Injury, Int. J. Care Injured 50 (2019) 2065–2069

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Identifying the optimal inlet for antegrade tibial intramedullary nailing *via* magnetic resonance imaging

Chi-Chuan Wu[a,*], Yon-Cheong Wong[b]

[a] *Department of Orthopedic Surgery, Chang Gung Memorial Hospital, Chang Gung University, 5 Fu-Hsin St., 333, Kweishan, Taoyuan, Taiwan*
[b] *Department of Medical Imaging and Intervention, Chang Gung Memorial Hospital, Chang Gung University, Taoyuan, Taiwan*

ARTICLE INFO

Keywords:
Antegrade
Inlet
Intramedullary nail
Magnetic resonance imaging
Tibia

ABSTRACT

Introduction: Tibial shaft fractures treated with antegrade rigid tibial intramedullary nailing has been supported worldwide. However, the optimal inlet for nailing is still controversial. Practically, varied inlets may significantly affect the tibial alignment. This retrospective study intended to utilize magnetic resonance imaging (MRI) to investigate the optimal inlet for antegrade tibial nailing.
Methods: MRIs of 100 consecutive adult patients (50 men and 50 women, average 27 years) were used in this study. All patients had MRIs for meniscus or knee ligament injuries. There were no fractures or prior bony anomalies. The center of the tibial width (TW) at the level of the tibial tubercle (TT) was considered the optimal inlet and was positioned on the axial view of the MRIs. Various related anatomic landmarks were investigated concomitantly. All parameters were compared statistically.
Results: The medial edge of the patellar tendon (PT) was 55% from the lateral end of the TW. The apex of the TT was 38% from the lateral end of the TW. The lateral edge of the PT was 19% from the lateral end of the TW. The TT was 2.5 cm distal to the tibial articular surface. The PT width was 2.3 cm. Except for the TW, the distance from the TT to the articular surface, and PT width between genders ($p < 0.001$), all other parameters showed no statistical significance ($p > 0.05$).
Conclusions: The optimal inlet for antegrade rigid tibial intramedullary nailing may be at a site 3 mm laterally to the medial edge of the PT. There are normally no differences for the nail inlet between men and women. The PT splitting approach for nail insertion may require modification.

Introduction

Tibial shaft fractures are common injuries, and antegrade rigid intramedullary nailing has been the preferred treatment of choice worldwide [1]. The advantages of this technique include a small surgical wound, sufficient stability for fracture healing, no need of joint immobilization, and low complication rates [2]. The reported success rate for closed tibial shaft fractures treated with closed reamed locked nails is as high as 100% [3].

Techniques for inserting an antegrade locked nail are still controversial. The traditionally preferred proximal inlet is infrapatellar and may be medial, central, or lateral to the tibial tubercle (TT) [4,5]. Because a valgus deformity easily occurs when proximal tibial shaft fractures are nailed, a suprapatellar or parapatellar approach has been developed [6,7]. However, both approaches have not been supported widely due to its intraarticular involvement with concerns of ligament and cartilage injuries [6,8]. A technique with infrapatellar insertion of a blocking screw for aiding nailing of proximal tibial shaft fractures has also been developed [9].

In principle, a locked nail should be placed centrally in the marrow cavity. Therefore, the proximal nail inlet should be at the center of the tibial width (TW) [10–13]. In human anatomy, the TT is generally located laterally in the TW, which subsequently causes the quadriceps angle to be larger than the angle of the anatomic axis (normally, 6–7°) [14,15]. The length and width of the patellar tendon (PT) are typically 3.9 cm and 3.2 cm, respectively with clinical measurements [16]. When a tibial nail is inserted, the relative location of the inlet to the PT may deeply affect whether the nail is centralized. Practically, magnetic resonance imaging (MRI) reveals soft tissues and has been widely used in TT studies [17–19]. However, to the best of our knowledge, MRI has rarely been used in tibial nail inlet studies. Theoretically, an ideal nail inlet around the TT may be accurately positioned in an MRI investigation. The aims of this retrospective study were to utilize MRI to search for an ideal inlet for tibial nailing. Consequently, the tibial nailing technique might become more predictable and satisfactory.

* Corresponding author.
E-mail address: ccwu@mail.cgu.edu.tw (C.-C. Wu).

https://doi.org/10.1016/j.injury.2019.09.005

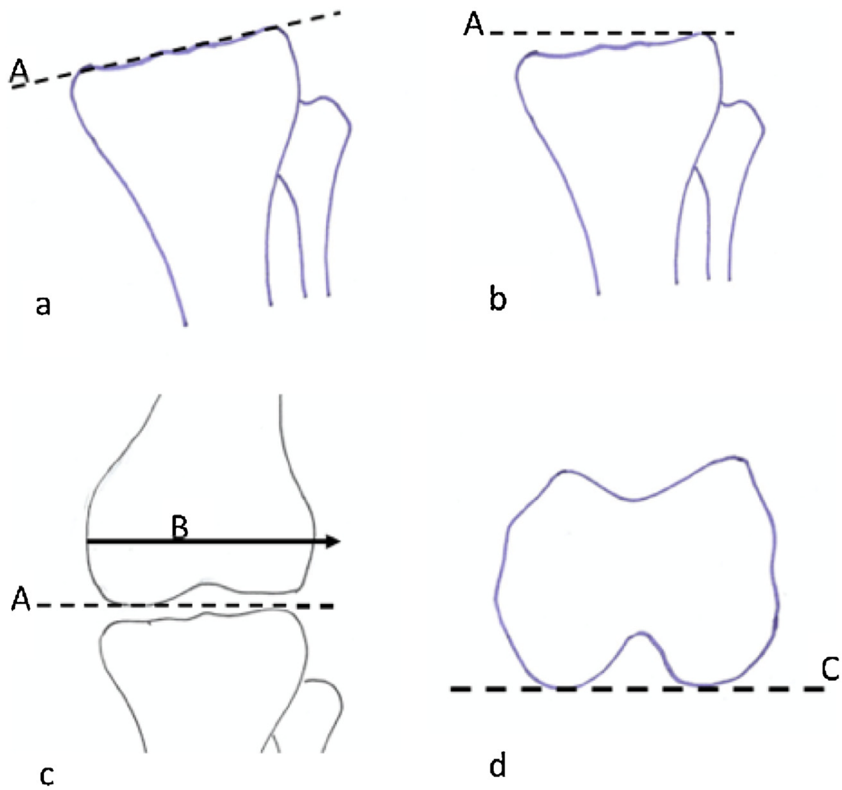

Fig. 1. A standardized magnetic resonance imaging (MRI) scan is shown: (a) Line A is drawn to connect the medial and lateral tibial plateau surfaces. (b) Line A was externally rotated 3° and kept horizontal. (c) Line B was created at the medial femoral epicondyle and parallel to line A. (d) The axial plane was demonstrated and line C was drawn to connect the posterior cortices of the medial and lateral femoral condyles. Line C was kept horizontal.

Materials and methods

This study had been approved by the Institutional Review Board of the authors' institution (IRB No. 201700752B0).

Establishing MRI data

From February 2017 to April 2018, 100 consecutive adult patients (50 men and 50 women) who had undergone knee MRI examination were included in this study. These patients were aged 18–40 years (average, 27 years), and underwent MRI for ligament or meniscus injuries, and no fractures or bony anomalies were noted.

All patients were placed on the MRI examining table in the supine position without anesthesia. MRIs were obtained by a routine knee protocol using a 1.5 T GE Signa HDe MRI machine (Milwaukee, WI, USA) with a dedicated knee surface coil. The knee was fully extended with the quadriceps femoris relaxed. The interval of the MRI slices was 4 mm.

MRIs of all 100 patients were stored in the picture achieving and communication systems (PACS) software (GE Healthcare, Waukesha, WI, USA) at the authors' institution [20]. Data around the knee were selected for analysis.

Positioning of the TT and PT for MRI

In the frontal view of MRI, line A connecting the medial and lateral tibial plateau surfaces was drawn (Fig. 1a). Consequently, line A was externally rotated 3° and kept horizontal in the frontal plane (Fig. 1b). Line B was created along the medial femoral epicondyle and was parallel to line A (Fig. 1c). The axial view at line B was demonstrated (Fig. 1d). Line C was drawn by connecting the

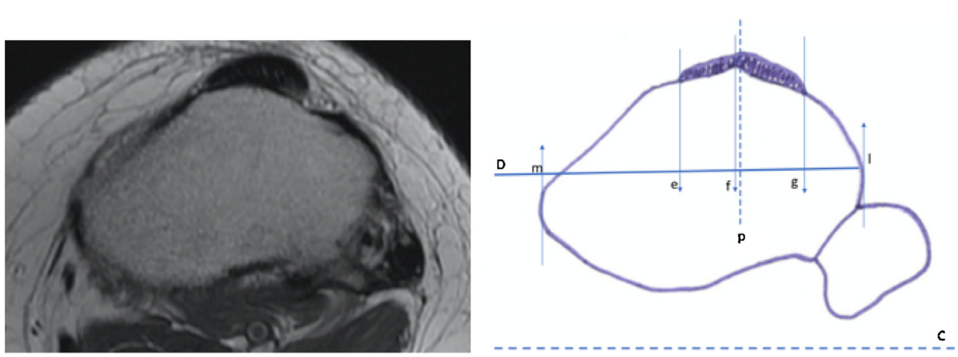

Fig. 2. The axial plane of the tibial tubercle (TT) is shown. Line D (parallel to line C) is drawn from the most lateral edge (point l) to the most medial edge (point m) of the tibial width. Three lines (lines e, f, and g), which were vertical to line D were created. Line p is the midline between line e and line g. Line e was along the medial edge of the patellar tendon (PT). Line f was at the apex of the TT. Line g was along the lateral edge of the PT.

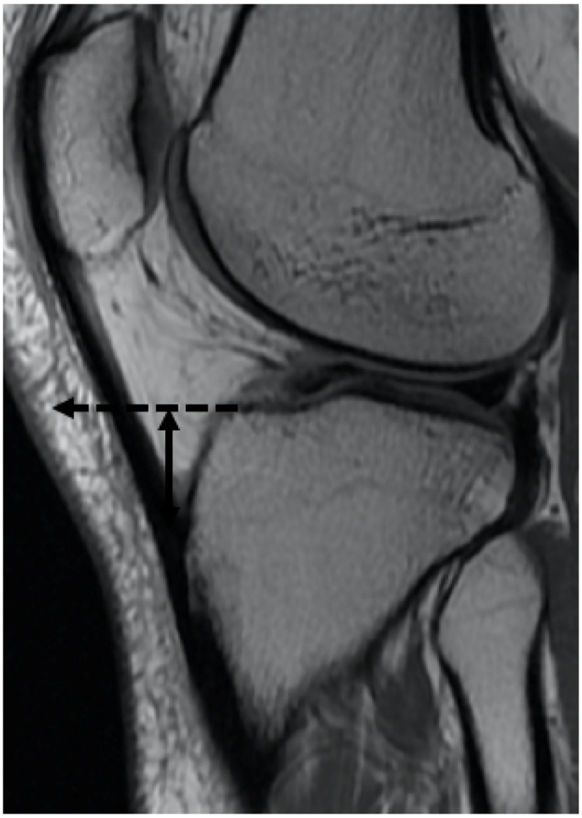

Fig. 3. The sagittal view of the magnetic resonance imaging scan is shown. The distance between the anterior edge of the tibial articular surface and the upper margin of the tibial tubercle (TT) was measured.

posterior cortices of both medial and lateral femoral condyles (Fig. 1d). Line C was rotated until it became horizontal (Fig. 1d). Overall, the reference MRI plane is shown in Fig. 1.

The MRI cursor was moved distally until the most distal inserting site of the PT on the TT was demonstrated. Line D (points l–m) was made by traversing the TW, which was parallel to line C (Fig. 2). Point l was at the most lateral edge, and the point m was vertical to the most medial edge of the tibia. Three lines were created (lines e, f, and g) and all were vertical to line D (Fig. 2). Line e was along the medial edge of the PT. Line f was at the apex of the TT. Line g was drawn along the lateral edge of the PT. The lengths of l–m, e–l, f–l, and g–l were measured, and were expressed by mm. The ratios of e–l / l–m, f–l / l–m, and g–l / l–m were measured, and were expressed by a percentage of the l–m length.

At this level, the sagittal view of the MRI was demonstrated (Fig. 3). The distance between the anterior edge of the tibial articular surface and the upper margin of the TT was measured.

Table 1
Comparison of various parameters related to tibial nail inlet (n = 100).

Parameter	Total patients (n = 100)	Men (n = 50)	Women (n = 50)	*p* value
Age (yr)	27 (26–28)	28 (26–30)	26 (24–28)	0.19
Tibial width (mm)	64 (62–66)	69 (67–71)	59 (57–61)	<0.001
Medial edge (%)	55 (54–56)	55 (54–56)	55 (54–56)	0.63
Apex (%)	38 (37–39)	39 (38–40)	38 (37–39)	0.09
Lateral edge (%)	19 (18–20)	19 (18-20)	19 (18–20)	0.96
Center (%)	37 (36–38)	37 (36–38)	37 (36–38)	0.92
PT width (mm)	23 (22–24)	25 (24–26)	21 (20–22)	<0.001
Articular distance (mm)	25 (24–26)	26 (25–27)	23 (22–24)	<0.001

Apex, apex of the tibial tubercle; Articular distance, distance from the tibial tubercle to articular surface; Center, center of the PT; Lateral edge, lateral edge of the PT; Medial edge, medial edge of the PT; PT, patellar tendon.

Various related parameters in 100 patients were investigated and compared. The difference between genders was also compared.

Statistical analysis

Data were analyzed using Microsoft Office Excel 2010 (Microsoft Corporation, Taipei, Taiwan) software. Statistical comparison used a two-sample unpaired Student's *t*-test and $p < 0.05$ was considered statistically significant. Pearson product-moment correlation coefficient was used to study the correlation between two samples.

Results

The data in 100 patients (50 men and 50 women) were collected for statistical comparison. All data were shown with an average and 95% confidence interval (CI) (Table 1).

The average age of 100 patients was 27 years (26–28 years). There was no statistical difference between sexes ($p = 0.19$).

The average TW in 100 patients was 64 mm (62–66 mm). A high statistical difference occurred between sexes (male of average 69 mm versus female of average 59 mm, $p < 0.001$).

The medial edge of the PT in 100 patients was 55% (54–56%) from the lateral end of the TW. There was no statistical difference between sexes ($p = 0.63$).

The average apex of the TT in 100 patients was 38% (37–39%) from the lateral end of the TW. There was no statistical difference between sexes ($p = 0.09$).

The average lateral edge of the PT in 100 patients was 19% (18–20%) from the lateral end of the TW. There was no statistical difference between sexes ($p = 0.96$).

The average center of the PT in 100 patients was 37% (36–38%) from the lateral end of the TW. There was no statistical difference between sexes ($p = 0.92$).

The average PT width in 100 patients was 23 mm (22–24 mm). A high statistical difference occurred between sexes (male of average 25 mm versus female of average 21 mm, $p < 0.001$).

In the sagittal plane of MRI, the average distance between the anterior edge of the tibial articular surface and the upper margin of the TT in 100 patients was 25 mm (24–26 mm). A high statistical difference occurred between sexes (male of average 26 mm versus female of average 23 mm, $p < 0.001$).

The correlation between the apex of the TT and the center of the PT in 100 patients was 0.84. However, there was statistical significance between the two groups (38% *vs*. 37%, $p = 0.02$).

The correlation for the TW and the PT width in 100 patients was 0.71.

The correlation for the TW and the articular distance in 100 patients was −0.16.

Discussion

Anatomically, if the nail is placed laterally to the center of the TW of the proximal tibia, a varus knee will be caused [21]. The mechanical axis and anatomic axis of the tibia are identical [22]. Therefore, central or slightly medial placement of nailing is essential. In the current study, the medial edge of the PT was located slightly medial to the TW center (55% from the lateral end of the TW, about 3 mm). Thus, a skin incision along the medial edge of the PT should be most reasonable [23]. With retraction of the PT laterally, the nail inlet is created 0–3 mm laterally. Under this situation, the tibial alignment should be most ideal (Fig. 4).

In the current study, the apex of the TT was slightly medial to the center of the PT (38% *vs*. 37% from the lateral end of the TW, p = 0.02, correlation coefficient of 0.84). Therefore, splitting the PT

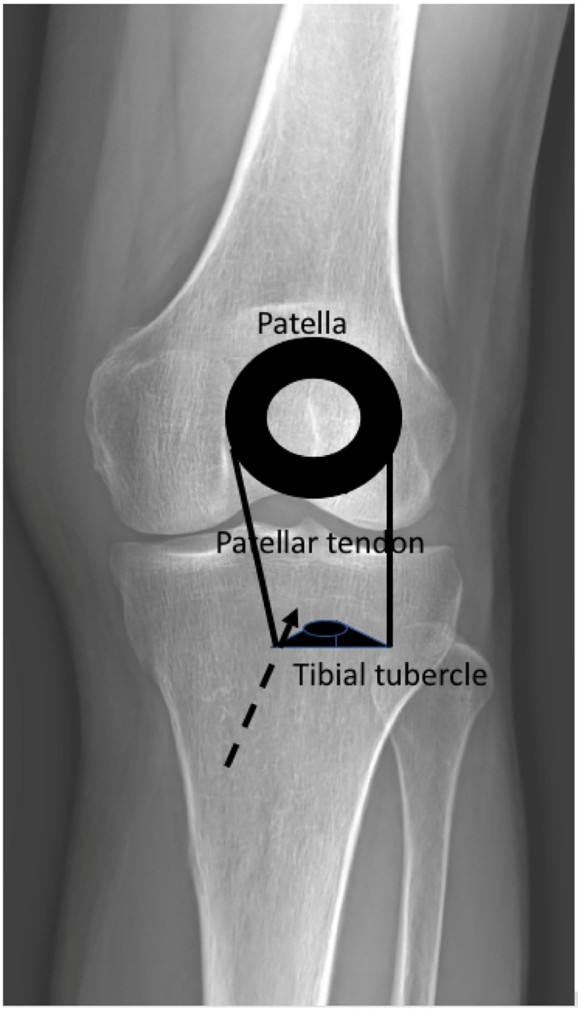

Fig. 4. The optimal nail inlet is shown. An infrapatellar medial patellar tendon (PT) edge approach was made. Within 2.5 cm distal to the articular surface, a bone hole (arrow head) was created 3 mm laterally to the medial PT edge.

to create the nail inlet should be inadequate [5,12,24]. Under this situation, the tibial shaft and knee will become varus.

The PT width was 2.3 cm in the current study. This value was smaller than that reported in articles with clinical measurements (2.3 cm *vs*. 3.2 cm) [16]. After all, subcutaneous soft tissues may maximize the PT caliber and hinder accurate measurements. Direct measurements during surgeries around the TT may be feasible. However, this has not been reported in the literature. In the current study, the center of the PT was 13% lateral from the TW center (about 8 mm). The correlation between the TW and the PT width was high (correlation coefficient, 0.71). This may indicate that men have a wider TW and PT.

In the literature, the normal proximal medial tibial angle has been reported to be 87° [25]. In the current study, line A was externally rotated 3° in order to achieve a standardized reference axis. By keeping the reference axis horizontally, all landmarks in the frontal plane may be inspected more habitually. At the medial femoral epicondyle level, a standardized axial plane was established. Consequently, studies around the TT may be fulfilled more smoothly.

For nailing of proximal tibial shaft fractures, the lateral inlet has been recommended in the literature [26,27]. The nail is inserted with a flexed knee, and the proximal fragment will be anteriorly and varusly pulled by the quadriceps femoris and pes anserinus [28,29]. Lateral insertion of a nail in the proximal fragment may prevent the distal fragment from valgus deformity [26,27,30]. However, a varus tibia shaft will appear. To prevent this, semi-extension of the knee by pushing the patella slightly laterally by enlarging the medial skin incision whenever necessary may be used to achieve satisfactory results [31,32].

The wider TW and larger interspace from the TT to the articular surface between genders should be related to the body height between men and women. However, the correlation between the two parameters is small (correlation coefficient, −0.16). In the literature, men have a longer tibia of 4 cm as compared to women [33]. For nails with a similar caliber, inserting techniques in men may be easier. In the current study, the relative location of PT on the tibia was similar between genders (19–55% from the lateral end of the TW). The surgical approach therefore needs no especial alternation between genders.

In the wider population, the presence of laterally inserting patellar tendons, genu varus and valgus deformity, and tibial bowing may make it more difficult to define the optimum entry point. The optimum entry point may well be better defined by the structure of the tibial shaft than the shape of the proximal tibial segment. The entry point may be affected by other issues in the wider population. Simple fluoroscopy screening to determine the alignment of the tibial medullary canal may yield a different entry point in the wider population [31].

There are some limitations in the current study. The slice interval of the MRI scan was 4 mm. The end of the PT on the MRI may not be on the TT. Therefore, the exact TT may be somewhat distal as compared to the current study. However, this discrepancy probably did not significantly affect the measurements of the parameters. Furthermore, the tibial contour is not round and symmetric. The medial or lateral space of the marrow cavity may affect the nail position [21]. Consequently, the tibial alignment may somewhat be distorted. Fortunately, the deviation is normally mild and clinically it may be accepted.

Conclusions

The optimal inlet of antegrade rigid tibial nailing may be at a site 3 mm lateral to the medial edge of the PT. Men and women normally have no difference in terms of nail inlet. The PT splitting approach for nail insertion may require modification.

Funding

There is no funding support in this study.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2019.09.005.

References

[1] Zirkle LG, Shahab F. Snahabuddin. Interlocked intramedullary nail without fluoroscopy. Orthop Clin North Am 2016;47:57–66.
[2] Kuhn S, Appelmann P, Pairon P, Mehler D, Hartmann F, Rommens PM. A new angle stable nailing concept for the treatment of distal tibia fractures. Int Orthop 2014;38:1255–60.
[3] Lam SW, Teraa M, Leenen LP, van der Heijden GJ. Systemic review shows lowered risk of nonunion after reamed nailing in patients with closed tibial shaft fractures. Injury 2010;41:671–5.
[4] Walker RM, Zdero R, McKee MD, Waddell JP, Schemitsch EH. Ideal tibial intramedullary nail insertion point varies with tibial rotation. J Orthop Trauma 2011;25:726–30.

[5] Boulton C, O'Toole RV. Tibia and fibula shaft fractures. 8th ed. In: Court-Brown CM, Heckman JD, McQueen MM, Ricci WM, Tornetta III P, editors. Rockwood and Green's fractures in adults, vol. 2. Philadelphia, PA: Wolters Kluwer; 2015. p. 2415–72.

[6] Zamora R, Wright C, Short A, Seligson D. Comparison between suprapatellar and parapatellar approaches for intramedullary nailing of the tibia. Cadaveric study. Injury 2016;47:2087–90.

[7] Chan DS, Serrano-Riera R, Griffing R, Steverson B, Infante A, Watson D, et al. Suprapatellar versus infrapatellar tibial nail insertion: a prospective randomized control pilot study. J Orthop Trauma 2016;30:130–4.

[8] Beltran MJ, Collinge CA, Patzkowski JC, Masini BD, Blease RE, Hsu JR. Intra-articular risks of suprapatellar nailing. Am J Orthop 2012;41:546–50.

[9] Hannah A, Aboelmagd T, Yip G, Hull P. A novel technique for accurate Poller (blocking) screw placement. Injury 2014;45:1011–4.

[10] Stucinskas J, Ribertsson O, Sirka A, Lebedev A, Wingstrand H, Tarasevicius S. Moderate varus/valgus malalignment after total knee arthroplasty has little effect on knee function or muscle strength. Acta Orthop 2015;86:728–33.

[11] McPherson EJ, Browne JA, Thompson JR. Adult reconstruction. In: Miller MD, Thompson SR, editors. Miller's review of orthopedics. 7th ed. Philadelphia, PA: Elsevier; 2015. p. 403–81.

[12] Maderbacher G, Baier C, Springorum HR, Zeman F, Grifka J, Keshmiri A. Lower limb anatomy and alignment affect natural tibiofemoral knee kinematics: a cadaveric investigation. J Arthroplasty 2016;31:2038–42.

[13] Jones CW, Jerabek SA. Current role of computer navigation in total knee arthroplasty. J Arthroplasty 2018;33:1989–93.

[14] Holme TJ, Henckel J, Hartshorn K, Cobb JP, Hart AJ. Computed tomography scanogram compared to long leg radiograph for determining axial knee alignment. Acta Orthop 2015;86:440–3.

[15] Thienpont E, Schwab PE, Fennema P. Efficacy of patient-specific instruments in total knee arthroplasty: a systemic review and meta-analysis. J Bone Joint Surg Am 2017;99:521–30.

[16] Zooker C, Pandarinath R, Kraeutler MJ, Ciccotti MG, Cohen SB, DeLuca PF. Clinical measurement of patellar tendon: accuracy and relationship to surgical tendon dimensions. Am J Orthop 2013;42:317–20.

[17] Carson VR, Sheehan FT, Shen A, Yao L, Jackson JN, Boden BP. The relationship of static tibial tubercle-trochlear groove measurement and dynamic patellar tracking. Am J Sports Med 2017;45:1856–63.

[18] Hinckel BB, Gobbi RG, Kihara Filho EN, Demange MK, Pecora JR, Rodrigues MB, et al. Why are bone and soft tissue measurements of the TT-TG distance on MRI different in patients with patellar instability? Knee Surg Sports Traumatol Arthrosc 2017;25:3053–60.

[19] Graf KH, Tompkins MA, Agel J, Arendt EA. Q-vector measurements: physical examination versus magnetic resonance imaging measurements and their relationship with tibial tubercle- trochlear groove distance. Knee Surg Sports Traumatol Arthrosc 2018;26:697–704.

[20] Wu CC. Is clinical measurement of anatomic axis of the femur adequate? Acta Orthop 2017;88:407–10.

[21] Gilroy AM. *Anatomy: an essential textbook*. 2nd ed. New York, NY: Thieme; 2017.

[22] Hakimian D, Khoury A, Mosheiff R, Liebergall M, Weil YA. Radiographic markers for measuring tibial rotation based on CT-reconstructed radiographs: an accuracy and feasibility study. Skeletal Radiol 2018;47:483–90.

[23] Rudloff MI. Fractures of the lower extremity. 13th ed. In: Azar FM, Beaty JH, Canale ST, editors. *Campbell's operative orthopedics*, vol. 2. Philadelphia, PA: Elsevier; 2017. p. 2712–86.

[24] Jagow DM, Garcia BJ, Yacoubian SV, Yacoubian SV. Recurrent patellar tendon rupture in a patient after intramedullary nailing of the tibia: reconstruction using an Achilles tendon allograft. Am J Orthop 2015;44:e153–5.

[25] Bellemans J, Colyn W, Vandenneucker H, Victor J. Is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 2012;470:45–53.

[26] Buehler KC, Green J, Woll TS, Duwelius PJ. A technique for intramedullary nailing of proximal third tibia fractures. J Orthop Trauma 1997;11:218–23.

[27] Nork SE, Barei DP, Schildhauer TA, Agel J, Holt SK, Schrick JL, et al. Intramedullary nailing of proximal quarter tibial fractures. J Orthop Trauma 2006;20:523–8.

[28] Jones M, Parry M, Whitehouse M, Mitchell S. Radiologic outcome and patient-reported function after intramedullary nailing: a comparison of the retrospective and infrapatellar approach. J Orthop Trauma 2014;28:256–62.

[29] Triantafillou K, Perez E. Proximal third tibia fracture treated with intramedullary nailing. In: Tejwani NC, editor. *Fractures of the tibia: a clinical casebook*. New York, NY: Springer; 2016. p. 97–106.

[30] Schlegl AT, Szuper K, Somoskeoy S, Than P. Three dimensional radiological imaging of normal lower-limb alignment in children. Int Orthop 2015;39:2073–80.

[31] Kubiak EN, Widmer BJ, Horwitz DS. Extra-articular technique for semiextended tibial nailing. J Orthop Trauma 2010;24:704–8.

[32] Yasuda T, Obara S, Haysshi J, Arai M, Sato K. Semiextended approach for intramedullary nailing via a patellar eversion technique for tibial-shaft fractures: evaluation of the patellofemoral joint. Injury 2017;48:1264–8.

[33] Wu CC. Does pelvic width influence patellar tracking? A radiological comparison between sexes. Orthop Traumatol Surg Res 2015;101:157–61.