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ORIGINAL PAPER

Degree of axis correction in valgus high tibial osteotomy: proposal of an individualised approach

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Abstract

Purpose The first purpose of this study was to introduce an individualized, pathology-based approach for the amount of axis correction in valgus high tibial osteotomy (HTO), in which the weight-bearing line (WBL) is transferred in one of three adjacent 5 %-areas of the transverse diameter of the tibial plateau. The second purpose was to define the corresponding mechanical femorotibial angle (mFTA) for the margins of each 5 %-area.

Methods Reported indications for valgus HTO were assorted to one of three groups, based on the underlying pathology and expected accompanying degree of osteoarthritis. Three adjacent 5 %-areas on the tibial plateau were defined, ranging from the 50 % to 65 % coordinate. The medial border of the tibial plateau was defined as 0 % and the lateral border was defined as 100 %. To define the corresponding mFTA, valgus HTO was simulated in 69 patients using commercial available planning software (mediCAD®, Hectec GmbH, Germany). The corresponding mFTA was recorded at four different positions (50 %, 55 %, 60 %, and 65 %).

Results Within the purposed approach, the WBL is aimed in one of three 5 %-areas (50–55 %, 55–60 %, and 60–65 %) of the transverse diameter of the tibial plateau, according to the underlying pathology. Based on the findings of simulated HTO, the mean mFTA was 0.3°±0.2° at the 50 % position, 1.3°±0.2° at the 55 % position, 2.4°±0.3° at the 60 % position, and 3.4°±0.3° at the 65 % position. The mean difference of the mFTA between each adjacent valgus position was 1.1°±0.1°.

Conclusion The present paper introduces an individualized approach to adopt the degree of valgus correction in dependence of the underlying pathology. The area of interest on the tibial plateau lies in between the 50 % and 65 % coordinate on the tibial plateau, or in between a mean mFTA of 0.3° and 3.4° of valgus, respectively. Differences of the resulting mFTA between each area are small, and therefore a precise surgical technique is mandatory.

Keywords High tibial osteotomy · Osteoarthritis · Varus malalignment · Axis correction · Cartilage repair · Meniscal transplantation

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Introduction

Valgus high tibial osteotomy (HTO) is a well-established treatment option for medial compartment osteoarthritis (OA) and varus malalignment in relatively young and active patients [6, 19, 22, 45, 47, 58, 63]. With improvements in surgical technique, the indications for HTO have evolved in recent years. Nowadays, HTO is also used on a routine base for a variety of different indications such as medial compartment overload, ligamentous insufficiency, and as a concomitant procedure in patients undergoing cartilage repair or meniscus transplantation [4, 5, 10, 11, 22, 25, 42, 57, 67].

Besides appropriate patient selection, precise surgical technique, and stable osteotomy fixation, postoperative alignment is one of the critical factors for long-term success of HTO [65]. Both, under- and overcorrection have been associated with poor outcomes after HTO [16, 30, 32, 36, 53, 60, 66]. To date, however, the ideal postoperative alignment is discussed controversially [7, 15, 21, 30, 48, 65]. In the case of medial compartment OA, most authors aim to align the weightbearing axis through the 62 % coordinate of the width of the tibial plateau [21, 22]. While this alignment may work well in patients with significant OA, less valgus position may be beneficial in patients with medial compartment overload or in the case of concomitant cartilage repair or meniscus transplantation [3, 7, 38]. Current concepts in HTO therefore include individualized alignment [22, 37, 38, 43, 65]; however, a comprehensive approach for different indications for HTO has not been published so far.

The first purpose of this study was to review the literature for different indications for valgus HTO and to develop an individualized approach for the amount of axis correction, in which the weightbearing line (WBL) is aimed at one of three adjacent 5 %-areas on the tibial plateau. The second purpose was to define the corresponding mechanical femorotibial angle (mFTA) for the margins of each area.

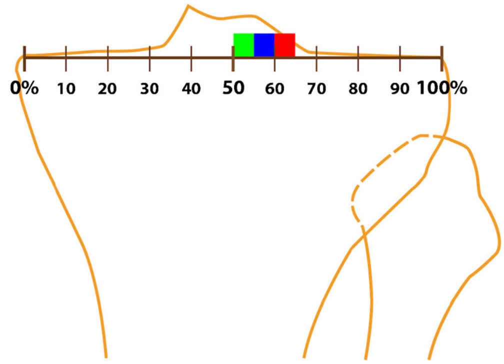

Fig. 1 Three different areas for the desired postoperative alignment were defined. Each of these areas measures 5 % of the width of the tibial plateau. The medial border of the tibial plateau was defined as 0 %, and the lateral border was defined as 100 %. *Green square*: 50–55 % area; *blue square*: 55–60 % area; *red square*: 60–65 % area

Methods

Development of an individualized, pathology-based approach for axis correction in valgus HTO

A non-systematic review of the literature was conducted to identify common indications for valgus HTO [4, 6, 8, 12, 17, 25, 38, 52, 57, 64]. Each identified indication was assorted to one of three groups (group 1–3) according to the underlying pathology and expected accompanying degree of OA. Based on the position of the WBL in relation to the width of the tibial plateau, three different areas for the target postoperative alignment were defined. Each of these areas measures 5 % of the total width of the tibial plateau, ranging from 50 to 65 % (Fig. 1). The medial border of the tibial plateau was defined as 0 %, and the lateral border was defined as 100 %. Percentage values were chosen to allow for osteotomy planning independent from the absolute knee size. The area between 50 and 65 % was chosen based on common correction values reported in the literature [6, 15, 16, 21, 22, 37, 41, 45, 48, 51, 57].

Computerized osteotomy simulation

Digital full single-leg weight-bearing anterior-posterior radiographs were obtained from 80 consecutive patients undergoing medial open-wedge HTO. Eleven radiographs were excluded because the patella was not exactly centred anteriorly. Therefore, 69 radiographs of 69 patients were available for osteotomy simulation. The mean age of the patients was 45±11 years (range, 18–66 years). Seventy-five percent of the patients (n=52) were male and 25 % (n=17) were female. The right knee was involved in 57 % (n=39) and the left knee was involved in 44 % (n=30).

Osteotomy simulation was conducted by a single observer using a landmark-based planning software (mediCAD®, Hectec GmbH, Germany) (Fig. 2). This software allows for precise analysis of the alignment as well as simulation of single and multiple osteotomies with a high intra- and interrater reliability [28, 62]. Planning was done according to the user manual of the manufacturer. In brief, the digital radiographs were imported to the mediCAD® program and calibrated. All necessary landmarks were marked, including the centre of the femoral head, the apex of the greater trochanter, femoral and tibial knee base, medial and lateral border of the femoral condyles and tibial plateau, medial and lateral border of the talus, the joint line of the talus, and the anatomical shaft axis of the femur and tibia. Next, the osteotomy and the hinge point were marked. To achieve a standardized osteotomy in every patient, the osteotomy started at the medial site at 4 cm below the joint line and ended at the lateral cortex at 2 cm below the joint line. The hinge point was set at 90 % of the total medial-to-lateral length of the osteotomy. Subsequently, the osteotomy was simulated four times in each patient with the WBL crossing the tibial plateau at 50 %, 55 %, 60 %, and 65 %. The corresponding mFTA for each correction value was recorded.

Mean value, standard deviation, and range of the measured mFTA were calculated for each simulated valgus position.

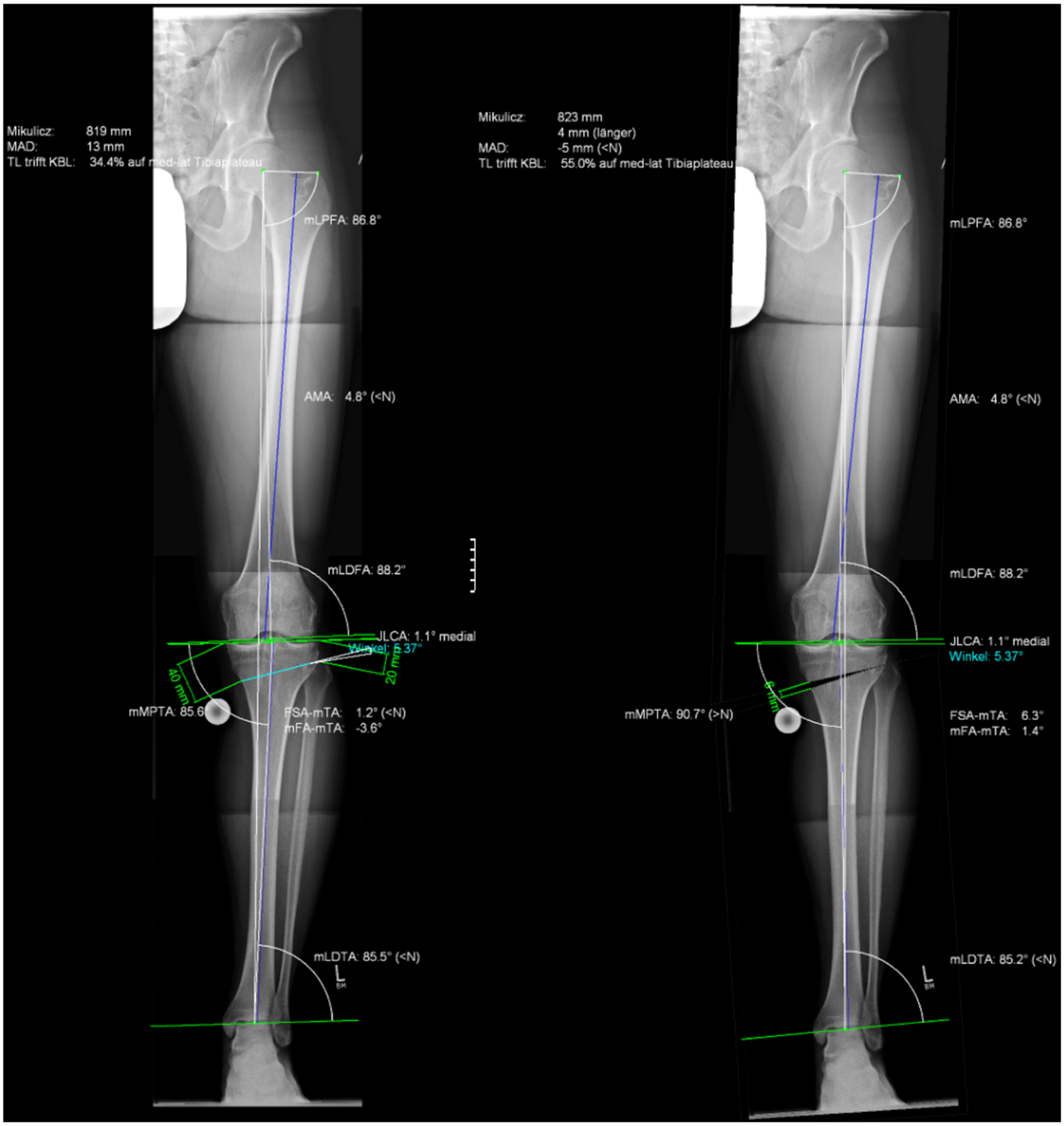

Fig. 2 Screenshot of computerized osteotomy simulation using a landmark-based planning software (mediCAD®, Hectec GmbH, Germany). On the *left*, a full single-leg weight-bearing anterior-posterior radiograph with marked landmarks and all relevant axes and angels is shown. On the *right*, an osteotomy was simulated with the weight bearing line crossing the tibial plateau at the 55 % position

Results

Development of an individualized, pathology-based approach for axis correction in valgus HTO

Identified indications for valgus HTO were varus malalignment combined with medial compartment OA, medial compartment overload, cartilage repair of the medial compartment, medial meniscus transplantation, and ligamentous insufficiency with or without OA [4, 6, 8, 12, 17, 25, 38, 52, 57, 64]. Table 1 shows the allocation of these indications to the three groups. The main characteristic feature of patients assorted to group 1 is that no radiographic signs of OA are present. In patients belonging to group 2, mild signs of OA are already present (grades 1 and 2 according to the Kellgren-Lawrence classification [34]), and patients of group 3 present with progressed OA (grades 3 and 4). The three defined 5 %-areas range from the 50 % coordinate to the 65 % coordinate of the transverse diameter of the tibial plateau (Fig. 1). For group 1, the WBL is aimed to cross the tibial plateau at the 50–55 % area, for group 2 at the 55–60 % area, and for group 3 at the 60–65 % area (Table 1).

Table 1 Allocation of different indications for valgus HTO reported in the current literature [4, 6, 8, 12, 17, 25, 38, 52, 57, 64] to one of three groups, based on the underlying pathology. In each of these groups the postoperative weight-bearing line is aimed in a different 5 %-area of the tibial plateau (Fig. 1). Osteoarthritis (OA) is graded according to the Kellgren-Lawrence classification [34]

Group	Underlying pathology	Postoperative valgus position
Group 1	• Medial compartment overload without signs of OA • Cartilage repair of the medial compartment without signs of OA • Medial meniscus transplantation without signs of OA • Ligamentous insufficiency combined with varus / hyperextension varus thrust without signs of OA	50–55 %
Group 2	• Medial compartment OA grades 1 and 2±ligamentous insufficiency • Cartilage repair of the medial compartment with mild signs of OA • Medial meniscus transplantation with mild signs of OA	55–60 %
Group 3	• Medial compartment OA grades 3 and 4±ligamentous insufficiency	60–65 %

Computerized osteotomy simulation

The mean pre-simulation mFTA was 5.5°±2.7° (range, 2.0–15.6°) of varus deviation. The corresponding values at each simulated valgus position are shown in Table 2 and Fig. 3. The 50–55 % area was bounded by a mean mFTA of 0.3° and 1.3° (range, −0.2 to 1.8°), the 55–60 % area by a mean mFTA of 1.3° and 2.4° (range, 0.9–3.0°), and the 60–65 % area by a mean mFTA of 2.4° and 3.4° (range, 1.9–4.1°). The mean difference of the mFTA was 1.1°±0.1° (range 0.8–1.2°) between the 50 % and 55 % position, 1.1°±0.1° (range, 0.9–1.5°) between the 55 % and 60 % position, and 1.1°±0.1° (range, 0.7–1.2°) between the 60 % and 65 % position. In other words, transferring the WBL to the adjacent 5 % area changes the mFTA by approximately one degree.

Discussion

The main purpose of the present study was to introduce an individualized, pathology-based approach for the amount of axis correction in valgus HTO, in which the WBL is transferred into one of three adjacent 5 %-areas of the transverse diameter of the tibial plateau The area between 50 and 65 % and the respective indications were chosen based on common correction values for different indications reported in the current literature [6, 15, 16, 21, 22, 37, 41, 45, 48, 51, 57]. Based on the findings of computerized osteotomy simulation, the 50–55 % area corresponds to a mean mFTA of 0.3–1.3° of valgus, the 55–60 % area corresponds to a mean mFTA of 1.3° and 2.4° of valgus, and the 60–65 % area corresponds to a mean mFTA of 2.4° and 3.4° of valgus. The mean difference of the mFTA between the margins of each 5 %-area was 1.1°± 0.1°.

Table 2 Corresponding mechanical femorotibial angle (mFTA) at each position of the weight-bearing line (WBL) during computerized osteotomy simulation. The values are expressed as mean±standard deviation (range). The mean difference of the mFTA between the margins of each 5 %-area was 1.1°±0.1°

Position of the WBL	Corresponding mFTA
50 %	0.3°±0.2° (−0.2°-0.7°)
55 %	1.3°±0.2° (0.9–1.8°)
60 %	2.4°±0.3° (1.9–3.0°)
65 %	3.4°±0.3° (2.9–4.1°)

The ideal postoperative alignment for valgus HTO is unknown [7, 15, 21, 30, 48, 65]. Since the indications for valgus HTO have evolved, one uniform alignment most likely does not exist, and the postoperative alignment has to be customized to the patients needs [3, 7, 37, 38, 43, 65]. Current guidelines for postoperative alignment are mainly based on clinical experience, and only few biomechanical studies exist [3, 39, 56, 69]. Agneskirchner et al. [3] quantified the effect of different loading axes on tibiofemoral cartilage pressure in six cadaveric knees. By simulating a varus deformity (WBL at the 0 % coordinate), the medial compartment pressure exceeded that of the lateral compartment by approximately 45 %. Contrarily, at neutral alignment (WBL at the 50 % coordinate), the mean contact pressure of the lateral compartment exceeded the medial compartment pressure by 17 %, and at the 62 % coordinate by 35 %. Similarly, Riegger-Krugh et al. [56] found less medial average and maximum contact pressure than lateral contact pressure for neutral (0° of mechanical valgus) and valgus (5° of mechanical valgus) alignment. Both studies suggest that markedly overcorrection into valgus might not be necessary since even neutral mechanical alignment leads to decreased loading of the medial compartment. Mina et al. [39] examined the minimum alignment correction required for unloading a medial chondral defect. All examined specimens demonstrated complete unloading of the medial compartment between 6° and 10° of anatomic valgus. Equally distributed contact pressure between the medial and lateral compartment was found for alignments of 0° to 4° of anatomic valgus. Finally, Van Thiel et al. [69] evaluated the effect of

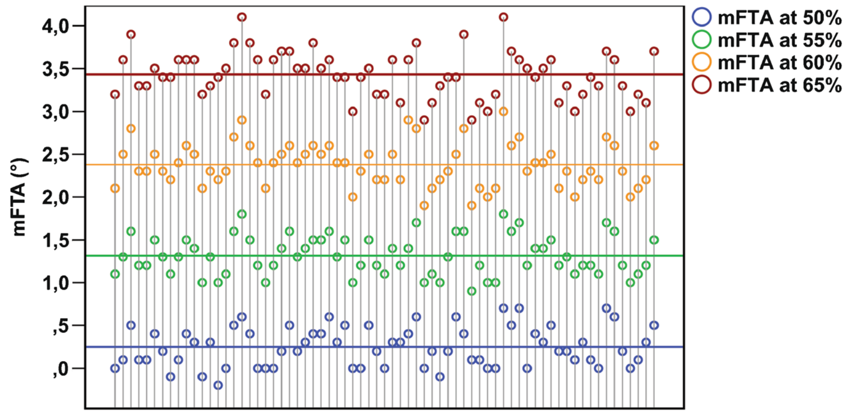

Fig. 3 The corresponding mechanical femorotibial angle (mFTA) at the 50 %, 55 %, 60 %, and 65 % position during computerized osteotomy simulation. Each *vertical line* represents one single patient. The *colored horizontal lines* display the mean mFTA at each valgus position

valgus HTO in the context of medial meniscal transplantation. The authors did not find a significant difference in medial compartment peak pressure between 6° and 3° of mechanical varus, and between 3° of mechanical varus and neutral alignment for the intact, meniscectomized and transplanted state. However, there was a significant decrease in medial compartment peak pressure between neutral and 3° of mechanical valgus for all three states. No difference was found between 3° and 6° of mechanical valgus, and between 6° and 8° of mechanical valgus. The findings of this study, do not support a correction beyond 3° of mechanical valgus.

Since the rational for valgus HTO differs between different indications, a pathology-based approach for the amount of axis correction seems to be reasonable. In the case of progressed medial compartment OA, the aim of valgus HTO is to transfer the weight-bearing axis to the unaffected lateral compartment, in order to reduce pain and to delay the need for knee replacement [1, 6, 14, 30, 41]. The role of HTO in patients undergoing cartilage repair is to provide an optimal biomechanical environment for healing by decreasing the load of the operative site [8, 40, 52]. Higher failure rates after osteochondral allograft transplantation have been reported in patients with concomitant malalignment compared to patients without malalignment [24, 50]. Unloading of the medial compartment may therefore be beneficial in patients with varus malalignment undergoing cartilage repair of the medial compartment [10, 39, 42, 46, 59]. Good clinical results have been reported after valgus HTO combined with microfracture [67, 68], osteochondral autologous transfer [42], and autologous cartilage implantation [10, 20] of the medial femoral condyle. The basic principles for additional valgus HTO in the case of medial meniscus transplantation are the same as for cartilage repair [5, 11]. Overload due to malalignment may damage the graft over time, leading to failure [5]. Combined meniscal allograft transplantation and realignment osteotomy have been shown to produce good clinical results [13, 70]. The role of valgus HTO in knee instabilities is versatile. In the case of ligamentous deficiency combined with varus / hyperextension varus thrust, isolated ligament repair or reconstruction is prone to failure because of repetitive overloading of the soft tissue reconstruction [9, 35, 44, 48, 49]. Valgus HTO in these patients is performed to augment ligamentous reconstruction by redistributing the forces acting on the knee joint [4, 25, 54, 57]. Chronic ligamentous insufficiency is often associated with varus malalignment and medial compartment OA. The role of valgus HTO in these patients is mainly to unload the medial compartment. However, additional controlled alterations of the tibial slope during valgus HTO can be used to address symptoms of instability associated with ACL and PCL deficiency [17, 31]. Based on the findings of biomechanical studies, increasing the tibial slope seems to be beneficial in the case of PCL deficiency, whereas decreasing the tibial slope might be favourable in ACL deficient knees [2, 26, 27, 71]. Therefore, HTO may also be performed as a stabilizing procedure with or without concomitant ligament reconstruction [17, 25, 44, 57].

In order to allow for individualized deformity correction, different concepts have been described, which focus on the status of the articular cartilage [37, 43]. Marti et al. [37] planned the WBL through the 10 % position in the presence of a one-third loss of medial cartilage thickness, with 0 % being the centre of the knee joint and 100 % being the lateral border of the plateau. With two-thirds loss of medial cartilage thickness, the WBL was planned through the 20 % position, and with a total loss through the 30 % position of the lateral compartment. Müller and Strecker [43] described an approach in which the correction depends on the difference of chondromalacia (Outerbridge classification) between the medial and lateral compartment during arthroscopy prior to HTO. The maximum amount of correction to 5° of valgus was performed in patients with a difference of IV (grade IV chondromalacia of the medial compartment and grade 0 of the lateral compartment). A correction to 3.3° of valgus was performed in patients with a difference of III, and to 1.7° in patients with a difference of II [43].

The approach introduced within this article also respects the amount of OA, however, it also takes the underlying pathology into account. Our approach distinguishes three different groups of indications, which in our opinion need to be aligned differently. The main characteristic of patients belonging to group 1 is that no radiographic signs of OA are present. Valgus HTO in these patients is used as a combined procedure to augment biological reconstructive procedures such as ligament reconstruction, cartilage repair, and meniscal transplantation, or as a single procedure in patients with painful medial compartment overload. These patients are commonly younger compared to patients with medial compartment OA, and considerable overcorrection may negatively influence the clinical outcome by poor cosmesis and progressive deterioration of the lateral compartment [30, 32]. In accordance with other authors [22, 38, 39, 57], we therefore prefer correction to neutral or slightly valgus. In our clinical practice, the WBL in this group is aimed between the 50 % and 55 % coordinate. With regard to the findings of this study, this area corresponds to a mean mFTA between 0.3° and 1.3° of valgus. Group 2 consists of patients who present with varus malalignment and early stage medial compartment OA grade 1 or 2 according to the Kellgren and Lawrence classification (with or without instability) and patients with varus malalignment and focal cartilage defects of the medial femoral condyle and/or significant loss of the medial meniscus but also mild signs of OA. Cartilage repair or meniscal transplantation in the latter patients must be regarded as a critical indication, but may be performed as a salvage procedure [18, 61]. In this group we prefer to transfer the WBL more laterally compared to group 1, but not as far as for patients with progressed medial compartment OA. We therefore aim the WBL between the 55 % and 60 % coordinate, which corresponds to a mean mFTA between 1.3° and 2.4° of valgus. Group 3 consists of patients with varus malalignment and progressed medial compartment OA with or without instability. The common consent in these patients is that correction should be beyond neutral, however, the exact amount of valgus correction has to be determined [1, 14, 15, 21, 30, 43, 57]. In accordance with other authors [15, 21, 41, 48], we aim to align the WBL between the 60 % and 65 % coordinate. With regard to the findings of our study, this area lies in between a mean mFTA of 2.4° and 3.4° of valgus.

The amount of axis correction can be controlled intraoperatively by several methods including fluoroscopic simulation of the WBL with a wire cable or a long alignment rod. However, these methods have variable accuracy, since limb rotation can influence the measurement of lower limb alignment [33]. Computer navigation has been reported to improve the accuracy and reproducibility of axis correction during valgus HTO [23, 29, 55]. In the present study, the differences of the resulting mFTA between the margins of each 5 %-area were small, with a mean value of 1.1°. These data underline the importance of a precise surgical technique. Computer navigation might therefore be a valuable tool for precise individualized HTO.

One limitation of the present study is that the osteotomy simulation was not controlled by postoperative long leg X-rays. Further clinical studies are therefore necessary to proof the accuracy for the proposed approach. The main weakness of the present study is that the presented approach lacks evidence because of missing outcome data. However, the authors have extensive experience in the field of HTO, reflected by more than 20 related publications listed on PubMed®. This paper describes our current clinical practice for valgus HTO, which provides high patient satisfaction in our hands. We therefore believe that this “expert opinion” is of general interest for surgeons performing HTO, and might positively influence further research on the ideal alignment after valgus HTO. As stated by Andrew Amis, many of the accepted “rules” for HTO have little scientific evidence to show that they represent the best practice for long-term preservation of the knee joint [7]. Therefore, the introduced approach for individualized axis correction has to be confirmed in clinical studies in the future.

Conclusion

Transferring the WBL into one of three 5 %-areas on the tibial plateau according to the underlying pathology is an alternative method for individualized axis correction in valgus HTO. The 50–55 % area corresponds to a mean mFTA of 0.3–1.3° of valgus, the 55–60 % area corresponds to a mean mFTA of 1.3° and 2.4° of valgus, and the 60–65 % area corresponds to a mean mFTA of 2.4° and 3.4° of valgus. The mean difference of the resulting mFTA between the margins of each 5 %-area is small, and therefore a precise surgical technique is mandatory.

Conflict of interest The authors state that they have no conflict of interest.

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