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ORIGINAL STUDY

Femur can be lengthened over nail, along its mechanical axis : a modified lengthening over nail technique

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The theoretical risk of medialisation of the knee joint and the lateral shift of the lower extremity mechanical axis, due to achievement of lengthening along the anatomical axis is present in the process of lengthening with elongation nails and the "lengthening over nail" technique. With this new technique described in this study we aimed to prove that lengthening over nail can be performed along the mechanical axis of the femur. Six lower-limb models were used to perform three different lengthening techniques. In group 1, lengthening was achieved along the anatomical axis with an external fixator. In group 2, the clamps of the external fixator were adjusted at 6° to achieve lengthening along the mechanical axis. In group 3, eight different sized nails were applied with an external fixator (angle adjustable clamps were at 6°) to achieve lengthening along the mechanical axis by LON technique. Photographs were taken after each cm of lengthening and the distance from the mechanical axis line were measured. The modified LON technique described in this study provided lengthening along the mechanical axis. One of the main advantages of the procedure described in our study is the chance for reconsideration and revision of unforeseen angulations and malalignments, via the help of the distal angular adjustable clamps; during the time of the surgery for external fixator removal before application of the poller screws.

Key words : Lengthening over nail, mechanical axis deviation, femoral lengthening

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INTRODUCTION

"Lengthening over nail" (LON) technique was first described by Paley et al, and they emphasized the theoretical risk of medialisation of the knee joint and lateral shift of the lower extremity mechanical axis, due to achievement of lengthening along the anatomical axis with this technique. (*22*) This theoretical risk is also present in lengthening with elongation nails, as they also provide lengthening along the anatomical axis of the femur. (*2,6,9,10,27*) There are several publications in the literature both supporting and opposing the mentioned theoretical risk. (*2,3,6,7,9,10,22,26,27*) Baumgart et al described the reverse planning method (RPM) consisting of preoperative templating and poller (blocking) screws technique, in order to maintain the mechanical axis during lengthening with elongation nails. With this new technique described in this study we aimed to

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prove that lengthening over nail can be performed along the mechanical axis of the femur. This novel technique was also compared with RPM, in terms of the possible advantages and disadvantages.

MATERIALS AND METHODS

Lower limb model set up

Six right femur bone models (Synbone 1152.1, Synbone AG, Switzerland) with 135° neck-shaft angle, 15° anteversion, 465 mm height and 9,5 mm intramedullary canal diameter were used for lower limb model construction. Specifically designed and manufactured iron bar and three iron plates were welded together and used to simulate tibia, instead of tibia bone models to achieve standardisation of the knee joint. The horizontal iron plate was welded to the 400mm long iron bar with an angle of 87° to simulate medial proximal tibial angle. The coronal plate was assembled to assure full contact with the posterior femoral condyles, providing standard rotation of the tibia model. Finally the sagittal plate was mounted to contact medial femoral epicondyle and prevent translation of the femur. In order to provide the 1.2 ratio between femur and tibia, the iron bar was marked on 350 mm. (*29*) (Fig. 1).

In this study we planned to perform 6 cm of lengthening with a 420 mm long unilateral fixator (Unix rail fixator, Response-Ortho). The fixator was aligned with whether the anatomical or the mechanical axises by the use of two distal and two proximal schanz screws (6×45×180 mm, stainless steel, TIPMED) attached to the fixator with angle

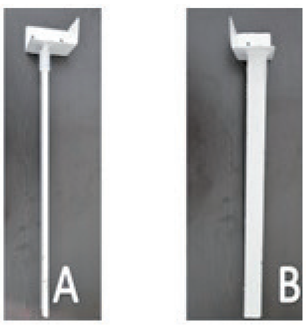


Fig. 1. – Tibia simulated model A: anteroposterior B: lateral view.

adjustable clamps (Angular Correction Clamp, Response-Ortho).

Right femur bone models, all containing standard openings at the distal end of the medullary canals, were reamed with flexible reamers up to 13 mm (TIPMED, supracondylar nail system) in a retrograd manner under fluoroscopy. After reamerisation nails with two and three sizes smaller diameter than the 13 mm reamed medulla, were chosen. Also the longest nail length preferred was 320 mm-long which does not approach to the lesser trochanter closer than 2cm. (*15*) The shortest nail inside the set was 200 mm long, is used. Besides, 240 and 280 mm long nails were planned to be used in this study.

Level of the distal metaphyseal osteotomy was determined 2 cm away from the distal locking screw which is located 60 mm proximal to the end of the nail applied. While determining this level, the suggested use of a poller screw in 1-3 cm distance to the fracture site with a minimum of 1cm, was taken into consideration. (*24,25*)

Lower limb model construction

Two 30 × 100 cm in size, wooden base plates with slippery surface were manufactured. Unilateral fixator (Unix rail fixator, Response-Ortho) was assembled on the wooden base plates with wooden blocks and the position was standardised. Femur bone and tibia simulation models were articulated in the standardized position as described. Then the first schanz screw through the proximal clamp of the external fixator was advanced to the femur bone model at the level of lesser trochanter with a right angle in coronal plane, centering the bone in the sagittal plane. (*8,11,12,15,22*) A goniometer was used to ensure the screw was placed at a right angle, and the distance between bone and fixator was standardised as 4,5 cm. 11×240 mm retrograde nail were applied to the femur model which was reamed up to 13 mm. 45 and 55 mm long two proximal locking screws were applied from the medial side with the aid of the IMN guide. Distal Schanz screw was advanced thorough the distal clamp of the external fixator, under fluoroscopic confirmation of the absence of contact with the nail. (*22*) The third and fourth Schanz screws were applied through the guidance of proximal and distal clamps on monorail fixator. Finally after removal of IMN, the osteotomy was located 2 cm apart from the distal one of the two proximal locking screws and performed by a Gigli saw wire.

Six lower-limb models were used to perform three different lengthening techniques. In group 1, lengthening was achieved along the anatomical axis with external fixator (angle adjustable clamps were at 0°). In group 2, the clamps of the external fixator were adjusted in 6° to achieve lengthening along the mechanical axis. In group 3, 8 different sized nails (10×200mm, 10×240mm, 10×280mm, 10×320mm, 11×200mm, 11×240mm, 11×280mm, 11×320mm) were applied with external fixator (angle adjustable clamps were at 6°) to achieve lengthening along the mechanical axis by LON technique. In group 3 wooden blocks were attached to the base plate proximal to the osteotomy site on both sides of the bone model to prevent bending of bone models that may occur during lengthening. (Fig. 2).

Evaluation of the mechanical axis deviation

Photographs, framed at the center of the knee joint, were taken after each cm of lengthening applied on lower extremity models. During photo shooting of all specimens, a photo ID was created, including the number of the model, the group number and the amount of lengthening. Mechanical axis was determined by drawing a line on Windows Paint software, between two points representing the center of the ankle and the femoral head; both of which were pre-marked with 0.3mm pin pointed acetate pencil. (Fig. 3 and 4).

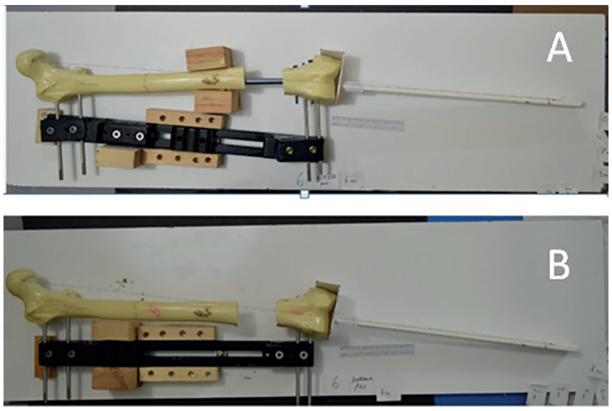


Fig. 2. — A) lengthening along the mechanical axis with external fixator B) lengthening along the anatomical axis with external fixator.

Fig. 3. — Determination of the mechanical axis by drawing a line on Windows Paint software.

Fig. 4. — Photos with mechanical axes drawn, under magnification to 400%.

Photos with mechanical axes, were viewed under magnification to 400% with the IMAGEJ v1.48 software. By the use of a 20 mm ruler attached proximally to the simulated tibial model allowed calibration of pixels to millimeters. The distance between mechanical axis line and the reference point on horizontal iron plate of models simulating tibia were measured by one hundredth of a millimeter value.

Statistical analysis

After each cm of lengthening of the lower extremity models, MAD were measured and mean, median, standard deviation were calculated with SPSS 15.0 software. Wilcoxon Signed Ranks test is used to assess whether the difference of MAD values for each cm of lengthening, between group 2 and group 3 are statistically significant; with a p value of <0,05 considered significant.

RESULTS

In group 1, after 6 cm lengthening of six lower limb models, an average MAD of 3.62 mm (min. 3.18, max 3.92) and 0.60 mm/cm MAD was observed. (Table I)

In group 2, different average MAD values for each cm of lengthening were measured. For the first

Table I. — Mechanical axis deviation values in Group 1.

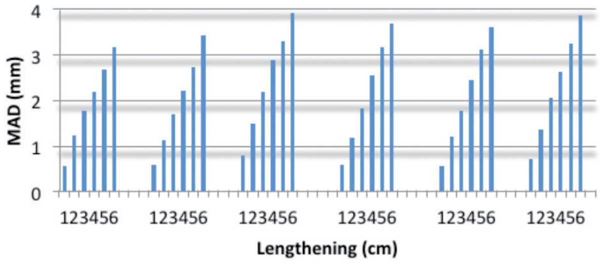
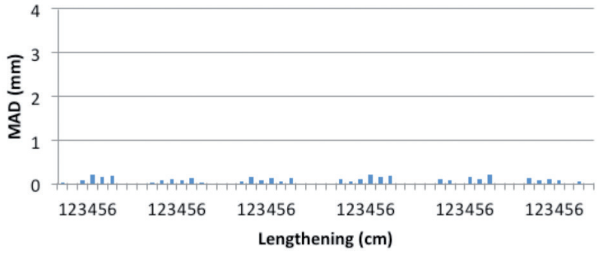


Table II. — Mechanical axis deviation values in Group 2.



and second centimeters of lengthening 0.08 mm MAD occured; however for the third, fourth, fifth and sixth centimeters MAD values of 0.09 mm; 0.15 mm; 0.11 mm; and 0.14 mm was observed, respectively. (Table II)

In group 3, eight nails with different sizes (10×200mm, 10×240mm, 10×280mm, 10×320mm, 11×200mm, 11×240mm, 11×280mm, 11×320mm) were used to achieve 6 cm lengthening with the LON technique and MAD values were determined.

Table III. — Mechanical axis deviation values in Group 3 with different sized nails.

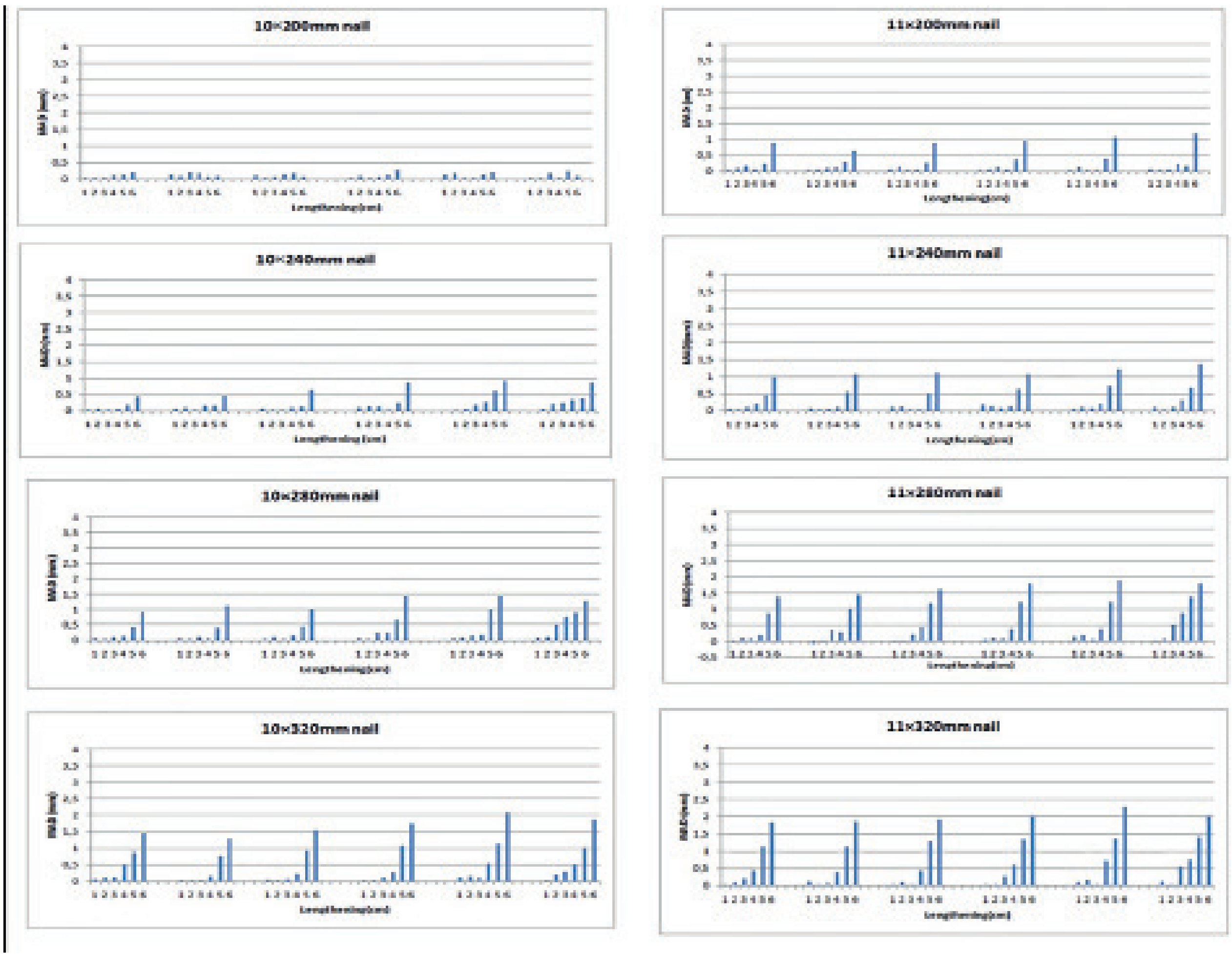
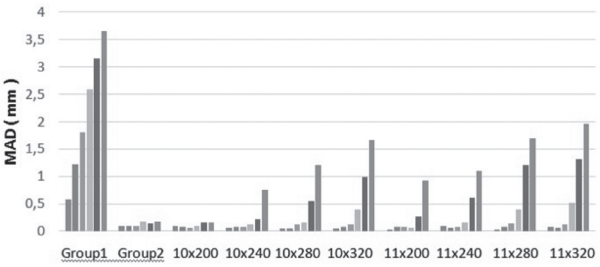


Table IV. — Mean mechanical axis deviation values in Group 1, 2 and 3(with different sized nails)



(Table III and IV) During the first three centimeters of lengthening, no statistically significant MAD difference was observed between group 2 and the eight nails in group 3. On the fourth centimeter, nails with 10×320 mm, 11×280 mm, 11×320 mm sizes showed statistically significant difference compared to group 2. ($p<0,05$) On the fifth and sixth centimeters of lengthening, all nails, except the 10×200 mm nail, created a statistically significant difference on MAD again with respect to group 2. ($p<0,05$)

DISCUSSION

Excessive lengthening over 5-6 cm or more than 20% of limb length was reported to be associated with increased complication rates. (*4,11,28*). As emphasized by Paley et al, there are several publications recently investigating the theoretical risk of lateral shift of the lower extremity mechanical axis, due to achievement of lengthening along the femur anatomical axis.

Although Simpson et al stated that no difference on MAD was observed after lengthening of femur with LON technique, there is an uncertainty about their study in terms of MAD values. (*26*) Even though it has not been specified quantitatively, Gordon et al indicated that some of their patients developed increased valgus leading to minimal changes on lower extremity alignment, and they had to perform hemiepyphyseal stapling on three of their patients to overcome residual angular deformities. (*7*) There is also an uncertainty in the study of Singh et al. They reported no MAD after lengthening over nails, but this study had limitations such as the lengthening was performed on both femur and tibia at the same side, and they did not mention whether deformity correction was added to lengthening or not. (*27*) Similarly Kirane et al declared that no iatrogenic genu valgum was observed in their studies, however this study lacked quantitative MAD values and only evaluated the patients for iatrogenic genu valgum. (*10*) On the other hand Garcia et al reported the necessity for valgus deformity correction in one of their 24 patients who underwent femoral lengthening.(*6*) Guichet et al presented their patient series of 13 cases, mechanical axis lateralisation occured in all patients and genu valgum degrees increased 1.04°±1.3° in average. (*9*) Burghardt et al also observed mechanical axis lateralisation in 26 of their 27 patients. They determined 1mm/cm (0-3.5mm/cm) average lateral shift of mechanical axis. (*2*) Besides clinical case series, Burghardt et al developed trigonometric formulas to calculate the predicted MAD, using lengths of the femur, tibia, whole lower extremity, amount of lengthening and the angle between anatomical and mechanical axis of the femur. They underlined the angle between anatomical and mechanical axes was the most important parameter. (*3*)

In our study we determined 0.60 mm/ cm MAD after lengthening along the anatomical axis in group 1; which is lower than the 1 mm/ cm deviation reported by Burghardt et al. (*2*) However, 27 femurs evaluated in this study included 11 congenital, 7 constitutional, 9 posttraumatic leg length discrepancies. These ethiologies suggests that the average length of femurs used in this study are possibly shorter than our femoral model. It is well known that the angle between anatomical and mechanical axis of the femur is increased in shorter femurs due to hip offset does not vary widely between short and tall people. For this reason, ≥ 8 degree valgus cut is recommended for short (<150 cm)and ≤4 degree valgus cut is recommendended for tall (>190cm) people in adult reconstruction surgery. (*16*) Therefore femoral lengthening through its anatomic axis becomes more important in terms of lateral shift of the lower limb mechanical axis in short people especially <150 cm due to angle between anatomical and mechanical axis of the femur is the most important parameter. (*3,16*) Consequently we consider that higher MAD values than our results were measured in the study of Burghardt et al due to the application of lengthening on relatively shorter femurs. (*2*)

With the LON technique, in order to achieve lengthening along the mechanical axis, the nail must permit some translation over anatomical axis of the femur. In our study, metaphyseal osteotomy, shorter diameter and/or length of nails are used to create iatrogenic instability which allowed translation over anatomical axis. (*13,21,23*) It is usually recommended to implant a 1,5mm narrower nail than the maximum reamer diameter. (*4,7,12,15,22,26*) There are also authors suggesting the use of 2mm narrower nails with the LON technique. (5,8,28). In this study along with the 2mm narrower nails, we also used 3mm narrower IMN to create an iatrogenic instability. During the first three centimeters of lengthening along mechanical axis over all the nails in group 3, no statistically significant MAD difference was observed compared to group 2. These results showed that metaphyseal osteotomy alone provided sufficient instability enough for the first three centimeters of lengthening. On the fourth centimeter, nails with 10×320 mm, 11×280 mm, 11×320 mm sizes showed statistically significant difference compared to group 2; suggesting that besides the instability created with metaphyseal osteotomy there is a need for additional instability which can be provided with shorter nails. On the fifth and sixth centimeters of lengthening, only the 10×200 mm nail achieved lengthening along mechanical axis without a statistically significant difference on MAD again with respect to group 2. This situation which could not be tolerated by the nail, is simply impingement of the nail in the coronal plane. This intolerated translation leads to MAD. If lengthening is continued with excessive force on the system results in stress rises on proximal and distal schanz screws, besides MAD increase. This would also aggravate schanz screw loosening and pin tract infections. *(18)*

Level of osteotomy was standardised in all femur models, so the only variable between nails with same diameter is the length of nail proximal to the osteotomy. The reason for nail impingement during distraction is considered to arise from the bone segment proximal to the osteotomy level. On the fourth centimeter of lengthening, lengthening along mechanical axis, which could not be achieved with 10x320mm nail, was obtained with 10x280mm nail. Similarly 11x280 mm nail could not maintain the mechanical axis whereas 11x240 nail provided lengthening along mechanical axis. When the length of nail proximal to osteotomy level after distraction is considered; for nails 3mm narrower than the reamed medullary diameter being shorter than 20cm; and for nails 2mm narrower than the reamed medullary diameter being shorter than 16cm helped to achieve lengthening along mechanical axis with LON technique.

On the fifth centimeter of lengthening, lengthening along mechanical axis, which could not be achieved with 10x240mm nail, was obtained only with 10x200mm nail. So after lengthening with the 3mm narrower nail than the reamed medullary diameter, the length of the nail proximal to osteotomy level should be shorter than 11 cm. It has been recommended in the literature to keep a nail segment longer than 8cm distal to osteotomy level. (*12,22*)

Baumgart et al described the reverse planning method (RPM) consisting of preoperative templating and poller screws, in order to maintain the mechanical axis during lengthening with elongation nails.(*1*) But this technique may endanger the mechanical axis by a failure in planning or application of poller screws, or in cases of unforeseen malalignments during lengthening. With the modified LON technique described in this study we planned to use appropriate poller screw technique applied both proximal and distal to the osteotomy at the end of lengthening before external fixator removal, in order to increase stability and maintain nail position. (*13,14,25*). One of the main advantages of the procedure described in our study is the chance for reconsideration and revision of unforeseen angulations and malalignments, by the aid of the distal angular adjustable clamps; at the time of surgery for external fixator removal before application of the poller screws. Meanwhile, deformity correction on the osteotomy level can be incorporated in planning with RPM, this study was conducted on femur models without any deformities. However with this technique, it should be kept in mind that, during simultaneous valgus deformity correction medial femoral cortex on the distal segment would approach the nail and may limit desired translation in the course of modified LON technique.

Unlike the standard LON technique, deforming forces created by soft tissues could not be neutralised by IMN because of the iatrogenic instability and would act like a unilateral external fixator. In addition, the rigidity of unilateral fixator would eventually decrease due to the use of the angle adjustable clamps which increases fixator-bone distance on the distal end.(*19*) Woo-kie Min et al conducted a biomechanical study on cadaveric femur bones. They created a 12,5 folds stiffer construct by the combination of IMN and external fixator with two proximal and two distal Schanz screws, compared to external fixator alone with three proximal and three distal Schanz screws. They attributed this increase in stiffness to friction forces between IMN and medulla. (*17*) Therefore, with the described technique, together with the increase in the amount of lengthening, friction between IMN and bone medulla would increase; resulting in recuperation of axial stiffness. But in the initial phases of lengthening, because the system acts as a unilateral fixator, use of three Schanz screws in the proximal and distal segments may be considered. (*19,20*) In this case, due to the increasing number of schanz screws, the risk of intramedullary progression of superficial pintract infections will also rise.(*22*) Likewise, Küçükkaya et al, reported that only one proximal schanz screw with good bone purchase at lesser trochanter level, and two distal schanz screws provided adequate fixation for LON technique applied with retrograde IMN. (*15*)

One of the important limitations of our study is that lengthening was not performed under physiological loadings. Also, few number of bone models and evaluation of only one osteotomy level are other major limitations. If an IMN which allows a more distal osteotomy is used in the described technique; due to the longer nail extent in the proximal segment when impingement develops; it might be expected expected to achieve a better chance of stability.

CONCLUSIONS AND RECOMMENDATIONS

The mechanical axis deviation due to the lengthening along anatomical axis of femur should be prevented and a new deformity should not be created. If excessive lengthening is being planned on a patient whose height is shorter than 150cm and lower extremity mechanical axis is passing nearer to the lateral side of the center of the knee, the risk of knee valgus deformity after lengthening along anatomical axis of femur, is increased. The clinical knee valgus deformity that Paley et al. reported as 1 out of 25 and Garcia et al reported 1 out of 24, is a result of the theoretically known risk. (*22*) (*6*) The modified LON technique described in this study, in similar purpose with RPM, provided lengthening along the mechanical axis. Preoperative misplanning or failure in application of poller screws with RPM technique may lead to unforeseen angulations. The revision of mechanical axis would be more difficult in RPM than the modified LON technique. By the aid of the distal angular adjustable clamps used in the modified LON technique, there is a chance for reconsideration and revision of such unforeseen angulations and malalignments at the time of surgery for external fixator removal. Before clinical application of this technique, further studies should be conducted with different femur sizes and osteotomy levels under physiological loadings.

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