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Total knee arthroplasty in the varus knee: tips and tricks

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].

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

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

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

41 Thienpont and Parvizi [12] recently proposed a new classification mainly based on deformity
42 location. Intra-articular deformities (Type IA) can be divided according to the degree of reducibility
43 into four group. Group 1 included reducible antero-medial osteoarthritis (AMOA) with intact
44 Anterior Cruciate Ligament (ACL), in which there is a Kellegren-Lawrence (KL) type 4 OA with bone
45 on bone contact, and the antero-medial wear can be confirmed with Magnetic Resonance Imaging
46 (MRI) or Computer Tomography (CT) scans. Group 2 included reducible postero-medial OA (PMOA)
47 with a deficient ACL, in which there is a bone on bone medial OA and the postero-medial wear can

48 be observed on x-rays and confirmed with MRI or CT scans. Group 3 included fixed varus deformities
49 without lateral laxity and group 4 included fixed varus deformities with lateral laxity. The second
50 type are the metaphyseal deformity (Type M), located within 5 cm of joint line, and can be at the
51 femoral (F) or tibial (T) side. These deformities can be further divided into 2 groups: Metaphyseal
52 involvement because of wear or metaphyseal involvement because of changed joint line obliquity.
53 The last type is the diaphyseal deformity (Type D), located at least 5 cm away from joint line. These
54 deformities are further divided into 3 groups: 1) Deformity at the tibial level; 2) Deformity at the
55 femoral level; 3) Combined femoral and tibial deformity. Table 1 summarized this classification.
56 Once the varus knee has been classified, a careful pre-operative planning should be performed.
57 Different surgical technique can be performed for TKA in the varus knee. In this manuscript, the
58 preoperative planning and implant selection, as well as surgical techniques and outcomes of TKA in
59 the varus knee will be discussed.

60

61 **PRE-OPERATIVE PLANNING AND IMPLANT SELECTION**

62 **Radiographic planning**

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

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

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

87

88 **Knee evaluation**

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

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

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

106

107 **Selection of the implant**

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

120 coronal plane or if the plane of the distal cut compromised the attachment of the lateral collateral
121 ligament on the lateral epicondyle, a corrective extra-articular osteotomy may be indicated and
122 carefully planned.

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

127 If the varus knee is associated to flexion contracture, the PCL is part of the deformity, and it needs
128 to be released. Some authors described an increased revision rate, together with a decreased ROM
129 and survivorship if a CR implant is performed compared to PS implant in severe varus deformities
130 associated to flexion contracture. In these cases, a PS implant is indicated over a CR implant [18,
131 21].

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

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

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

151

152 **SURGICAL TECHNIQUE**

153 **Approach**

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

161

162 **Soft Tissue balancing**

163 Releasing procedure has been described in different articles [26-30], by the way Mullaji et al. [31]
164 proposed a sequence based on the analysis of the releases performed under computer assisted
165 surgery control (Table 2). The first release is made removing osteophytes by the medial border of
166 the plateau and femoral condyle with a rongeur. This procedure permits to reduce the bow-string

167 effect on the medial collateral ligament and open the gap medially reducing the deformity. In most
168 of the cases, this is enough to obtain a well-balanced knee.

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

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

175 At this time, gap symmetry can be grossly checked in order to decide the need for further releases.

176 Posterior osteophytes can influence the extension gap and the removal has always to be performed.

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

185

186 **Bone cuts**

187 Bone cuts have to be performed in a standard manner. Historically, tibial proximal has been
188 performed perpendicular to the long tibial axis. The amount of bone to be resected has to be
189 evaluated on the lateral side (8-10 mm according to the prosthetic design). When the medial plateau

190 has a large bone defect it is possible to increase the tibial bone cut of 2 mm reducing the dimension
191 of the bone defect.

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

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

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

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

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

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

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

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

212

213 **Other procedures**

214 TIBIAL REDUCTION OSTEOTOMY

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

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

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

224

225 SLIDING MEDIAL COLLATERAL LIGAMENT OSTEOTOMY

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

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

237

238

239 **RESULTS**

240 Different authors described the outcomes of TKA in varus deformities [1, 44-46, 48-56].

241 Most of these studies are focused on deformities greater than 10°. The reported outcomes are good,
242 with a survivorship ranging between 92% and 98% at ten years follow-up. The most relevant and
243 recent articles are summarized in **Table 2**.

244

245 **OUR TECHNIQUE**

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

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

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

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

257 After bone cuts, the extension gap is checked with the 10 mm spacer block. A contracted medial
258 gap at this time of the surgery can be tolerated, especially if there are posterior osteophytes
259 stretching the capsule. The next step is to assess dimension and rotation of the femoral component,
260 taking care to completely remove the posterior condyles and all osteophytes in the posterior aspect
261 of the joint, especially on medial side. With regard to antero-posterior cuts, we triple-check the

262 posterior condylar reference cutting block position with both Whiteside line and transepicondylar
263 axis; moreover, with the cutting blocks in site, we further check the balancing in flexion before
264 performing the cuts.

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

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

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

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

281

282 **CONCLUSION**

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

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

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

291

292 **CONFLICT OF INTEREST**

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

295

296 **FIGURES AND TABLES**

297 **Table 1.** Varus Deformity Classification According to “Thienpont and Parvizi.” (AMOA=anterior
298 medial osteoarthritis, PMOA posterior medial osteoarthritis)

299

300 **Table 2.** Sequence of releases proposed by Mullaji et al

301

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

305

306 **Figure 1.** X-rays demonstrating a varus knee deformity

307

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

309
310

311 **REFERENCES**

- 312 1. Verdonk PC, Pernin J, Pinaroli A, Ait Si Selmi T, Neyret P (2009) Soft tissue balancing in varus
313 total knee arthroplasty: an algorithmic approach. *Knee Surg Sports Traumatol Arthrosc* 17:660-
314 666. DOI 10.1007/s00167-009-0755-7
- 315 2. Mullaji A, Marawar S, Sharma A (2007) Correcting varus deformity. *J Arthroplasty* 22:15-19. DOI
316 10.1016/j.arth.2007.01.017
- 317 3. Thienpont E, Schwab PE, Cornu O, Bellemans J, Victor J (2017) Bone morphotypes of the varus
318 and valgus knee. *Arch Orthop Trauma Surg* 137:393-400. DOI 10.1007/s00402-017-2626-x
- 319 4. Mihalko WM, Saleh KJ, Krackow KA, Whiteside LA (2009) Soft-tissue balancing during total knee
320 arthroplasty in the varus knee. *J Am Acad Orthop Surg* 17:766-774
- 321 5. Bellemans J, Colyn W, Vandenneucker H, Victor J (2012) The Chitranjan Ranawat award: is
322 neutral mechanical alignment normal for all patients? The concept of constitutional varus. *Clin*
323 *Orthop Relat Res* 470:45-53. DOI 10.1007/s11999-011-1936-5
- 324 6. Vandekerckhove PTK, Matlovich N, Teeter MG, MacDonald SJ, Howard JL, Lanting BA (2017) The
325 relationship between constitutional alignment and varus osteoarthritis of the knee. *Knee Surg*
326 *Sports Traumatol Arthrosc* 25:2873-2879. DOI 10.1007/s00167-016-3994-4
- 327 7. Gao F, Ma J, Sun W, Guo W, Li Z, Wang W (2016) The influence of knee malalignment on the
328 ankle alignment in varus and valgus gonarthrosis based on radiographic measurement. *Eur J Radiol*
329 85:228-232. DOI 10.1016/j.ejrad.2015.11.021
- 330 8. Norton AA, Callaghan JJ, Amendola A, Phisitkul P, Wongsak S, Liu SS, Fruehling-Wall C (2015)
331 Correlation of knee and hindfoot deformities in advanced knee OA: compensatory hindfoot
332 alignment and where it occurs. *Clin Orthop Relat Res* 473:166-174. DOI 10.1007/s11999-014-3801-
333 9
- 334 9. Mullaji A, Shetty GM (2011) Persistent hindfoot valgus causes lateral deviation of weightbearing
335 axis after total knee arthroplasty. *Clin Orthop Relat Res* 469:1154-1160. DOI 10.1007/s11999-010-
336 1703-z
- 337 10. De Muylder J, Victor J, Cornu O, Kaminski L, Thienpont E (2015) Total knee arthroplasty in
338 patients with substantial deformities using primary knee components. *Knee Surg Sports Traumatol*
339 *Arthrosc* 23:3653-3659. DOI 10.1007/s00167-014-3269-x
- 340 11. Mullaji AB, Shetty GM (2014) Correction of varus deformity during TKA with reduction
341 osteotomy. *Clin Orthop Relat Res* 472:126-132. DOI 10.1007/s11999-013-3077-5
- 342 12. Thienpont E, Parvizi J (2016) A New Classification for the Varus Knee. *J Arthroplasty* 31:2156-
343 2160. DOI 10.1016/j.arth.2016.03.034
- 344 13. Rossi R, Rosso F, Cottino U, Dettoni F, Bonasia DE, Bruzzone M (2014) Total knee arthroplasty
345 in the valgus knee. *Int Orthop* 38:273-283. DOI 10.1007/s00264-013-2227-4
- 346 14. Tanzer M, Makhdom AM (2016) Preoperative Planning in Primary Total Knee Arthroplasty. *J*
347 *Am Acad Orthop Surg* 24:220-230. DOI 10.5435/JAAOS-D-14-00332
- 348 15. Mullaji AB, Shetty GM (2016) Correcting deformity in total knee arthroplasty: Techniques to
349 avoid the release of collateral ligaments in severely deformed knees. *Bone Joint J* 98-B:101-104.
350 DOI 10.1302/0301-620X.98B1.36207
- 351 16. Mullaji A, Lingaraju AP, Shetty GM (2012) Computer-assisted total knee replacement in
352 patients with arthritis and a recurvatum deformity. *J Bone Joint Surg Br* 94:642-647. DOI
353 10.1302/0301-620X.94B5.27211

354 17. Jenkinson ML, Bliss MR, Brain AT, Scott DL (1989) Peripheral arthritis in the elderly: a hospital
355 study. *Ann Rheum Dis* 48:227-231

356 18. Meftah M, Blum YC, Raja D, Ranawat AS, Ranawat CS (2012) Correcting fixed varus deformity
357 with flexion contracture during total knee arthroplasty: the "inside-out" technique: AAOS exhibit
358 selection. *J Bone Joint Surg Am* 94:e66. DOI 10.2106/JBJS.K.01444

359 19. Noyes FR, Barber-Westin SD, Hewett TE (2000) High tibial osteotomy and ligament
360 reconstruction for varus angulated anterior cruciate ligament-deficient knees. *Am J Sports Med*
361 28:282-296. DOI 10.1177/03635465000280030201

362 20. Mullaji A, Shetty GM (2009) Computer-assisted total knee arthroplasty for arthritis with extra-
363 articular deformity. *J Arthroplasty* 24:1164-1169 e1161. DOI 10.1016/j.arth.2009.05.005

364 21. Laskin RS (1996) The Insall Award. Total knee replacement with posterior cruciate ligament
365 retention in patients with a fixed varus deformity. *Clin Orthop Relat Res*:29-34

366 22. Adravanti P, Vasta S (2017) Varus-valgus constrained implants in total knee arthroplasty:
367 indications and technique. *Acta Biomed* 88:112-117. DOI 10.23750/abm.v88i2 -S.6521

368 23. Pancio SI, Sousa PL, Krych AJ, Abdel MP, Levy BA, Dahm DL, Stuart MJ (2017) Increased Risk of
369 Revision, Reoperation, and Implant Constraint in TKA After Multiligament Knee Surgery. *Clin*
370 *Orthop Relat Res* 475:1618-1626. DOI 10.1007/s11999-017-5230-z

371 24. Lachiewicz PF, Soileau ES (2006) Ten-year survival and clinical results of constrained
372 components in primary total knee arthroplasty. *J Arthroplasty* 21:803-808. DOI
373 10.1016/j.arth.2005.09.008

374 25. Crawford DA, Law JI, Lombardi AV, Jr., Berend KR (2018) Midlevel Constraint Without Stem
375 Extensions in Primary Total Knee Arthroplasty Provides Stability Without Compromising Fixation. *J*
376 *Arthroplasty*. DOI 10.1016/j.arth.2018.03.070

377 26. Clayton ML, Thompson TR, Mack RP (1986) Correction of alignment deformities during total
378 knee arthroplasties: staged soft-tissue releases. *Clin Orthop Relat Res*:117-124

379 27. Engh GA (2003) The difficult knee: severe varus and valgus. *Clin Orthop Relat Res*:58-63. DOI
380 10.1097/01.blo.0000092987.12414.fc

381 28. Luring C, Bathis H, Hufner T, Grauvogel C, Perlick L, Grifka J (2006) Gap configuration and
382 anteroposterior leg axis after sequential medial ligament release in rotating-platform total knee
383 arthroplasty. *Acta Orthop* 77:149-155. DOI 10.1080/17453670610045849

384 29. Warren LA, Marshall JL, Girgis F (1974) The prime static stabilizer of the medical side of the
385 knee. *J Bone Joint Surg Am* 56:665-674

386 30. Markolf KL, Mensch JS, Amstutz HC (1976) Stiffness and laxity of the knee--the contributions of
387 the supporting structures. A quantitative in vitro study. *J Bone Joint Surg Am* 58:583-594

388 31. Mullaji A, Sharma A, Marawar S, Kanna R (2009) Quantification of effect of sequential
389 posteromedial release on flexion and extension gaps: a computer-assisted study in cadaveric
390 knees. *J Arthroplasty* 24:795-805. DOI 10.1016/j.arth.2008.03.018

391 32. Niki Y, Nagura T, Nagai K, Kobayashi S, Harato K (2018) Kinematically aligned total knee
392 arthroplasty reduces knee adduction moment more than mechanically aligned total knee
393 arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 26:1629-1635. DOI 10.1007/s00167-017-4788-z

394 33. Eckhoff DG, Bach JM, Spitzer VM, Reinig KD, Bagur MM, Baldini TH, Flannery NM (2005) Three-
395 dimensional mechanics, kinematics, and morphology of the knee viewed in virtual reality. *J Bone*
396 *Joint Surg Am* 87 Suppl 2:71-80. DOI 10.2106/JBJS.E.00440

397 34. Eckhoff D, Hogan C, DiMatteo L, Robinson M, Bach J (2007) Difference between the
398 epicondylar and cylindrical axis of the knee. *Clin Orthop Relat Res* 461:238-244. DOI
399 10.1097/BLO.0b013e318112416b

- 400 35. Liao JJ, Cheng CK, Huang CH, Lee YM, Chueh SC, Lo WH (1999) The influence of contact
401 alignment of the tibiofemoral joint of the prostheses in in vitro biomechanical testing. *Clin*
402 *Biomech (Bristol, Avon)* 14:717-721
- 403 36. Werner FW, Ayers DC, Maletsky LP, Rullkoetter PJ (2005) The effect of valgus/varus
404 malalignment on load distribution in total knee replacements. *J Biomech* 38:349-355. DOI
405 10.1016/j.jbiomech.2004.02.024
- 406 37. Chang AH, Moision KC, Chmiel JS, Eckstein F, Guermazi A, Prasad PV, Zhang Y, Almagor O, Belisle
407 L, Hayes K, Sharma L (2015) External knee adduction and flexion moments during gait and medial
408 tibiofemoral disease progression in knee osteoarthritis. *Osteoarthritis Cartilage* 23:1099-1106. DOI
409 10.1016/j.joca.2015.02.005
- 410 38. Sharma L, Hurwitz DE, Thonar EJ, Sum JA, Lenz ME, Dunlop DD, Schnitzer TJ, Kirwan-Mellis G,
411 Andriacchi TP (1998) Knee adduction moment, serum hyaluronan level, and disease severity in
412 medial tibiofemoral osteoarthritis. *Arthritis Rheum* 41:1233-1240. DOI 10.1002/1529-
413 0131(199807)41:7<1233::AID-ART14>3.0.CO;2-L
- 414 39. Mahmoudian A, van Dieen JH, Bruijn SM, Baert IA, Faber GS, Luyten FP, Verschueren SM
415 (2016) Varus thrust in women with early medial knee osteoarthritis and its relation with the
416 external knee adduction moment. *Clin Biomech (Bristol, Avon)* 39:109-114. DOI
417 10.1016/j.clinbiomech.2016.10.006
- 418 40. Miller EJ, Pagnano MW, Kaufman KR (2014) Tibiofemoral alignment in posterior stabilized total
419 knee arthroplasty: Static alignment does not predict dynamic tibial plateau loading. *J Orthop Res*
420 32:1068-1074. DOI 10.1002/jor.22644
- 421 41. Vanlommel L, Vanlommel J, Claes S, Bellemans J (2013) Slight undercorrection following total
422 knee arthroplasty results in superior clinical outcomes in varus knees. *Knee Surg Sports Traumatol*
423 *Arthrosc* 21:2325-2330. DOI 10.1007/s00167-013-2481-4
- 424 42. Chang CB, Koh IJ, Seo ES, Kang YG, Seong SC, Kim TK (2011) The radiographic predictors of
425 symptom severity in advanced knee osteoarthritis with varus deformity. *Knee* 18:456-460. DOI
426 10.1016/j.knee.2010.08.010
- 427 43. Lo GH, Tassinari AM, Driban JB, Price LL, Schneider E, Majumdar S, McAlindon TE (2012) Cross-
428 sectional DXA and MR measures of tibial periarticular bone associate with radiographic knee
429 osteoarthritis severity. *Osteoarthritis Cartilage* 20:686-693. DOI 10.1016/j.joca.2012.03.006
- 430 44. Dixon MC, Parsch D, Brown RR, Scott RD (2004) The correction of severe varus deformity in
431 total knee arthroplasty by tibial component downsizing and resection of uncapped proximal
432 medial bone. *J Arthroplasty* 19:19-22
- 433 45. Mullaji AB, Padmanabhan V, Jindal G (2005) Total knee arthroplasty for profound varus
434 deformity: technique and radiological results in 173 knees with varus of more than 20 degrees. *J*
435 *Arthroplasty* 20:550-561. DOI 10.1016/j.arth.2005.04.009
- 436 46. Ritter MA, Faris GW, Faris PM, Davis KE (2004) Total knee arthroplasty in patients with angular
437 varus or valgus deformities of > or = 20 degrees. *J Arthroplasty* 19:862-866
- 438 47. Mullaji AB, Shetty GM (2013) Surgical technique: Computer-assisted sliding medial condylar
439 osteotomy to achieve gap balance in varus knees during TKA. *Clin Orthop Relat Res* 471:1484-
440 1491. DOI 10.1007/s11999-012-2773-x
- 441 48. Teeny SM, Krackow KA, Hungerford DS, Jones M (1991) Primary total knee arthroplasty in
442 patients with severe varus deformity. A comparative study. *Clin Orthop Relat Res*:19-31
- 443 49. Bellemans J, Vandenuecker H, Van Lauwe J, Victor J (2010) A new surgical technique for
444 medial collateral ligament balancing: multiple needle puncturing. *J Arthroplasty* 25:1151-1156.
445 DOI 10.1016/j.arth.2010.03.007

446 50. Rames RD, Mathison M, Meyer Z, Barrack RL, Nam D (2018) No impact of under-correction and
447 joint line obliquity on clinical outcomes of total knee arthroplasty for the varus knee. *Knee Surg*
448 *Sports Traumatol Arthrosc* 26:1506-1514. DOI 10.1007/s00167-017-4507-9

449 51. Goudarz Mehdikhani K, Morales Moreno B, Reid JJ, de Paz Nieves A, Lee YY, Gonzalez Della
450 Valle A (2016) An Algorithmic, Pie-Crusting Medial Soft Tissue Release Reduces the Need for
451 Constrained Inserts Patients With Severe Varus Deformity Undergoing Total Knee Arthroplasty. *J*
452 *Arthroplasty* 31:1465-1469. DOI 10.1016/j.arth.2016.01.006

453 52. Puliero B, Favreau H, Eichler D, Adam P, Bonnomet F, Ehlinger M (2018) Total knee
454 arthroplasty in patients with varus deformities greater than ten degrees: survival analysis at a
455 mean ten year follow-up. *Int Orthop*. DOI 10.1007/s00264-018-4019-3

456 53. Karachalios T, Sarangi PP, Newman JH (1994) Severe varus and valgus deformities treated by
457 total knee arthroplasty. *J Bone Joint Surg Br* 76:938-942

458 54. Liu HC, Kuo FC, Huang CC, Wang JW (2015) Mini-midvastus total knee arthroplasty in patients
459 with severe varus deformity. *Orthopedics* 38:e112-117. DOI 10.3928/01477447-20150204-58

460 55. Saragaglia D, Sigwalt L, Gaillot J, Morin V, Rubens-Duval B, Pailhe R (2018) Results with eight
461 and a half years average follow-up on two hundred and eight e-Motion FP(R) knee prostheses,
462 fitted using computer navigation for knee osteoarthritis in patients with over ten degrees genu
463 varum. *Int Orthop* 42:799-804. DOI 10.1007/s00264-017-3618-8

464 56. Czekaj J, Fary C, Gaillard T, Lustig S (2017) Does low-constraint mobile bearing knee prosthesis
465 give satisfactory results for severe coronal deformities? A five to twelve year follow up study. *Int*
466 *Orthop* 41:1369-1377. DOI 10.1007/s00264-017-3452-z

467