplasty in the valgus knee. Int Orthop 38:273-283. DOI 10.1007/s00264-013-2227-4

14. Tanzer M, Makhdom AM (2016) Preoperative Planning in Primary Total Knee Arthroplasty. J Am Acad Orthop Surg 24:220-230. DOI 10.5435/JAAOS-D-14-00332

15. Mullaji AB, Shetty GM (2016) Correcting deformity in total knee arthroplasty: Techniques to avoid the release of collateral ligaments in severely deformed knees. Bone Joint J 98-B:101-104. DOI 10.1302/0301-620X.98B1.36207

16. Mullaji A, Lingaraju AP, Shetty GM (2012) Computer-assisted total knee replacement in patients with arthritis and a recurvatum deformity. J Bone Joint Surg Br 94:642-647. DOI 10.1302/0301-620X.94B5.27211

17. Jenkinson ML, Bliss MR, Brain AT, Scott DL (1989) Peripheral arthritis in the elderly: a hospital study. Ann Rheum Dis 48:227-231
18. Meftah M, Blum YC, Raja D, Ranawat AS, Ranawat CS (2012) Correcting fixed varus deformity with flexion contracture during total knee arthroplasty: the "inside-out" technique: AAOS exhibit selection. J Bone Joint Surg Am 94:e66. DOI 10.2106/JBJS.K.01444
19. Noyes FR, Barber-Westin SD, Hewett TE (2000) High tibial osteotomy and ligament reconstruction for varus angulated anterior cruciate ligament-deficient knees. Am J Sports Med 28:282-296. DOI 10.1177/03635465000280030201
20. Mullaji A, Shetty GM (2009) Computer-assisted total knee arthroplasty for arthritis with extra-articular deformity. J Arthroplasty 24:1164-1169 e1161. DOI 10.1016/j.arth.2009.05.005
21. Laskin RS (1996) The Insall Award. Total knee replacement with posterior cruciate ligament retention in patients with a fixed varus deformity. Clin Orthop Relat Res:29-34
22. Adravanti P, Vasta S (2017) Varus-valgus constrained implants in total knee arthroplasty: indications and technique. Acta Biomed 88:112-117. DOI 10.23750/abm.v88i2 -S.6521
23. Pancio SI, Sousa PL, Krych AJ, Abdel MP, Levy BA, Dahm DL, Stuart MJ (2017) Increased Risk of Revision, Reoperation, and Implant Constraint in TKA After Multiligament Knee Surgery. Clin Orthop Relat Res 475:1618-1626. DOI 10.1007/s11999-017-5230-z
24. Lachiewicz PF, Soileau ES (2006) Ten-year survival and clinical results of constrained components in primary total knee arthroplasty. J Arthroplasty 21:803-808. DOI 10.1016/j.arth.2005.09.008
25. Crawford DA, Law JI, Lombardi AV, Jr., Berend KR (2018) Midlevel Constraint Without Stem Extensions in Primary Total Knee Arthroplasty Provides Stability Without Compromising Fixation. J Arthroplasty. DOI 10.1016/j.arth.2018.03.070
26. Clayton ML, Thompson TR, Mack RP (1986) Correction of alignment deformities during total knee arthroplasties: staged soft-tissue releases. Clin Orthop Relat Res:117-124
27. Engh GA (2003) The difficult knee: severe varus and valgus. Clin Orthop Relat Res:58-63. DOI 10.1097/01.blo.0000092987.12414.fc
28. Luring C, Bathis H, Hufner T, Grauvogel C, Perlick L, Grifka J (2006) Gap configuration and anteroposterior leg axis after sequential medial ligament release in rotating-platform total knee arthroplasty. Acta Orthop 77:149-155. DOI 10.1080/17453670610045849
29. Warren LA, Marshall JL, Girgis F (1974) The prime static stabilizer of the medical side of the knee. J Bone Joint Surg Am 56:665-674
30. Markolf KL, Mensch JS, Amstutz HC (1976) Stiffness and laxity of the knee--the contributions of the supporting structures. A quantitative in vitro study. J Bone Joint Surg Am 58:583-594
31. Mullaji A, Sharma A, Marawar S, Kanna R (2009) Quantification of effect of sequential posteromedial release on flexion and extension gaps: a computer-assisted study in cadaveric knees. J Arthroplasty 24:795-805. DOI 10.1016/j.arth.2008.03.018
32. Niki Y, Nagura T, Nagai K, Kobayashi S, Harato K (2018) Kinematically aligned total knee arthroplasty reduces knee adduction moment more than mechanically aligned total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 26:1629-1635. DOI 10.1007/s00167-017-4788-z
33. Eckhoff DG, Bach JM, Spitzer VM, Reinig KD, Bagur MM, Baldini TH, Flannery NM (2005) Three-dimensional mechanics, kinematics, and morphology of the knee viewed in virtual reality. J Bone Joint Surg Am 87 Suppl 2:71-80. DOI 10.2106/JBJS.E.00440
34. Eckhoff D, Hogan C, DiMatteo L, Robinson M, Bach J (2007) Difference between the epicondylar and cylindrical axis of the knee. Clin Orthop Relat Res 461:238-244. DOI 10.1097/BLO.0b013e318112416b

35. Liau JJ, Cheng CK, Huang CH, Lee YM, Chueh SC, Lo WH (1999) The influence of contact alignment of the tibiofemoral joint of the prostheses in in vitro biomechanical testing. Clin Biomech (Bristol, Avon) 14:717-721

36. Werner FW, Ayers DC, Maletsky LP, Rullkoetter PJ (2005) The effect of valgus/varus malalignment on load distribution in total knee replacements. J Biomech 38:349-355. DOI 10.1016/j.jbiomech.2004.02.024

37. Chang AH, Moisio KC, Chmiel JS, Eckstein F, Guermazi A, Prasad PV, Zhang Y, Almagor O, Belisle L, Hayes K, Sharma L (2015) External knee adduction and flexion moments during gait and medial tibiofemoral disease progression in knee osteoarthritis. Osteoarthritis Cartilage 23:1099-1106. DOI 10.1016/j.joca.2015.02.005

38. Sharma L, Hurwitz DE, Thonar EJ, Sum JA, Lenz ME, Dunlop DD, Schnitzer TJ, Kirwan-Mellis G, Andriacchi TP (1998) Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. Arthritis Rheum 41:1233-1240. DOI 10.1002/1529-0131(199807)41:7<1233::AID-ART14>3.0.CO;2-L

39. Mahmoudian A, van Dieen JH, Bruijn SM, Baert IA, Faber GS, Luyten FP, Verschueren SM (2016) Varus thrust in women with early medial knee osteoarthritis and its relation with the external knee adduction moment. Clin Biomech (Bristol, Avon) 39:109-114. DOI 10.1016/j.clinbiomech.2016.10.006

40. Miller EJ, Pagnano MW, Kaufman KR (2014) Tibiofemoral alignment in posterior stabilized total knee arthroplasty: Static alignment does not predict dynamic tibial plateau loading. J Orthop Res 32:1068-1074. DOI 10.1002/jor.22644

41. Vanlommel L, Vanlommel J, Claes S, Bellemans J (2013) Slight undercorrection following total knee arthroplasty results in superior clinical outcomes in varus knees. Knee Surg Sports Traumatol Arthrosc 21:2325-2330. DOI 10.1007/s00167-013-2481-4

42. Chang CB, Koh IJ, Seo ES, Kang YG, Seong SC, Kim TK (2011) The radiographic predictors of symptom severity in advanced knee osteoarthritis with varus deformity. Knee 18:456-460. DOI 10.1016/j.knee.2010.08.010

43. Lo GH, Tassinari AM, Driban JB, Price LL, Schneider E, Majumdar S, McAlindon TE (2012) Cross-sectional DXA and MR measures of tibial periarticular bone associate with radiographic knee osteoarthritis severity. Osteoarthritis Cartilage 20:686-693. DOI 10.1016/j.joca.2012.03.006

44. Dixon MC, Parsch D, Brown RR, Scott RD (2004) The correction of severe varus deformity in total knee arthroplasty by tibial component downsizing and resection of uncapped proximal medial bone. J Arthroplasty 19:19-22

45. Mullaji AB, Padmanabhan V, Jindal G (2005) Total knee arthroplasty for profound varus deformity: technique and radiological results in 173 knees with varus of more than 20 degrees. J Arthroplasty 20:550-561. DOI 10.1016/j.arth.2005.04.009

46. Ritter MA, Faris GW, Faris PM, Davis KE (2004) Total knee arthroplasty in patients with angular varus or valgus deformities of > or = 20 degrees. J Arthroplasty 19:862-866

47. Mullaji AB, Shetty GM (2013) Surgical technique: Computer-assisted sliding medial condylar osteotomy to achieve gap balance in varus knees during TKA. Clin Orthop Relat Res 471:1484-1491. DOI 10.1007/s11999-012-2773-x

48. Teeny SM, Krackow KA, Hungerford DS, Jones M (1991) Primary total knee arthroplasty in patients with severe varus deformity. A comparative study. Clin Orthop Relat Res:19-31

49. Bellemans J, Vandenneucker H, Van Lauwe J, Victor J (2010) A new surgical technique for medial collateral ligament balancing: multiple needle puncturing. J Arthroplasty 25:1151-1156. DOI 10.1016/j.arth.2010.03.007

50. Rames RD, Mathison M, Meyer Z, Barrack RL, Nam D (2018) No impact of under-correction and joint line obliquity on clinical outcomes of total knee arthroplasty for the varus knee. Knee Surg Sports Traumatol Arthrosc 26:1506-1514. DOI 10.1007/s00167-017-4507-9
51. Goudarz Mehdikhani K, Morales Moreno B, Reid JJ, de Paz Nieves A, Lee YY, Gonzalez Della Valle A (2016) An Algorithmic, Pie-Crusting Medial Soft Tissue Release Reduces the Need for Constrained Inserts Patients With Severe Varus Deformity Undergoing Total Knee Arthroplasty. J Arthroplasty 31:1465-1469. DOI 10.1016/j.arth.2016.01.006
52. Puliero B, Favreau H, Eichler D, Adam P, Bonnomet F, Ehlinger M (2018) Total knee arthroplasty in patients with varus deformities greater than ten degrees: survival analysis at a mean ten year follow-up. Int Orthop. DOI 10.1007/s00264-018-4019-3
53. Karachalios T, Sarangi PP, Newman JH (1994) Severe varus and valgus deformities treated by total knee arthroplasty. J Bone Joint Surg Br 76:938-942
54. Liu HC, Kuo FC, Huang CC, Wang JW (2015) Mini-midvastus total knee arthroplasty in patients with severe varus deformity. Orthopedics 38:e112-117. DOI 10.3928/01477447-20150204-58
55. Saragaglia D, Sigwalt L, Gaillot J, Morin V, Rubens-Duval B, Pailhe R (2018) Results with eight and a half years average follow-up on two hundred and eight e-Motion FP(R) knee prostheses, fitted using computer navigation for knee osteoarthritis in patients with over ten degrees genu varum. Int Orthop 42:799-804. DOI 10.1007/s00264-017-3618-8
56. Czekaj J, Fary C, Gaillard T, Lustig S (2017) Does low-constraint mobile bearing knee prosthesis give satisfactory results for severe coronal deformities? A five to twelve year follow up study. Int Orthop 41:1369-1377. DOI 10.1007/s00264-017-3452-z