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Surgical Technique

Total Hip Arthroplasty After Proximal Femoral Nailing: Preoperative Preparation and Intraoperative Surgical Techniques

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ABSTRACT

The combination of an aging population and increased utilization of total hip arthroplasty (THA) is leading to a higher incidence of conversion THA, defined as conversion from previous hip fracture surgery to THA. Conversion THA is a more technically challenging, time-consuming, and costly procedure compared to primary THA and frequently involve more medically complex patients.

Thus, the aim of this review is to provide a rubric for surgeons to use when preparing for a conversion THA. We have assessed the compatibility of commonly available extraction devices with popular femoral nails. Furthermore, we review technical pearls for conversion THA including equipment planning, operative setup, intraoperative imaging, extraction sequencing, and troubleshooting commonly encountered obstacles.

Introduction

It is estimated that there are between 260,000 and 300,000 admissions for hip fractures in the United States every year with projections of more than 500,000 per year by 2040 [1,2]. The American College of Surgeons National Surgical Quality Improvement Project database identified 2009 conversion total hip arthroplasty (THA) patients from 2009-2014 [3]. This number is expected to increase as previous hip surgeries in the expanding elderly population begin to fail. Given this rise in incidence, arthroplasty surgeons will encounter conversion THAs more regularly and should be comfortable managing these cases [4].

Conversion to THA in patients previously treated with proximal open reduction and internal fixation is technically challenging and associated with higher rates of surgical complications including the presence of failed internal fixation devices, potential infection, bone deformity, bone loss, poor bone quality, and poor femoral canal anatomy [5,6]. Conversion THA, also referred to as salvage THA, is associated with greater blood loss [6–8], longer case duration [6–8], and increased risk of complications such as prosthetic hip instability [9,10], intraoperative fracture [8–10], postoperative periprosthetic fracture [8–10], prosthetic joint infection [6], and formation of heterotopic ossification [6,11–13]. Furthermore, conversion of an intramedullary femoral nail to a THA is associated with worse functional outcomes compared to conversion THA after plate fixation, likely secondary to iatrogenic abductor damage during nail insertion or removal [5,10,14]. This abductor attenuation may also contribute to higher rates of instability following conversion THA [15]. Intramedullary nail removal presents unique technical challenges with which arthroplasty surgeons are often unfamiliar. Surgical dissection and exposure may be extensive in order to identify hardware and for safe removal of the implant [16].Skeletal anatomy may be distorted due to fracture nonunion or malunion [16]. Buried or broken hardware inside the greater trochanter, abductor deficiency, altered anatomy from nonunion or malunion, and poor bone quality are commonly encountered issues in these cases [17].

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Arthroplasty surgeons should be aware of the challenges and complications of conversion THA. In this review, we present preoperative planning, operative setup, intraoperative radiographs, and surgical techniques to allow for successful and expedient intramedullary femoral nail removal and conversion to THA. We list the compatibility of available extraction tools for commonly used intramedullary femoral nails that are encountered in patients undergoing conversion THA. Finally, we suggest a stepwise algorithm for complex nail removal when basic removal techniques are unsuccessful.

Surgical technique

Planning

Careful preoperative surgical planning is essential to performing a successful conversion THA. In the clinic, patients should be informed of the risks of conversion THA including greater blood loss [6–8], longer case duration [6–8], and increased risk of complications such as prosthetic hip instability [9,10], intraoperative fracture [8–10], postoperative periprosthetic fracture [8–10], prosthetic joint infection [6], and formation of heterotopic ossification [6,11–13]. Patient gait and leg-length discrepancy should be assessed clinically. Standard preoperative laboratory test results and medical clearances should be obtained. We recommend obtaining inflammatory markers (complete blood count with differential, erythrocyte sedimentation rate, and C-reactive protein) as well as a preoperative fluid aspiration from the hip joint if inflammatory markers are elevated. Latent infection should be considered, especially in cases of proximal femoral nonunion. Surgeons should have a low threshold to obtain multiple cultures regardless of preoperative laboratory test results. Additionally, if the surgeon has a concern for infection, extended oral antibiotic prophylaxis may be concerned after conversion THA [18,19].

Discussion with anesthesia preoperatively is helpful to familiarize all involved with the case complexity and possible need for blood products. For aseptic conversion cases, an intraoperative cell salvage device can be utilized to help minimize blood loss [20]. Obtaining the prior operative reports and implant records to identify the intramedullary nail will facilitate the planning and execution of the conversion THA. If not possible, then nail identification can often be performed radiographically as most nails and Cephalomedullary Nail (CMN) screws have a characteristic radiographic appearance.

Preoperative imaging prior to conversion THA requires calibrated plain radiographs with standing full-femur views to assess for union status, femoral version, residual femoral deformity, overall bone stock, nail length, leg-length discrepancy, and distal screw number and location. In addition, calibrated pelvic radiographs in the anteroposterior (AP) view should be obtained for THA templating purposes. Preoperative computed tomography can be helpful in the setting of malunion or nonunion. Previous pertrochanteric fractures often present with significant rotational malunion. Preoperative assessment of version can be judged on the computed tomography scan in comparison to the contralateral leg as needed. Magnetic resonance imaging may help assess for infection or abductor deficiency.

Arranging for the appropriate equipment is also crucial for successful conversion arthroplasty. In cases where the specific intramedullary femoral nail is known, it is advisable to have the corresponding extraction instruments available. It is not uncommon for the extraction site to become stripped, so having another compatible extractor device on hand is suggested (Tables 1-4). In cases where the nail is unable to be identified, the surgeon should prepare to have multiple extraction devices readily available. In addition to nail extraction tools, a broken screw removal set should be available even in cases where there is no identifiable broken hardware on preoperative imaging.

Table 1
Extractor compatibility with Stryker femoral nails.

Extractors	Stryker Gamma	Stryker T2 A/R	Stryker T2 Recon
Smith & Nephew universal – cannulated	Yes	Yes	Yes
Stryker 1407-4006	Yes	No	No
Stryker 1806-6130	No	No	No
Stryker cannulated (2351-0180)	Yes	Yes	Yes
Stryker piriformis (1806-6125)	Yes	Yes	Yes
Stryker tibial short (1806-0350)	No	Yes	Yes
Synthes – TFN	No	No	No
Synthes – TFNA	No	No	No
Synthes tibial extractor	Yes	Yes	Yes
Winquist 1/4 – 20	No	No	No
Winquist 1/4 – 28	No	No	No
Winquist 3/8 – 16	No	No	No
Winquist 3/8 – 24	No	No	No
Winquist 5/16 – 18	Yes	Yes	Yes
Winquist 5/16 – 24	Yes	Yes	Yes
Winquist 7/16 – 20	Yes[a]	No	No
Winquist conical	Yes	Yes	Yes
Winquist M10x1.5	Yes[b]	No	No
Winquist M5.5x0.9	No	No	No
Winquist M5x0.8	No	No	No
Winquist M6x0.75	No	No	No
Winquist M6x1	No	No	No
Winquist M8x1	No	Yes	Yes
Zimmer – 5/16	Yes	Yes	Yes
Zimmer conical extractor – cannulated	Yes	No	No

[a] Fully sunken extractor.
[b] Cross-threading but possible.

Table 2
Extractors compatible with Depuy Synthes femoral nails.

Extractors	Synthes piriformis (FRN)	Synthes TFN[b]	Depuy TFNA[c]
Smith & Nephew universal – cannulated	Yes	Yes	No
Stryker 1407-4006	No	Yes	Yes
Stryker 1806-6130	No	Yes	No
Stryker cannulated (2351-0180)	Yes	No	No
Stryker piriformis (1806-6125)	Yes	No	No
Stryker tibial short (1806-0350)	No	No	No
Synthes – TFN	No	Yes	No
Synthes – TFNA	No	No	Yes
Synthes tibial extractor	Yes	No	No
Winquist 1/4 – 20	No	No	No
Winquist 1/4 – 28	No	No	No
Winquist 3/8 – 16	No	No	No
Winquist 3/8 – 24	No	No	No
Winquist 5/16 – 18	Yes	No	No
Winquist 5/16 – 24	Yes	No	No
Winquist 7/16 – 20	No	Yes[a]	Yes[a]
Winquist conical	Yes	Yes	No
Winquist M10x1.5	Yes	No	No
Winquist M5.5x0.9	No	No	No
Winquist M5x0.8	Yes	No	No
Winquist M6x0.75	No	No	No
Winquist M6x1	No	No	No
Winquist M8x1	No	No	No
Zimmer – 5/16	No	No	No
Zimmer conical extractor – cannulated	No	Yes	Yes

[a] Fully sunken extractor.
[b] Set screw needs to be disengaged but cannot be fully removed.
[c] Set screw can be fully removed from the nail.

Table 3
Extractors compatible with Zimmer Biomet femoral nails.

Extractors	Zimmer CM[c]	Zimmer Affixus	Zimmer Piriformis
Smith & Nephew universal – cannulated	Yes	Yes	No
Stryker 1407-4006	Yes	Yes	No
Stryker 1806-6130	No	No	No
Stryker cannulated (2351-0180)	Yes	No	Yes
Stryker piriformis (1806-6125)	Yes	Yes	Yes
Stryker tibial short (1806-0350)	No	No	No
Synthes – TFN	No	No	No
Synthes – TFNA	No	No	No
Synthes tibial extractor	Yes	No	Yes
Winquist 1/4 – 20	No	No	No
Winquist 1/4 – 28	No	No	No
Winquist 3/8 – 16	No	Yes[a]	No
Winquist 3/8 – 24	No	Yes[b]	No
Winquist 5/16 – 18	Yes	No	Yes
Winquist 5/16 – 24	Yes	No	Yes
Winquist 7/16 – 20	Yes	No	No
Winquist conical	Yes	Yes	No
Winquist M10x1.5	No	No	No
Winquist M5.5x0.9	No	No	No
Winquist M5x0.8	No	No	No
Winquist M6x0.75	No	No	No
Winquist M6x1	No	No	No
Winquist M8x1	No	No	Yes
Zimmer – 5/16	Yes	No	Yes
Zimmer conical extractor – cannulated	Yes	Yes	No

CM, cephalomedullary.
[a] Poor engagement.
[b] Fully sunken extractor.
[c] Two levels of threads.

Conversion THA can be single-stage or staged (isolated hardware removal then THA), which can be decided preoperatively or intraoperatively. In the case of prolonged hardware removal in a medically compromised patient, a staged procedure should be considered. Postoperatively, radiation therapy and/or COX-2 selective nonsteroidal anti-inflammatory prophylaxis should be considered for heterotopic ossification prophylaxis [21]. Surgeons should have a low threshold for initiating a metabolic bone work up in patients undergoing conversion THA. All patients with history of low energy trauma, women older than 70 years of age, and men older than 80 years of age with previous fractures should undergo baseline dual-energy radiograph absorptiometry to assess bone mineral density as well as a serum vitamin D measurement [22]. Risk factors such as alcohol and tobacco use, malnutrition, and comorbidities such as renal failure or rheumatoid arthritis should be mitigated as much as possible [22]. Initiation of calcium and vitamin D supplementation, or anabolic agents as indicated in certain patients, should be considered prior to conversion THA [22].

Identifying the nail and extractor planning

The compatibility of extractors with different nail designs are presented by manufacturers (Tables 1-4). We obtained 25 extractors and 12 proximal femoral nails from the major manufacturing companies, including Stryker (Mahwah, NJ), Smith & Nephew (Memphis, TN), DePuy Synthes (Raynham, MA), Zimmer Biomet (Warsaw, IN), and Shukla Medical (St. Petersburg, FL). The 12 contemporary femoral nails included Stryker nails – Gamma (Fig. 1), T2 Anterograde/Retrograde, and T2 Reconstruction; Depuy-Synthes nails – Femoral Reconstruction Nail (FRN), Trochanteric Fixation Nail (TFN), and Trochanteric Fixation Nail Advanced (TFNA) (Fig. 2); Zimmer Biomet nails – CMN, Piriformis Nail, and Affixus Nail; and Smith & Nephew Nails – Fan, Intertan (Fig. 3), and Metatan. Data collection for extractor and femoral nail compatibility was done manually.

Overall, the extractor that had the compatibility with the most nails (11 of 12, 92%) was the Smith & Nephew universal cannulated conical extractor. However, there was no single extractor that we found to be "universal" or compatible with all the proximal femoral

Table 4
Extractors compatible with Smith & Nephew femoral nails.

Extractors	Smith & Nephew Fan	Smith & Nephew Metatan	Smith & Nephew Intertan[c]
Smith & Nephew universal – cannulated	Yes	Yes	Yes[b]
Stryker 1407-4006	No	No	Yes
Stryker 1806-6130	No	No	No
Stryker cannulated (2351-0180)	Yes	Yes	Yes
Stryker piriformis (1806-6125)	Yes	Yes	Yes
Stryker tibial short (1806-0350)	Yes	Yes	No
Synthes – TFN	No	No	No
Synthes – TFNA	No	No	No
Synthes tibial extractor	Yes	Yes	Yes
Winquist 1/4 – 20	No	No	No
Winquist 1/4 – 28	No	No	No
Winquist 3/8 – 16	No	No	No
Winquist 3/8 – 24	No	No	No
Winquist 5/16 – 18	Yes	Yes	Yes
Winquist 5/16 – 24	Yes	Yes	Yes
Winquist 7/16 – 20	No	No	No
Winquist conical	Yes	Yes	Yes
Winquist M10x1.5	No	No	Yes
Winquist M5.5x0.9	No	No	No
Winquist M5x0.8	No	No	Yes[a]
Winquist M6x0.75	No	No	No
Winquist M6x1	No	No	No
Winquist M8x1	Yes	Yes	Yes
Zimmer – 5/16	Yes	Yes	Yes
Zimmer conical extractor – cannulated	No	No	Yes

[a] Poor engagement (winquist M5×0.8).
[b] Do not need to remove set screw.
[c] Two levels of threads.

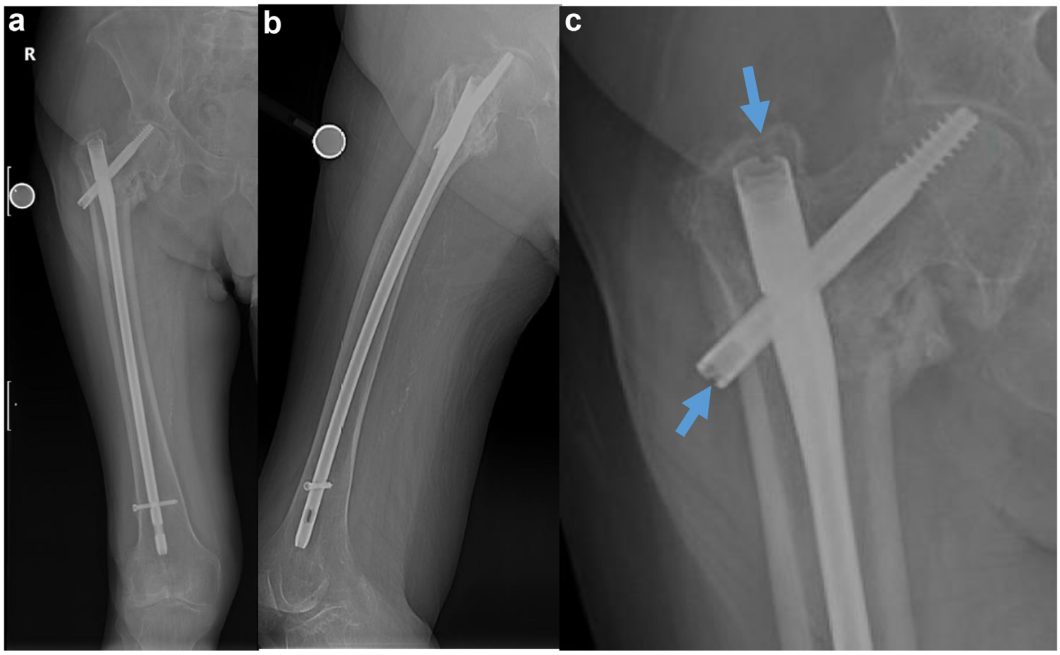

Figure 1. AP (a) and lateral (b) radiograph of the right femur with Gamma nail (Stryker) demonstrating device failure due to superior cut-out and varus intertrochanteric fracture nonunion. (c) Characteristics that identify this nail as Gamma (Stryker) include the divots present at the lateral aspect of the lag screw to allow engagement of inserter and extractor as well as a similar divot (arrows) present proximally in nail itself. AP, anteroposterior.

nails that were tested. The Winquist conical extractor (10 of 12, 83%) and Stryker piriformis (1806-6125) extractor (10 of 12, 83%) also had high compatibility. The TFN and TFNA extractors (Depuy Synthes) worked exclusively with their respective femoral nails and were not compatible with any other femoral nail design. Compatibility of contemporary nails with the extractors from the Winquist set was surprisingly low, with only 45 combinations of the possible 168 combinations compatible (Tables 1-4). The Winquist conical (10 of 12, 83%), Winquist 5/16-18 (9 of 12, 75%), Winquist 5/16-24 (9 of 12, 75%) were the most compatible extractors in the Winquist extractor set.

The proximal femoral nail with the least amount of available compatible extractors was the TFNA (DePuy Synthes). The extractor designed for this nail's removal, the TFNA extractor (Depuy Synthes) was compatible, but this extractor has a limited number of threads that requires absolute coaxial engagement for this to function. The Smith & Nephew conical extractor had a taper angle too narrow to engage prior to bottoming out; however, the 3 following extractor devices were effective including: Stryker 1407-4006, Zimmer Biomet conical cannulated, and Winquist 7/16-20 extractors were able to adequately engage. However, the

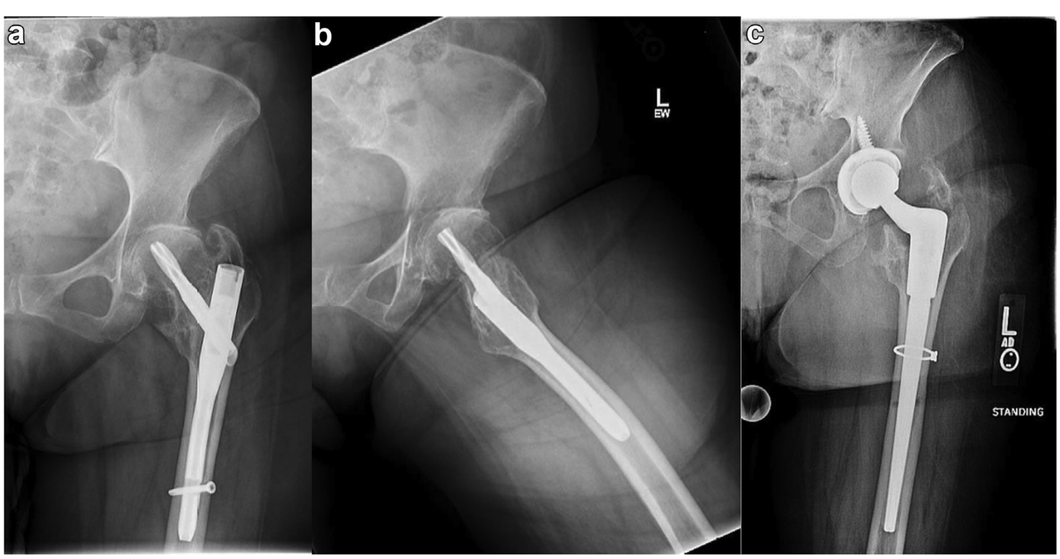

Figure 2. An 83-year-old female presented with posttraumatic arthritis 9 months after short Trochanteric Femoral Nail Advanced (Depuy Synthes) for an intertrochanteric fracture. AP (a) and frog-leg lateral (b) radiographs demonstrate from time of presentation. Intraoperatively, the left femoral neck had over 50 degrees of anteversion indicating malunion of the fracture. Postoperative AP radiograph (c) demonstrates an implanted diaphyseal-engaging stem for deformity correction.

Figure 3. AP Radiograph of left femur with Intertan (Smith & Nephew) nail. This nail can be distinguished from its Stryker, Depuy-Synthes, and Zimmer counterparts by the presence of both a lag screw and compression screw, whereas most other cephalomedullary nails have a single lag screw or helical blade option.

Winquist 7/16-20 extractor needs to be fully sunken before it can fully engage with the threads. In summary, the Smith and Nephew conical extractor is quite versatile and works with 11/12 intramedullary nails evaluated. However, when removing TFNA (Depuy Synthes), calling for Stryker 1407-4006 or Zimmer Biomet conical cannulated extractor allows for easiest engagement and TFNA (Depuy Synthes) nail removal. The Stryker 1407-4006 extractor can be found in the Gamma3 Basic set and/or the Stryker Universal Implant Extraction Set #1.

Keep in mind that removing the sliding hip screw and distal interlocking screw is also a mandatory component of the removal process. The sliding hip screw articulation with the driver varies amongst manufacturers, as does the set screw within the nail that allows the screw to slide without rotating. This set screw must be backed out before the sliding hip screw will rotate for the removal. While "universal" hip screw removal trays can be assembled, there is no substitution for knowing the manufacturer of the nail and having the appropriate sliding and set screw removal equipment available. All methods of knowing the manufacturer preoperatively should be exhausted before relying on intraoperative discovery.

Approach and positioning

Conversion THA in the setting of an intramedullary nail can be done via various surgical approaches. Our preference is to utilize prior incisions for nail removal which generally allows for a posterolateral approach in the lateral decubitus position to accommodate both nail removal and the THA. Given the possibility of buried or difficult to identify hardware, our preference is to utilize a radiolucent table to facilitate use of fluoroscopy. For lateral decubitus positioning, the surgeon should also consider radiolucent posts for holding the patient in stable position while avoiding obstruction of radiographic viewing intraoperatively. Possible positioners include a peg board, pelvic holders, or a bean bag. The senior author's preference is to position the patient on an OSI Modular table (Mizuho, Union City, CA) with a peg board. Standard operating room tables with a central base may not allow passage for the C-arm, unless the table is reversed and an extension. Even in cases where the surgeon anticipates expeditious removal of the nail and there is no bony overgrowth, it is best practice to have the ability to use fluoroscopy for these cases.

For a short intramedullary nail, removal of the distal interlock can be done through an extension of the surgical incision or a separate stab incision can be made for screw removal. The posterolateral approach also allows for extensile exposure of the femoral diaphysis which can be helpful in these complex cases. However, surgeons more familiar with the direct anterior, lateral, or anterolateral approach may prefer to combine approaches for these cases.

Draping

It is important to drape more proximal than a standard THA draping as extraction equipment will have to be passed frequently and the proximal incision may have to be extended in order to access the nail. As such, the entire iliac wing should be included in the sterile field.

For cases in which intraoperative fluoroscopy is required, the use of a C-Armor drape (TIDI, Neenah, WI) can assist with maintaining a sterile field when multiple AP and lateral radiographs are required. Prior incisions should all be marked prior to applying Ioban (3M, Saint Paul, MN) draping.

Intraoperative imaging

The need for intraoperative imaging depends on the anticipated difficulty for nail and screw removal. Fluoroscopy allows for expedient nail identification followed by targeted bone removal, extraction device insertion, and accurate stem placement, especially in cases with residual deformity. Intramedullary nails buried within remodeled greater trochanteric bone are difficult to find resulting in more bone removal soft-tissue exploration that can lead to iatrogenic abductor damage. These risks can be minimized with the judicious use of intraoperative fluoroscopy.

Steps to expose buried nails:

1. After performing the surgical approach, place a small sharp Steinman pin or guide wire that will fit within the cannulated reamer against the tip of the greater trochanter in a medial-lateral position that matches the location of entry on the preoperative radiograph.
2. Take an AP view radiograph with the boom of C-arm around operating room table. Use C-Armor drape (TIDI, Neenah, WI) or one time used sterile sheet to cover boom of C-arm.
3. Localize the top of nail with a guidewire with C-arm assessing the AP view (Fig. 4).
4. Move C-arm to assess lateral view and adjust the guidewire in anterior-posterior direction.
5. Once guidewire is confirmed to be inside top of nail (Fig. 4), place a cannulated reamer over the guidewire to remove overgrown bone blocking the threads from the extractor. If possible, the cannulated reamer from the manufacturer that was designed to open the femur at the time of the original surgery should be used, as it will be slightly larger in diameter than the proximal nail and will remove sufficient bone for the extraction.

Figure 4. Identifying the cephalomedullary nail via guidewire and fluoroscopy. Once the proximal aspect of a buried nail is identified and cannulated in this manner, a reamer can be used to clear bone and then the threads engaged.

Using a cannulated reamer will bring the operating surgeon down to the level of the proximal nail and will preserve much more surrounding tendon and bone than a manual open removal of overgrowth with a rongeur.

Implant selection

Choice of implants for the THA can be a challenge for conversion THA. The main options for femoral components included diaphyseal engaging stems or cemented stems. Studies have not shown superiority of a specific fixation choice [13]. In many cases of conversion THA following intramedullary femoral nailing, there will be deficiency of metaphyseal bone quality so a short uncemented femoral component is not recommended. In cases with malunion leading to excessive anteversion or retroversion of the femoral neck, a diaphyseal engaging stem that can allow for correction to appropriate anteversion is desirable. Typically, a modular fluted taper stem is typically adequate for conversion THA, however significant deformity may require an extended trochanteric osteotomy and plate fixation for correction. When deciding on the length of the femoral component, the planned implant should bypass prior drill holes to avoid stress risers that could potentiate periprosthetic fractures. However, in long intramedullary nails, distal locking screws do not need to be bypassed. In cases involving a wide intramedullary canal with thin cortices, often seen in elderly patients with failed intertrochanteric femur fractures treated with CMN (Fig. 1), a cemented stem may be a good option as cortical contact via a diaphyseal engaging stem may not be supportive enough to avoid subsidence or fracture. Prophylactic cabling can assist in minimizing fracture during stem insertion. Ultimately, surgeons will need to choose the implants used based on the specific patient anatomy, risk factors, and bone quality.

Choice of acetabular component is also dependent on bone quality and the patient's risk factors. Dislocation and instability are common problems after conversion hip arthroplasty [23–25]; however, these can be mitigated with larger femoral head sizes, dual mobility constructs, and/or use of anterior based approaches depending on surgeon preference.

Discussion

As a principle, it is generally recommended to dislocate the hip by removing any hardware, then reducing the hip again. This technique can avoid intraoperative fractures as there will be osseous defects in the proximal femur after hardware removal. Hardware may be completely overgrown with bone, completely obscuring any direct visualization of the implant. In these cases, bone must be meticulously removed with any combination of burrs, curettes, saws, awls, or osteotomes to cannulate and remove the nail. One must be very careful to remove as little bone and tendon in this process as possible. As mentioned above, the most reliable method of minimizing bone/tissue destruction is to use cannulated reamers to reopen the original insertion track. This is done using a guide wire to recannulate the proximal aspect of the intramedullary nail under fluoroscopic guidance. This can typically be malleted through overgrowth without difficulty. Then use a small (5.0 mm-12.0 mm diameter) cannulated drill bit and cannulated opening reamers over this guide wire to rapidly remove bone from around the threaded slot and prepare this region to accept a threaded extraction instrument. A flexible reamer and guidewire can be helpful for initial bone preparation. A high-speed burr may be also needed to identify the hardware if there is overgrowth; fluoroscopic guidance is strongly recommended if this is chosen.

For CMNs, the derotational set screw which locks the screws or blade that enters the femoral head will need to be loosened through this proximal entry. In these cases, we recommend using the screwdriver from the specific nail for this step. Once the set screw has been loosened or removed, take out the helical blade or lag screw(s) from the lateral cortex. In cases where the nail cannot be identified, the lag screw component may need to be removed retrograde. This will require a femoral neck cut, removal of the head piecemeal from the lag screw, then backing out the implant.

We suggest leaving at least one point of fixation through the nail, typically a distal diaphyseal screw, to avoid spinning while the proximal nail is cannulated with a threaded extractor instrument. There are a variety of threaded extraction tools available for nail removal, but none that can be used universally. In general, a conical cannulated threaded extractor will remove most proximal femoral nails (Tables 1-4). Once the extractor is engaged with the proximal aspect of the nail, remove the final distal screws fixating the nail and proceed to backslapping the nail.

Broken distal interlock screws

Broken screws are unfortunately a common finding in conversion hip arthroplasty. Even in cases where all screws appear intact radiographically, the surgeon should be ready to encounter broken hardware intraoperatively. Broken screw removal sets should be available for all these cases and trephines can be helpful to free up embedded parts of threaded screws. Broken interlocking screws within nails are frequently in intertrochanteric or subtrochanteric nonunions [26]. Radiographically they may appear angulated secondary to subsidence of the nail. The headed portion of the screw can be realigned by withdrawing the nail slightly. The lateral screw segment is typically easily removed, while the medial segment can be driven out with a nonpointed, cylindrical pin or left in place. A metal-cutting burr is also helpful if there is a nonunion with broken screws or if the screws strip or shear off during attempted removal.

Cold-welded screws

The "cold-welded" phenomenon refers to a strongly adherent screw fastened under an overload without using a torque-limited driver [27,28]. This can result in failure to engage the screw or screw breaking during an attempted removal. Reverse-threaded screw extractors and vise grip pliers may be helpful if the screw head is undamaged. Removing some bone around the screw head circumference may also be helpful. As a last resort, a carbide tip drill bit can be used to remove a damaged screw head, followed by reverse threaded screw shaft extractor to remove the remaining fragment. Also, a metal-cutting burr can be used to remove interlocks adherent to the nail distally or proximally.

Nail extraction after screw removal

Sometimes, even after all screws and points of fixation have been removed from the femoral nail, it does not extract. This may be from bony ingrowth at the distal interlocks. We suggest drilling through all available distal interlocks to remove any of this resistance. If alternatives are unsuccessful, an extended trochanteric osteotomy can be done to free the nail from surrounding bone and allow it to be removed under more direct visualization.

Broken nails

Femoral nail breakage is a fortunately rare occurrence but one that can be quite difficult to manage. A common site of nail fracture is the lag screw hole due to smaller cross-sectional diameter [26]. The TFNA (DePuy Synthes) has been reported to have broken in multiple cases just distal to the helical blade/lag screw aperture, which is the weakest point of the nail [29–31]. This occurrence may be on the rise with the contemporary TFNA compared to the previous version of the TFN (DePuy Synthes) because of the newer version's narrower proximal diameter and the relief it has laterally at the distal aspect of the helical blade/lag screw aperture [31]. One useful feature of the TFNA is the ability to thread a coupling screw into the nail below the sliding hip screw. This allows the broken proximal segment of the nail to be removed and still have the ability to thread into the distal segment.

The Stryker Gamma nail has also had reports of fatigue failure and breakage at the level of the aperture, but a recent review found that this was happening at a later time point compared to the cases of TFNA failure (DePuy Synthes) [31].

Removing the distal nail fragment is a challenging task. Broken nails may be removed with long biopsy forceps but may also require special techniques [26]. Numerous techniques have been reported including extraction using guidewires [32], hooks and guidewires [33], and Schanz pins and T-handle bars [34,35]. These techniques attempt to minimize the need for specialized equipment, the risk of distal fragment migration, and any additional incision. As a last resort, an extended trochanteric osteotomy can be done into the side of nail, then a bone tamp can be used to extract the nail in a retrograde fashion.

Summary

Conversion THA after femoral nailing is a technically complex procedure involving longer operating times, increased blood loss, and increased risk of complications, namely dislocation and infection. In this review, we have developed a guide for choosing extraction tools based on compatibility with available extractors. Furthermore, we have presented framework for surgeons to use to optimize this procedure through preoperative planning, operative setup, intraoperative radiographs, sequencing, and strategies for addressing common problems.

Conflicts of interest

Peter Sculco received royalties from Lima Corporate; is a part of speakers bureau for Zimmer Biomet; and is a paid consultant for Zimmer Biomet and Depuy Synthes. Matthew P. Abdel received royalties from OsteoRemedies, Stryker, and Springer; is a board or committee member of IOEN, American Association of Hip and Knee Surgeons, and Mid-America Orthopedic Association. David Wellman is a part of speakers bureau of DePuy and A Johnson & Johnson Company; is a paid consultant for OrthoDevelopment; has stock or stock options in Imagen; and is a part of HSS Journal editorial/governing board. Elizabeth Gausden received royalties from Depuy (2022); is a paid consultant for BICMD and Stryker; and a board or committee member for IOEN and AAHKS. All other authors declare no potential conflicts of interest.

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Appendix

Nails

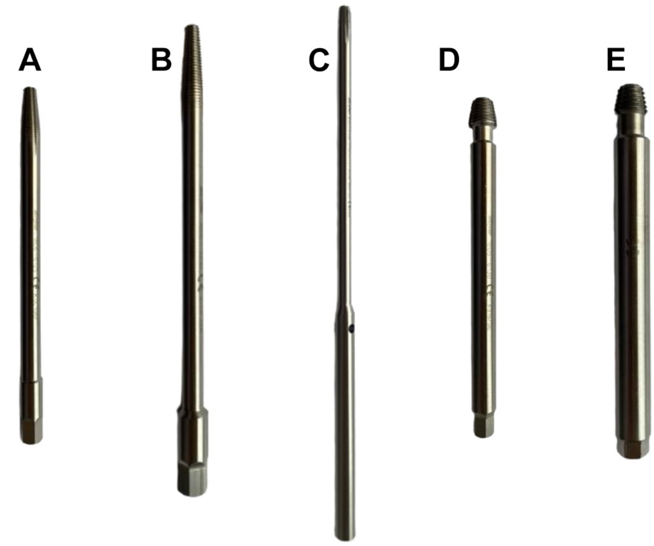
Appendix Figure 1. Depuy Synthes Trochanteric Fixation Nail (a), Trochanteric Fixation Nail Advanced (b), Femoral Reconstruction Nail (c).

Appendix Figure 2. Zimmer Biomet Cephalomedullary Nail (a), Piriformis Nail (b), Affixus Nail (c).

Appendix Figure 3. Smith & Nephew Intertan Nail (a), Metatan Nail (b), Fan Nail (c).

Appendix Figure 4. Stryker Gamma Nail (a), T2 Reconstruction Nail (b), T2 Antero-grade/Retrograde Nail (c).

Extractors



Appendix Figure 5. Stryker 1806-6125 (a), 1806-0350 (b), 2351-0180 (c), 1407-4006 (d), 1806-6130 (e) extractors.

Appendix Figure 6. Zimmer Biomet conical, cannulated extractor (a) and 5/16 extractor (b).

Appendix Figure 7. Winquist conical extractor.

Appendix Figure 8. Smith & Nephew conical, cannulated universal extractor.