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Research Article

3D Printed Cutting Guide for Subtrochanteric Transverse Shortening Osteotomy in Total Hip Replacement for Crowe Type 4 Developmental Dysplasia

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ABSTRACT

Objective: Subtrochanteric transverse femoral shortening osteotomy is a frequently employed technique to avoid potential complications in total hip arthroplasty with a high hip center. However, when performed freehand, the osteotomy may be associated with complications such as non-union, instability, and rotational deformities. Additional assistance is often required during prosthesis insertion and reaming procedures. In this study, we developed a simple, non-patient-specific 3D incision guide to improve the quality and outcomes of shortening osteotomy procedures.

Methods: Following design development in SolidWorks 2023, the 3D cutting guide was printed using an FLSUN T1 Ultra 3D printer. The cutting guide was printed with polylactic acid + filament (layer height 0.2 mm, infill 40%, nozzle 0.4 mm, 210 °C). The designed device has only been tested on a Sawbone synthetic foam cortical shell femur model using Wagner cone stems.

Results: Use of the non-patient-specific 3D cutting guide during subtrochanteric femoral shortening osteotomy in total hip arthroplasty with a high hip center resulted in a more precise osteotomy line, facilitated rotational adjustment, and reduced the overall duration of the prosthesis implantation procedure.

Conclusion: The non-patient-specific 3D cutting guide used in subtrochanteric transverse shortening osteotomy can enhance the quality of the osteotomy and minimize complications. Furthermore, owing to its circumferential design enveloping the femur, it may serve as a prophylactic splint, thereby reducing the risk of fissure formation during prosthesis implantation. Future clinical trials and further refinements of the cutting guide are expected to yield more favorable outcomes.

Keywords: Subtrochanteric femoral shortening osteotomy, Crowe type IV hip, 3D printed cutting guide, total hip arthroplasty

INTRODUCTION

Hip arthroplasty for osteoarthritis secondary to developmental dysplasia of the hip presents unique challenges compared with arthroplasty for primary hip osteoarthritis. The primary issue lies in the malpositioning of the femoral head away from its anatomical center.[1] Because the femoral head is located superior to the native acetabulum, the surrounding anatomical structures adapt to this altered development. Consequently, hip arthroplasty with shortening presents a number of challenges. In patients with leg length discrepancies of ≥ 4 cm, increased sciatic nerve tension, rotational abnormalities, and difficulties achieving reduction after prosthesis implantation have highlighted the need for femoral shortening osteotomy.[2-6]

The literature contains numerous descriptions of techniques for performing shortening osteotomies. In 1990, Paavilainen et al.[6] introduced femoral shortening osteotomy in conjunction with greater trochanteric advancement, reporting improvements in patients' gait patterns and reductions in pain scores.[7] Currently,

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subtrochanteric osteotomy is the most commonly used shortening technique in high hip dislocations. This approach was initially described by Becker and Gustilo[8], using a double-chevron osteotomy. Subsequently, Reikeraas et al.[9] reported the use of a transverse derotational subtrochanteric osteotomy for femoral shortening in a series of 25 patients. In cases where femoral shortening is achieved via subtrochanteric transverse osteotomy, the geometry of the osteotomy surfaces of the proximal and distal fragments is critical for stable fixation along the osteotomy line. Moreover, the configuration of the cut enhances bone-to-bone contact between fragments, thereby reducing complications such as malunion and non-union. The rotational alignment between the two segments is also pivotal in determining postoperative gait and hip stability.[10-12]

No previous study has demonstrated a method for performing a subtrochanteric transverse osteotomy that ensures complete and congruent bone contact after shortening. Moreover, reports addressing strategies to prevent potential complications resulting from an inadequate osteotomy are limited. In the present study, we aimed to facilitate and optimize the execution of subtrochanteric transverse femoral shortening osteotomy by employing the cutting guide we developed. We also aimed to streamline the surgical procedure to reduce operative time and thereby avoid complications associated with prolonged operations.

The primary hypothesis of the study was that the use of an appropriately designed cutting device would shorten the surgical duration in high hip arthroplasty and enhance the congruence of bony contact between the proximal and distal fragments following the osteotomy. The secondary hypothesis was that the reduction in surgical duration afforded by guide-assisted procedures would decrease the need for blood transfusions.

MATERIALS AND METHODS

Following the initial design stage in SolidWorks, iterative improvements were made using trial cutting guides produced using FLSUN T1 Ultra 3 dimensional (3D) printer. The cutting guide was printed with polylactic acid + filament (layer height 0.2 mm, infill 40%, nozzle 0.4 mm, 210 °C). The designed device has only been tested on a Sawbone synthetic foam cortical shell femur model using Wagner cone stems. Since it is not used on living organisms, sterilization is not required. However, for use on living organisms, the device can be manufactured from titanium and sterilized in an autoclave. This allows the cutting guide to be reused.

MAIN POINTS

- The newly developed cutting guide facilitates the application of femoral shortening osteotomy in Crowe Type 4 hip dysplasia surgery.
- The device may reduce the risk of intraoperative complications by shortening surgical time.
- Experimental tests demonstrate that it improves osteotomy accuracy.

The cutting guide comprises two components that are secured together using a screw and bolt system. The upper and lower bone segments firmly stabilize the intermediate piece, analogous to a component enclosed between two opposing supports. The upper component features five cutting slots, each 1.27 mm thick and spaced 7.46 mm apart. The saw blade used for the osteotomy is 1.25 mm thick. This configuration is intended to prevent the saw blade from oscillating proximally or distally, thereby avoiding irregularities along the osteotomy line that could compromise the press-fit between the bone segments. In addition, the guide is equipped with holes—aligned in a straight line at the distal, proximal, and midline positions—that allow for the insertion of 2-mm Kirschner wires (K-wires).

These holes serve two purposes: first, they facilitate fixation of the guide to the bone; second, following the osteotomy, they provide immediate information regarding the rotational alignment of the proximal and distal fragments without requiring additional markings. Furthermore, the holes adjacent to the midline openings at the most distal and proximal positions are angled at 15 °. Based on our preoperative planning, this approach enables us to determine the required amount of derotation by referencing this area in patients who need it (Figure 1).

The lower component of the guide has a simpler design. Although it mirrors the design of the upper part, it does not include any cutting slots or K-wire insertion holes. The bone, interposed between the upper and lower components (again resembling a hot dog in a bun), is secured to the assembly by a bolt system, with two bolts placed at the proximal and distal ends.

Two advantages of this design were observed during the Sawbone trials. First, the absence of cutting slots in the lower component prevents the saw blade from coming into contact with medial structures, effectively serving as a protective retractor. Second, once the osteotomized segment is resected, controlling the proximal and distal fragments can be challenging. This device allows the two segments to be approximated and, following rotational alignment, to be compressed together in a sandwich-like configuration, effectively reconstituting a single, continuous femur. Consequently, the separate reaming procedures for the proximal and distal fragments, as well as the reduction process following trial stem placement, are simplified, thereby eliminating intraoperative instability and rotational issues (Figures 2, 3, 4, and 5).

The presence of a cutting gap at different levels of the guide allows additional cuts in patients with insufficient shortening after testing, without removing the guide. When the rotational alignment of the proximal and distal fragments is deemed appropriate, the K-wires placed at the "0" position of the cutting guide can be used to establish rotational reference points for the osteotomy. In the Sawbone trials, the Wagner Cone Prosthesis (Zimmer Biomet) was used.

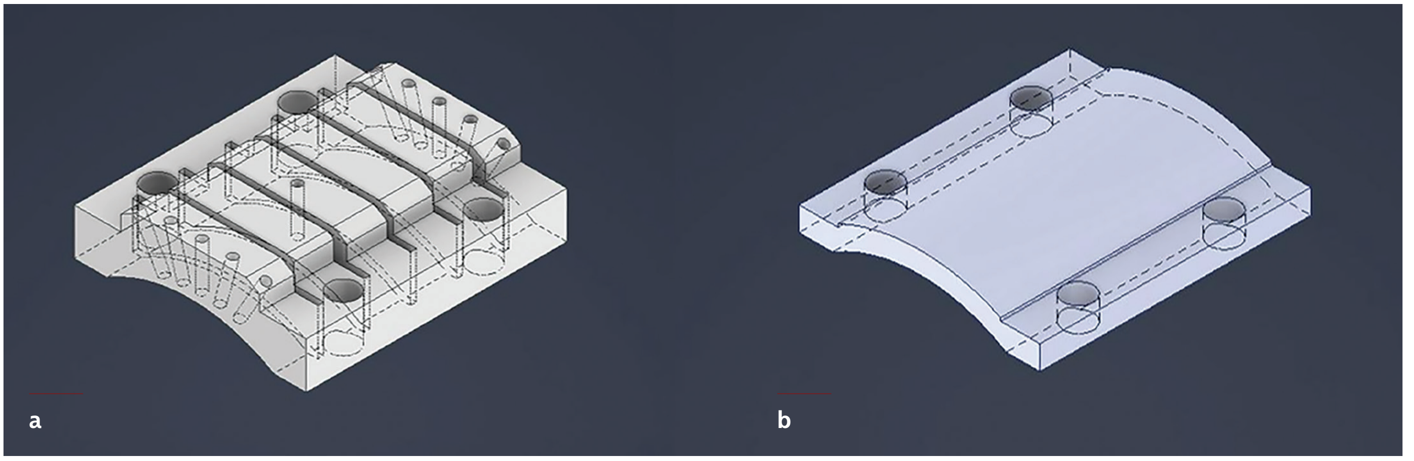

Figure 1. a, Upper part of the guide; b, Lower part of the guide

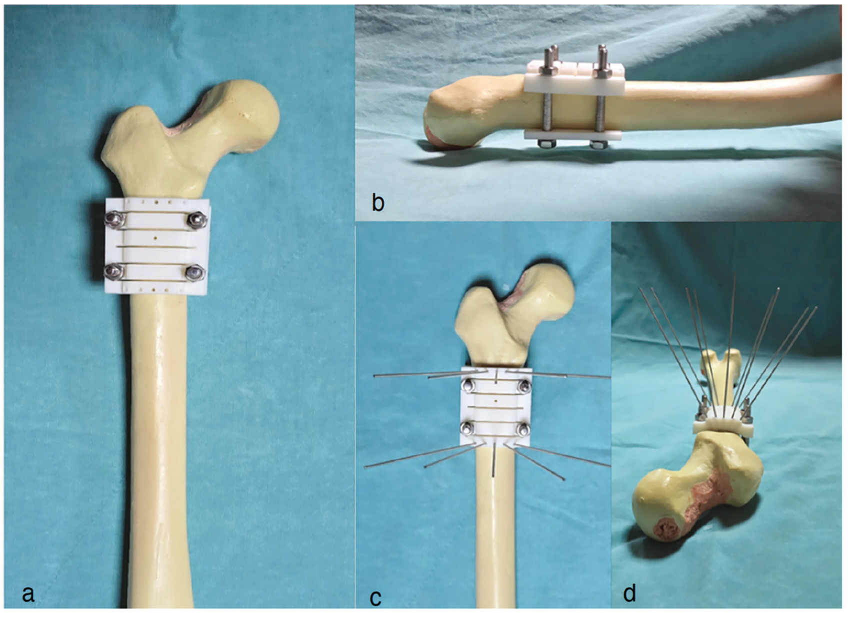

Figure 2. a, Anteroposterior view during positioning of the guide before the osteotomy; b, Lateral view of the guide during pre-osteotomy positioning; c, Image of the guide on the bone after placement of the rotational wires; d, Axial view of the guide after placing the rotational wires (demonstrating a 15° interval between the wires). Note: All wires are shown to clearly illustrate the angles.

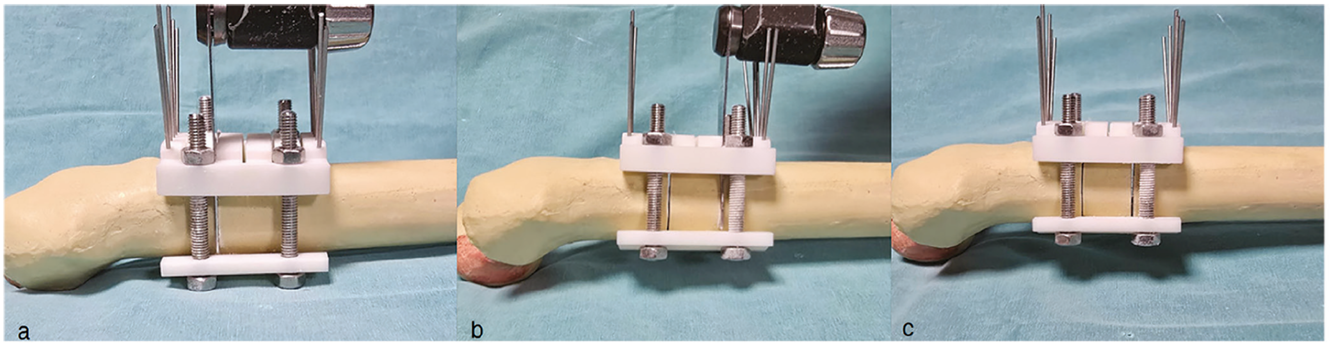

Figure 3. a, Proximal cut-of the fragment to be resected performed with the assistance of the guide; b, Distal cut-of the fragment to be resected performed with the assistance of the guide; c, Image showing the integrity of the resected fragment and the remaining bone following completion of the proximal and distal cuts.

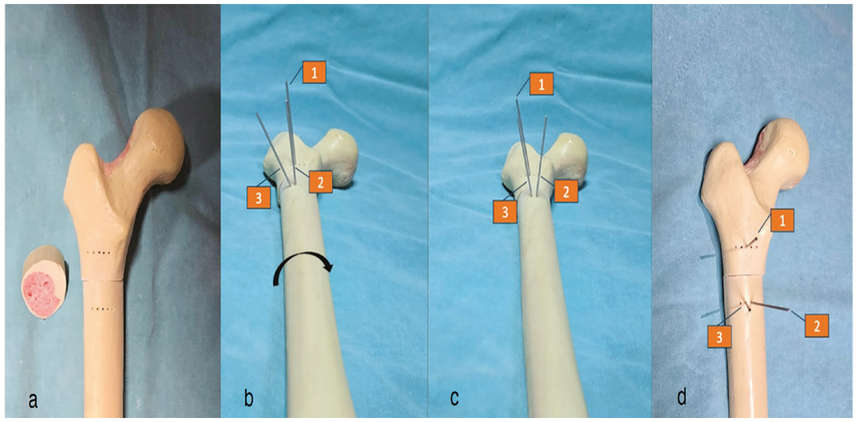

Figure 4. a, Image showing the congruity between the proximal and distal segments after the excised segment has been removed following the proximal and distal cuts; b–d, Demonstration of rotational adjustment on the Sawbone model using the K-wire insertion holes. In the neutral position, the first and second K-wires are aligned vertically; after internally rotating the distal fragment by 15°, the first and third K-wires come into opposition.

K-wires: Kirschner wires

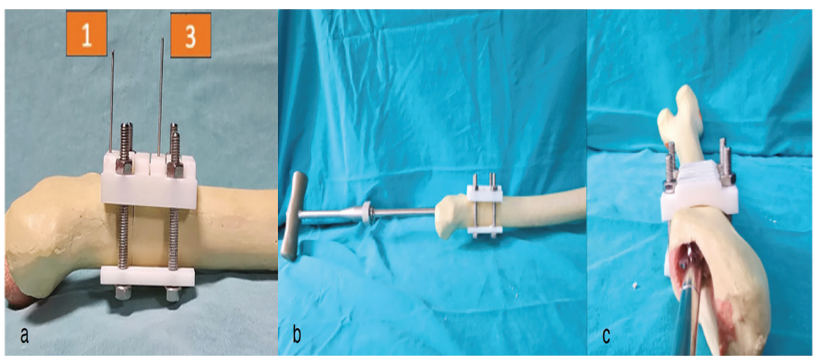

Figure 5. a, After achieving the desired rotational alignment of the proximal and distal fragments, the second K-wire is removed. The guide is passed over the wires on the proximal and distal fragments to secure proper alignment between them; b, With the assistance of the guide, the femur is stabilized prior to reaming; c, Reaming is performed on the femur, which has been consolidated into a single unit with the aid of the guide.

RESULTS

The guide was designed using SolidWorks 2023 and manufactured using an FLSUN T1 Ultra 3D printer. The 3D-printed osteotomy guide was positioned on a Sawbone so that it was aligned beneath the lesser trochanter and was secured with compression screws. For rotational orientation, K-wires were inserted through the designated holes in the guide, which demonstrated excellent stability when affixed to the bone. The saw used for the osteotomy was press-fit into the cutting slot of the guide, and no oscillation occurred during the cutting process. The bone segment produced after the osteotomy measured 2 cm, as planned, and the resulting surfaces were perfectly aligned.

Upon removal of the guide, the K-wire holes provided clear guidance regarding rotation. Following a 15° derotation, the proximal and distal segments were reassembled, the guide was repositioned, and no distraction was observed along the osteotomy line. Throughout the carving process, the guide remained well fixed to the bone; after prosthesis implantation and subsequent removal of the guide, no rotational instability was observed. The osteotomy line appeared to be perfectly aligned. Additionally, while the guide was in place, no fissure formation was detected during the carving and prosthesis implantation procedures Figure 6.

DISCUSSION

Currently, 3D cutting guides are used in many areas of orthopaedics.[13-22] One of the primary reasons for their widespread adoption in surgical procedures compared with the past is their increased accessibility and the fact that they no longer require large industrial facilities for production. The 3D-printed cutting guides can be produced specifically for individual patients or fabricated for one-time, general use.

Because the planned osteotomy is not complex, one of the most important features of the cutting guide we designed is that it can be produced as a single-use, non-patient-specific guide. In a study examining proximal femoral morphology in 51 hips from 45 patients with Crowe type IV dysplasia, the average femoral canal width—calculated from the mediolateral and

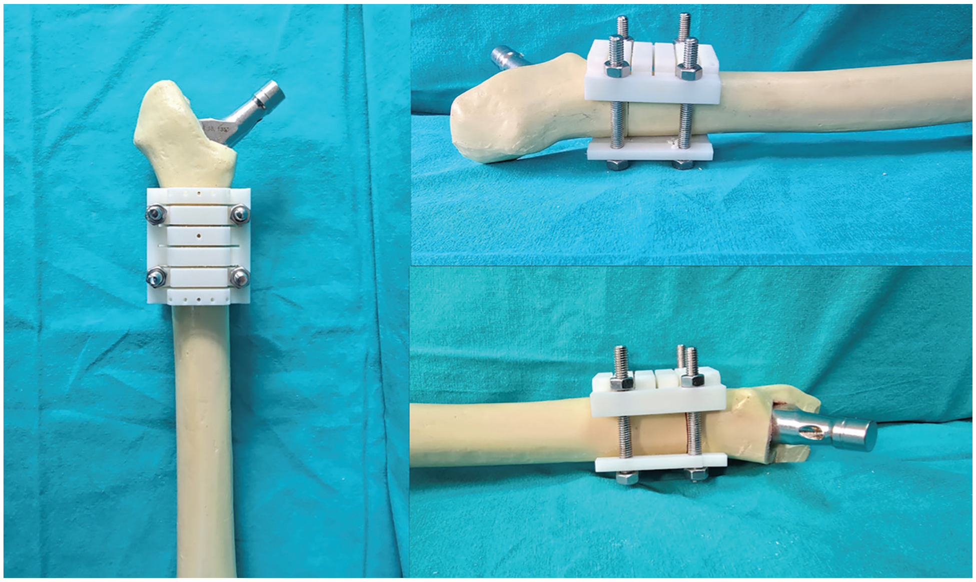

Figure 6. After reaming, the prosthesis is securely and smoothly implanted without removing the guide, as if placing it into an intact femur. Image showing the congruity and fixation between the fragments after prosthesis implantation.

anteroposterior dimensions—was approximately 2 cm in the widest patient, measured at a level 1-2 cm below the lesser trochanter.[1] Based on this information, the guide was oriented just distal to the lesser trochanter. The bone-contacting section of the guide was designed to be 3 cm wide with a slightly curved surface, ensuring that it is not patient-specific and is reusable. The ability to use a standardized guide without having to manufacture a separate one for each patient also provides a cost advantage. Numerous techniques have been described for subtrochanteric shortening osteotomy. One of the most common complications encountered with these procedures is inadequate union at the osteotomy site.[23,24] When osteotomies are performed freehand in a 3D context, achieving complete cortical contact is extremely challenging. Limited contact between bone ends has been reported to adversely affect union.[23,25] Huang et al.[26] reported that to maximize bone contact between the proximal and distal segments after osteotomy, the osteotomy level should be set approximately 1-1.5 cm below the lesser trochanter, which would promote union. Zadeh et al.[11] reported that, for a stable osteotomy, the portion of the femoral stem distal to the osteotomy should be at least 6 cm. Furthermore, if rotational correction is required following osteotomy, performing a freehand cut in the same plane becomes challenging, thereby hindering complete cortical contact between the proximal and distal fragments. Readjusting the bone ends with a saw would prolong operative time, increase bleeding, and make limb-length adjustment difficult because of excessive shortening. In the present study, evaluation of postoperative radiographs revealed that in all cases complete cortical contact was achieved along the osteotomy line on both anteroposterior and lateral views with no detectable gaps.

In hip arthroplasty performed on elevated hip surfaces, femoral anatomy differs from that of normal hips and includes rotational variations. In such hips, femoral anteversion is increased, and the greater trochanter is positioned more posteriorly.[27,28] Failure to adjust anteversion during surgery can cause recurrent anterior dislocations and result in the greater trochanter and abductor muscles remaining positioned posteriorly, thereby shortening the abductor lever arm and causing gait abnormalities and instability.[10-12,29] One of the most significant advantages of subtrochanteric transverse osteotomy is that the congruence between the cylindrical bone surfaces allows the proximal fragment to be rotated, thereby bringing the greater trochanter—and consequently the abductor muscles—into the proper anatomical position.[1,24,29] Under normal circumstances, various techniques exist for accurately adjusting the rotational alignment during a freehand osteotomy.[28] For example, some methods involve drilling holes with K-wires at the proximal and distal ends of the osteotomy or marking the bone intraoperatively with a surgical pen. However, such markings can disappear when additional bone resection is required or when the osteotomy surfaces need to be revised with a second cut. In particular, pen markings may easily be erased by intraoperative bleeding and fluids. This can necessitate repeating these steps, thereby increasing operative time and blood loss. In contrast, the K-wire holes positioned at 15 ° intervals along the proximal and distal edges of our cutting guide indicate the degree of rotational correction required and permit direct marking on the guide if an additional cut is required. This design facilitates easy and precise rotational adjustment.

Krych et al.[30] described the technique of total hip arthroplasty with subtrochanteric transverse shortening osteotomy in Crowe type IV hips and noted that, after resecting the femoral neck—and before proceeding with the shortening osteotomy—reaming should be performed. This step is critical for achieving a tight press-fit prosthesis in the distal fragment and contributes to the rotational stability of the implant and the osteotomy site.[30,31] Because our cutting guide securely approximates the distal and proximal femoral segments after the osteotomy—

effectively allowing them to function as a single continuous femur—it enables reaming to be performed post-osteotomy without requiring initial reaming. Consequently, this approach has the potential to reduce surgical duration and blood loss.

One of the most significant challenges encountered during femoral preparation in Crowe type IV hips is the occurrence of femoral fissures.[32,33] In a series of 28 Crowe type IV hip cases reported by Krych et al.[30], fissures developed in the distal region of the femoral osteotomy during prosthesis insertion in five of the patients. They stated that a prophylactic cable is routinely wrapped around the distal segment to prevent this from occurring.[30] Although this study was conducted using Sawbone models—thus precluding definitive conclusions—we believe that the way the cutting guide conforms to bone mimics the effect of a prophylactically applied cable and thus prevents fissure formation in the distal fragment. However, prophylactic cerclage wiring is still recommended to minimize fissure risk.

Infection remains one of the most significant complications of total hip arthroplasty. Numerous studies have demonstrated that prolonged surgical duration increases the risk of postoperative infection.[34-37] By employing the osteotomy cutting guide, the need for the pre-osteotomy reaming phase is eliminated, additional reaming of the distal segment is avoided, and the placement of trial stems and the reduction process are facilitated, resulting in a shorter surgical duration. This reduction in surgical duration may contribute to a lower infection rate.

Furthermore, a shorter surgical duration reduces the overall operating room usage, leading to decreased expenses related to electricity, materials, and personnel. In their study on high tibial osteotomy using a patient-specific 3D cutting guide, Pérez-Mañanes et al.[17] demonstrated that the reduction in surgical duration more than offset the cost of the guide, resulting in a net saving of €507 per procedure.[21] Although we have not yet quantified the exact economic benefit of our non-patient-specific, reusable cutting guide, it is evident that it offers substantial long-term cost savings.

Study Limitations

The main limitations of this study include that the device has not been tested in patients and that the biomechanical outcomes have not been evaluated using cadaveric specimens. Future multicenter, controlled studies with larger patient cohorts will be instrumental in elucidating these issues.

CONCLUSION

In Crowe type IV hip arthroplasty, the cutting guide that we developed for subtrochanteric transverse shortening osteotomy achieved complete cortical contact along the osteotomy surfaces during our Sawbone trials. We believe that the swift, practical execution of cutting and prosthesis-implantation procedures facilitated by the guide will lead to reduced surgical duration and a reduced need for blood transfusions. Additionally, the cutting guide's ability to act as a temporary cable to prevent fissure formation appears to be a key advantage.

Ethics

Ethics Committee Approval: Baltalimani Metin Sabanci Bone and Joint Diseases Education and Research Hospital Ethical Review Committee, İstanbul with decision no.: 188, date: 30.09.2024.

Informed Consent: No human participants or patient data were involved; ethical approval and informed consent were not required for this Sawbone model study.

Footnotes

Author Contributions

Concept Design – A.A., M.M., A.K.; Data Collection or Processing – M.Ö., M.B.K.; Analysis or Interpretation – M.Ö., A.A., B.P.; Literature Review – M.Ö., M.M., B.P.; Writing, Reviewing and Editing – M.Ö., A.A., A.K.

Declaration of Interest: The authors declared no conflicts of interest.

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