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Application of 3D-Printed Patient-Specific Guides for Femoral Bone Preparation in Cementless Total Hip Arthroplasty in a Dog

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Abstract

This case report presents the first successful Biomedtrix BFX™ total hip replacement in a dog with Legg–Calve–Perthes disease utilizing patient-specific 3D-printed guides to aid in femoral reaming. An 11-month-old, male, neutered goldendoodle weighing 11.8 kg presented with left hindlimb lameness of 2 to 3 months secondary to Legg–Calve–Perthes disease. Computed tomography and radiographs were used for surgical planning. Patient-specific instrumentation (PSI) and 3D bone models were printed out of a biocompatible material and used for preoperative rehearsal and intraoperative use. Patient-specific instrumentation enabled coaxial initial drilling and reaming. The PSI facilitated coaxial alignment during the initial drilling and reaming process. However, coaxial alignment was not maintained during broaching and stem insertion, deviating from the guided preparation of the initial bed. In the authors' opinion, PSI improved the precision of a major procedural step compared to traditional techniques. While this novel technique for BFX total hip replacement with PSI demonstrated promising results in this case, the limitations highlighted underscore the necessity for further research.

Keywords

- Legg–Calve–Perthes disease
- 3D printing
- total hip replacement

Introduction

Legg–Calve–Perthes disease (LCPD) is a developmental orthopaedic condition characterized by ischaemic necrosis and deformation of the femoral head.[1] Pathogenesis involves necrosis of the trabeculae in the proximal epiphysis of the femur and microfractures due to mechanical stress.[1] The average age of LCPD diagnosis is between 4 and 12 months and is a common cause of pelvic limb lameness in small breed dogs presenting with hip pain.[1] Untreated LCPD may lead to pelvic limb muscle atrophy, hip pain, limb length discrepancy, and lameness.

Reported surgical treatments for LCPD include femoral head and neck ostectomy (FHNO) and total hip replacement (THR).[1–3] Canine THR has proven to be highly effective. Biomedtrix manufactures two THR systems, a press-fit biologic (BFX) and cemented fixation (CFX). An advantage to Biomedtrix THR systems is that both applications follow the same fundamental surgical steps, which allow either press-fitting or cementing into the acetabular or femoral preparation sites. Implants come in a wide array of sizes, providing surgeons with versatile options to address hip reconstruction across a wide array of dog sizes and breeds.

The femoral BFX implant was previously recommended to fill approximately 85% of the femur.[4] Intraoperatively, this is achieved by reaming and broaching of the femoral canal. Failure of colinear femoral preparation may result in femoral fracture or fissure.[5] Notable risk factors include breed, age, canal flare index, cortical to medullary ratio, metaphyseal bone density, and surgeon's experience, for which a 0.011 to

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6.8% femoral fracture rate and a 0.005 to 21% femoral fissure rate has been recently published.[5–10]

3D printing in veterinary medicine has received more recent attention.[11,12] 3D printing permits surgeons to tailor their plan to unique anatomy, rehearse complex procedures, and precontour implants.[11–14] In humans, patient-specific instrumentation (PSI) provides higher accuracy in osteotomy alignment correction with a low rate of outliers, shorter operative time, and decreased intraoperative fluoroscopy.[15] This case represents the first successful Biomedtrix (Biomedtrix, Whippany, NJ) BFX™ small breed THR in a canine with LCPD utilizing a novel PSI as a 3D-printed reaming guide to aid in femoral preparation.

Case Description

Clinical History

An 11-month-old, 11.8 kg, male, neutered goldendoodle presented with left pelvic limb lameness of 2 to 3 months duration, secondary to presumed LCPD. Examination revealed left hip pain, crepitus, and reduced functional hip range of motion with severe thigh and gluteal muscle atrophy.

Radiographic findings included proximal femoral medullary sclerosis, chronic, severe, secondary degenerative joint remodelling, and collapse of the femoral head with loss in subchondral bone architecture consistent with LCPD. Sclerosis of the proximal femoral metaphysis and remodelling of the acetabular rim were noted on multiple projections and were consistent with a chronic phenomenon (►**Fig. 1**). A left THR was recommended and elected by the owner. A hematology and chemistry profile with urinalysis were performed and within normal limits.

Surgical Planning

Due to patient size and the presence of significant radiographic changes in femoral osseous density, a computed tomography (GE Ascend 16 slice, Bethesda, MD) was obtained and used to create PSI designed to facilitate femoral canal preparation.

A preoperative computed tomography was performed of the pelvis and hindlimbs using a bone algorithm and a slice thickness of 0.625 mm. Digital Imaging and Communications in Medicine data from the computed tomography were imported into the Digital Imaging and Communications in Medicine

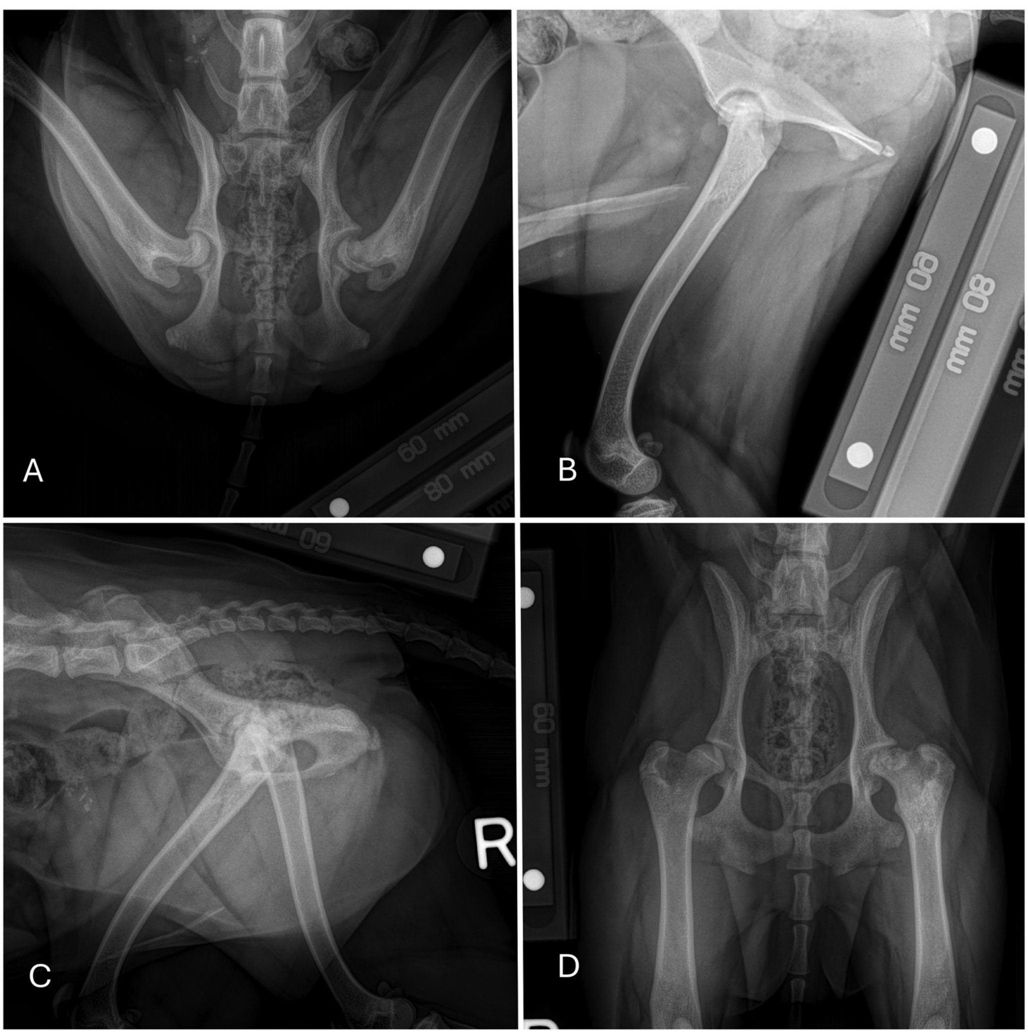

Fig. 1 (A–D) Preoperative total hip replacement planning radiographs (left is on the right side of the image in all views apart from B). (A) Frog leg ventrodorsal view, (B) mediolateral view, (C) right lateral pelvis, (D) hip-extended view.

viewer and segmentation software (3D Slicer), where the pelvis and femur underwent automatic thresholding and manual segmentation and were exported as mesh files. The mesh files were opened in SolidWorks (SolidWorks Corporation, Waltham, MA) and converted from mesh to solid models. Models of the femoral stem implant (BioMedtrix BFX™ number 4 Stem) were superimposed over the solid bone models to confirm the 3D templating of the femoral implant size and determine the drilling and broaching axis of the proximal femur. The PSI design footprint was oriented by the femoral head and the proximal medial diaphysis just distal to the lesser trochanter. The PSI was designed in computer-aided design (CAD; SolidWorks) and 3D printed on Formlabs Biomed Amber Resin according to the manufacturer's recommendations. Additionally, three drill guides, 2.7 mm, 4.0 mm, and 5.0 mm were developed and machined out of 316LVM stainless steel to accommodate the surgical technique for sequential reaming. 3D planning for the acetabular cup was not warranted.

Multiple CAD rehearsals were performed with the patient-specific 3D-printed femur model and resin reaming and drilling guides, with one surgical rehearsal with radiographs performed on the 3D-printed models (►**Fig. 2**).

Surgical Treatment

A craniolateral approach was made to the left hip with deep gluteal tenotomy and retraction for the placement of drill guides and bits. Additional femoral cortical preparation was performed by partial elevation of the origin of the vastus lateralis and vastus intermedius, to obtain adequate PSI footprint mating on the bone without soft tissue interference. The PSI was secured to the femoral head using two 1.1-mm Kirschner wires and a 20-gauge cerclage wire around the proximal femur and guide. The PSI was utilized for guided drilling of the proximal femur and femoral canal preparation prior to stem placement. Intraoperative fluoroscopy (GE OEC Brivo, Bethesda, MD) was used to confirm appropriate coaxial femoral canal preparation. The PSI contained an opening at the proximal aspect of the femur, offset from the greater trochanter, where sequential drill sleeves were inserted to create a femoral canal opening followed by coaxial enlargement. This was accomplished in a sequence of 2.7-, 4.0-, and then 5.0-mm drills (with matching drill sleeves) followed by a number 4 tapered reamer. A second drill sleeve through the PSI was used with a 5.0-mm drill for additional medial neck preparation (►**Fig. 3**), after which the PSI was removed, and the femoral head resection was performed. Next, a number 4 BFX™ broach was used for the final femoral canal preparation (non-guided). Finally, femur retraction and acetabular bed preparation were performed according to standard BioMedtrix BFX™ implant techniques.[5] An 18-mm BFX™ acetabular prosthesis was impacted into the prepped acetabular bed. A number 4 BFX™ Femoral Stem was then impacted in a routine fashion. Trial hip reductions were performed, and a 12 mm/+3 femoral head was selected and applied to the femoral stem.

The joint was reduced, and the surgical wound was lavaged with saline prior to bacterial culture and routine closure. Postoperative radiographs (►**Fig. 4**) were performed. Mild varus and caudal tipping of the femoral stem were noted (3.1° of varus in the frontal plane and 4.5° caudally tipped in the sagittal plane). The average canal fill was 63.7% (coronal plane = 65.3% and the sagittal plane = 62.1%) were identified and accepted as satisfactory.

Anaesthesia/surgery recovery was unremarkable. The patient was hospitalized for 3 days postoperative during which the dog demonstrated immediate and substantial left hind weight-bearing with improving strength, posture, and balance. The patient was discharged with grapiprant (2 mg/kg *per os* once daily; Galliprant, Elanco Animal Health Incorporated, Greenfield, IN), cephalexin (22 mg/kg *per os* twice a day; Cronus Pharma, East Brunswick, NJ), gabapentin (15 mg/kg *per os* three times a day; Amneal Pharmaceuticals, Bridgewater, NJ) medications for 10 days. Four weeks of strict confinement and 12 weeks of relative confinement were mandated.

Outcome

Six days postoperatively, the owner communicated gradual improvement in weight-bearing and range of motion. Four-week postoperative radiographic recheck found static implants in position with no evidence of complications. At the 10-week postoperative recheck, the owner reported the patient was fully weight-bearing on the left hindlimb without any concerns noted. Clinical assessment revealed good weight-bearing function, smooth, non-painful range of motion, and radiographs that showed the static appearance of implants. At the last clinical follow-up, 18 months postoperatively, no abnormalities were noted with symmetrical pelvic limb weight-bearing and muscle mass. Radiographs again revealed the static appearance of THR implants without complications. The owner did not report any abnormalities from discharge to 4 years postoperative at the last follow-up with excellent weight-bearing at walk, trot, and sprint (►**Video 1**) and overall great satisfaction with the postoperative result. During the clinical rechecks at 4 weeks, 10 weeks, and 18 months postoperatively, radiographs did not reveal any change in implant alignment or radiographic complications.

Video 1

(voiceover) At a 4-year follow-up after a total hip replacement, this dog demonstrates excellent mobility, trotting, and sprinting with ease. The last clip is zoomed in and slowed down by 90% to highlight the details of the sprinting motion. Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/a-2513-9753.

Discussion

LCPD responds poorly to conservative management. Total hip replacement is a superior alternative treatment in comparison to FHO/femoral head and neck excision for LCPD.[1–3,16] Some literature has found that 34% of patients that received a FHO experienced intermittent lameness and pain

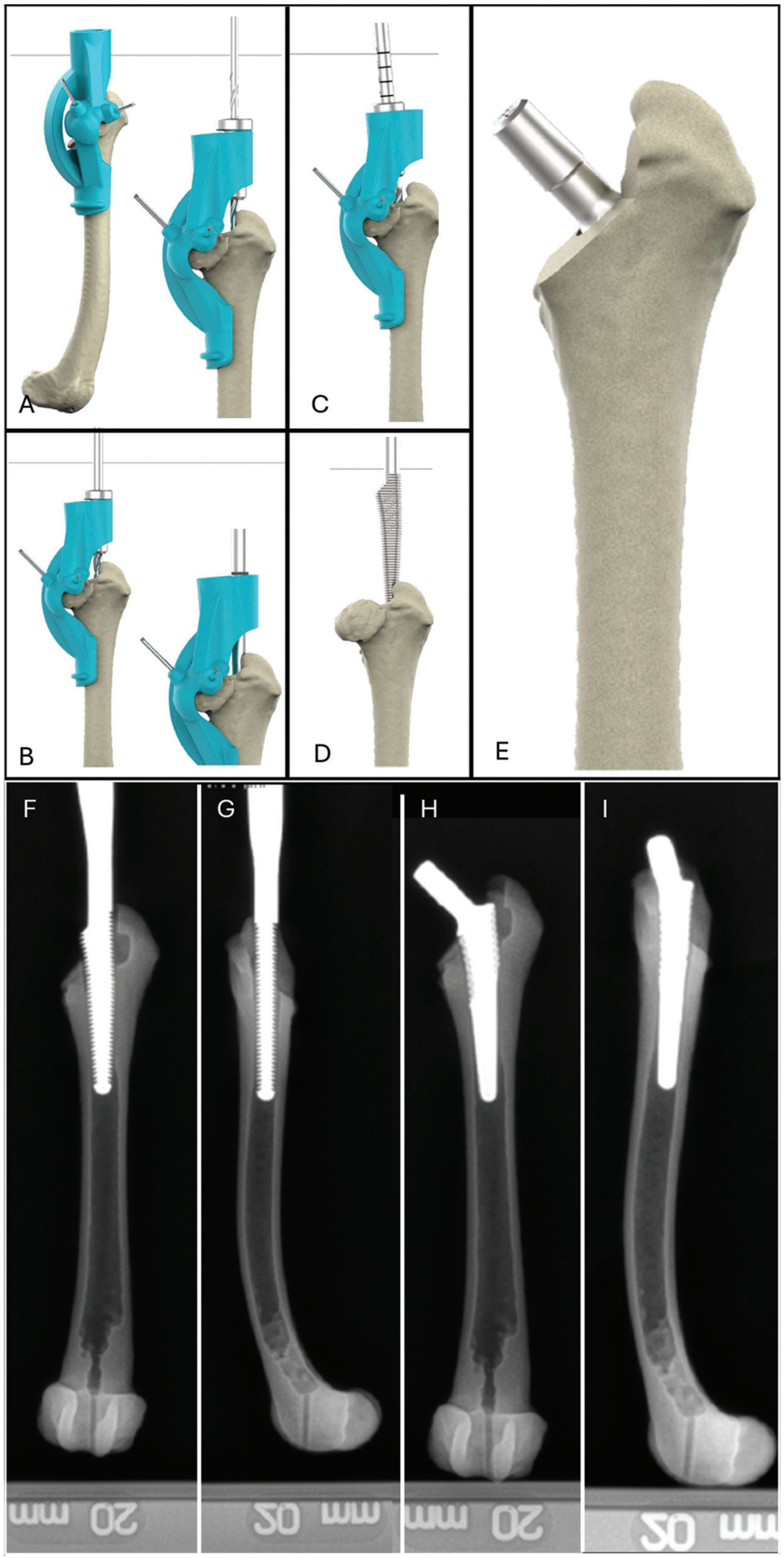

Fig. 2 (**A–E**) computer-aided design images of the surgical procedure to aid in utilization of the patient-specific instrumentation. (**A**) patient-specific instrumentation footprint clearance was established followed by securing the patient-specific instrumentation to the femoral head with K-wires and proximal femoral cerclage (not shown, left) prior to drilling with a 2.7-mm drill bil with mated drill sleeve. (**B**) Sequential drill planning using a 4.0-mm then a 5.0-mm drill bit with a mated drill sleeve. (**C**) Medial neck preparation using a 5.0-mm drill bit with a mated drill sleeve. (**D, E**) represent the final steps of the procedure where the (**D**) number 4 BFX™ Broach is shown proximal to the final femoral canal preparation, and finally (**E**) number 4 BFX™ Stem is implanted. Craniocaudal (**F, H**) and mediolateral (**G, I**) radiographs after rehearsal surgery. Radiographs (**F, G**) were simulated broaching while (**H, I**) were after BFX stem implantation.

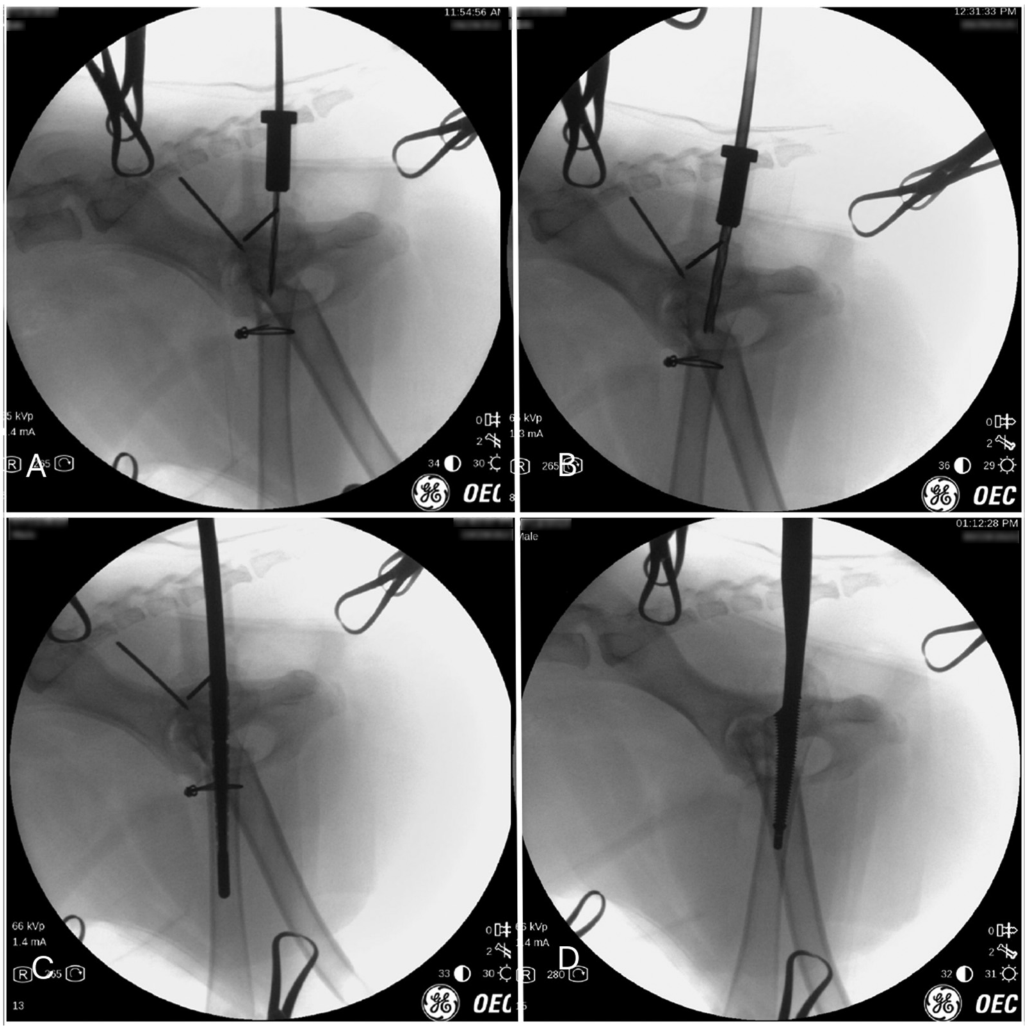

Fig. 3 (**A–D**) Intraoperative craniocaudal radiographic images taken during various steps in the process utilizing the patient-specific instrumentation. In images A–C, the patient-specific instrumentation is secured to the femur with two Kirschner wires and a proximal femoral cerclage. (**A, B**) show the 2.7-mm and 5.0-mm drill bit, applied through the mated drill sleeve, respectively. Images (**C, D**) show the number 4 tapered reamer through the patient-specific instrumentation, and number 4 broach being utilized in traditional fashion, respectively.

postoperatively.[17,18] In contrast, a study focusing on Micro THR in small breeds found no significant differences in thigh girth and ground reaction forces compared to the opposing pelvic limb postoperatively.[16] Lameness and postoperative pain were overall lower with THR in comparison to FHO/femoral head and neck excision.[1,2,16,18–20] Although cemented options were superior treatment for micro THRs if caught early in dogs with LCPD, they have a potential major long-term drawback. The longer life expectancy of smaller dogs, and increased potential for aseptic loosening over time, potentially make cemented implants suboptimal.[3,5,19] Because the patient was a young, small breed with LCPD, cementless implants were used to decrease the risk of aseptic loosening.

Micro THRs performed have been reported utilizing Biomedtrix CFX™ or the Kyon systems.[3,16,19–23] Cementless THRs require precise femoral bed preparation, which can be challenging to establish in sclerotic bone.[20,24] To improve femoral bed preparation in sclerotic bone, a PSI was utilized in this case, as PSI has been shown to improve accuracy in some surgeries.[25,26] The PSI was effective at ensuring accurate alignment and reaming of the femoral canal as shown by collinearity between drill bits and the femoral anatomical axis in fluoroscopic images. However, as evidenced by intraoperative fluoroscopy and postoperative radiographs, the free-handed portion of the surgery, including broaching and stem insertion, resulted in non-coaxial alignment. This deviation indicates that while the PSI and reaming guide performed well for the tasks they were designed for, the procedure still demands significant surgical input and the PSI, in the authors' opinion, should not be utilized without significant surgical experience. Despite malalignment, no clinical complications were observed postoperatively, suggesting that the deviations did not adversely affect clinical outcomes.

The use of PSI introduces potential variability in tool quality and accuracy, impacting surgical outcomes. Accurate PSIs rely on high-quality imaging, expert engineer and surgeon collaboration, and appropriate intraoperative use. Patient-specific instrumentation procedures can vary, but require apposition of the guide to osseous anatomical landmarks used for contact

Fig. 4 (**A–D**) Immediate postoperative radiographs. (**A**) Frog leg VD view, (**B**) mediolateral, (**C**) right lateral pelvis, and (**D**) caudocranial femur.

points; this requires dissection and retraction of all associated soft tissues at the site of the PSI footprint. Because the design of this PSI relies on contact over the medial aspect of the calcar, proximal metaphyseal and diaphyseal regions, a significant increase in the dissection of soft tissue compared to standard THR implantation techniques is required. The use of PSI requires validation through larger studies to confirm benefits and identify potential risks, as well as improved guide designs for THR applications. The complexity of the procedure highlights the need for surgeon familiarity with the technology, and overreliance on PSI is not recommended. The cost and accessibility of advanced imaging, CAD software, and 3D printing materials, along with the need for specialized equipment and training, present additional barriers. Long-term follow-up is crucial to understand the durability and longevity of this approach.

Procedural enhancements should aim to facilitate the complete and accurate execution of the planned surgical steps, thereby reducing reliance on free-handed techniques and minimizing the potential for human error and dissection requirements.

In conclusion, while the novel BFX THR technique with PSI for reaming demonstrated promising results in this case, the limitations underscore the necessity for further research. Future studies should aim to include larger sample sizes, longer follow-up periods, and comparative analyses with traditional techniques to fully establish the efficacy and safety of this innovative approach.

Authors' Contributions

J.H.C. collated the case information, wrote the manuscript, and aided in manuscript revision. B.P. aided in manuscript preparation and revision. R.L. performed the surgery and aided in manuscript revision.

Ethical Approval

All authors confirm that this journal's ethical policies have been adhered to. No ethical approval was required as this is a case study with no original research data.

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Conflict of Interest

None declared. R.L. is a paid consultant to BioMedtrix but received no compensation or has any conflict of interest.

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