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Trochanteric osteotomy in revision total hip arthroplasty

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- Trochanteric osteotomy is a technique that allows expanded exposure and access to the femoral canal and acetabulum for a number of indications.
- There has been renewed interest in variants of this technique, including the trochanteric slide osteotomy (TSO), extended trochanter osteotomy (ETO), and the transfemoral approach, for both septic and aseptic revision total hip arthroplasty (THA).
- Osteotomy fixation is crucial for achieving union, and wire and cable-plate systems are the most common techniques.
- TSO involves the creation of a greater trochanter fragment with preserved abductor attachment proximally and vastus lateralis attachment distally.
- This technique may be particularly useful in the setting of abductor deficiency or when augmented acetabular exposure is needed.
- ETO is a posterior-laterally based extensile approach that has been successfully utilized for aseptic and septic indications; most series report a greater than 90% rate of union.
- The transfemoral approach, as known as the Wagner osteotomy, is an extensile femoral approach and is more anterior-based than the alternate posterior-based ETO. It may be particularly useful for anterior-based approaches and anterior femoral remodelling; rates of union after this approach in most reports have been close to 100%.

Keywords: extended trochanter osteotomy; total hip arthroplasty; trochanteric osteotomy

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Background

Trochanteric osteotomy is a technique that allows expanded exposure and access to the femoral canal and acetabulum for a number of indications. Charnley strongly advocated for performance of a standard trochanter osteotomy during primary hip arthroplasty.[1–3] There has been renewed interest in variants of this technique including the trochanteric slide osteotomy (TSO), extended trochanter osteotomy (ETO), and the transfemoral approach for both septic and aseptic revision total hip arthroplasty (THA). This review focuses on variations in surgical technique, osteotomy fixation principles, and technical factors affecting successful performance of these techniques in revision hip arthroplasty.

Indications

All variations of trochanter osteotomy are performed to improve both acetabular and femoral exposure in complex primary and revision hip arthroplasty. The current indications for TSO in THA are relatively limited and the technique is utilized most commonly in young adults during hip resurfacing arthroplasty,[4] developmental hip dysplasia,[5] severe protrusio,[5] and trauma surgery[6] to improve acetabular exposure. TSO may also be indicated in complex primary THA, conversion THA from a prior hip arthrodesis,[7] as well as revision hip arthroplasty in patients with abductor deficiency as the modified TSO preserves the posterior capsule and short external rotators.[8]

Contrary to TSO, both the ETO and transfemoral osteotomy are the extensile workhorses for acetabular and femoral exposure during revision THA for aseptic and septic diagnoses. These surgical techniques are especially useful for removal of well-fixed femoral cemented, cementless, metaphyseal and diaphyseal fitting stems. ETO and transfemoral osteotomies may be utilized in aseptic loosening, revision for recurrent THA instability, resection arthroplasty for periprosthetic joint infection, periprosthetic fractures and during concomitant acetabular cup revisions.[9] Transfemoral osteotomy is especially useful in the removal of remaining cement fragments in the distal femur, extraction of broken femoral components and for significant anterior femoral bowing before revision stem insertion.[10]

Trochanteric slide osteotomy

Technique

A straight lateral incision is conventionally used to allow excellent access to the anterior trochanter even in hips with limited external rotation.[3,5,11] An interval is then developed between the hip capsule and gluteus medius. In order to access the vastus ridge, the posterior aspect of the vastus lateralis is incised 10 mm distal to the vastus ridge. A Hohmann retractor is passed through the defect under the vastus lateralis from posterior to anterior. The leg is then placed in internal rotation. An oscillating saw is used to osteotomize the trochanter from an initiation site just distal to the vastus ridge to an exit site just medial to the piriformis fossa between the gluteus minimus and capsule (Fig. 1A). The gluteus medius inserts into the proximal pole of the newly created fragment, and the vastus lateralis inserts into the distal pole. The fragment can be slid anterior or posteriorly (Fig. 1B) and the hip can be dislocated either anteriorly or posteriorly as needed. The final fragment in a TSO includes a proximal pole defined by the segment of the greater trochanter medial to the piriformis fossa and a distal pole that is just distal of the vastus lateralis ridge which includes the origin of the vastus lateralis. In arthroplasty cases, screw fixation can be used but more often cables, wires, or sutures are used to fix the osteotomy.

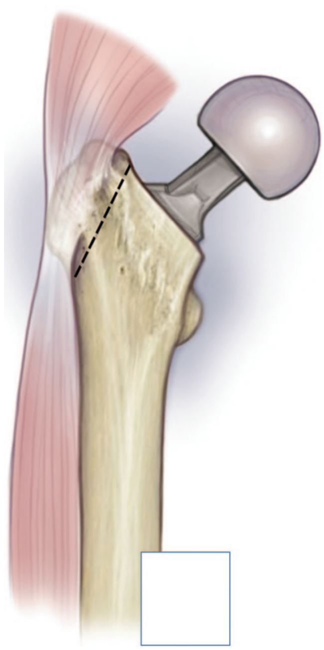

Fig. 1A During a trochanteric slide osteotomy, cuts are carried out.
Source. Adapted from Cleveland Clinic Foundation Images.

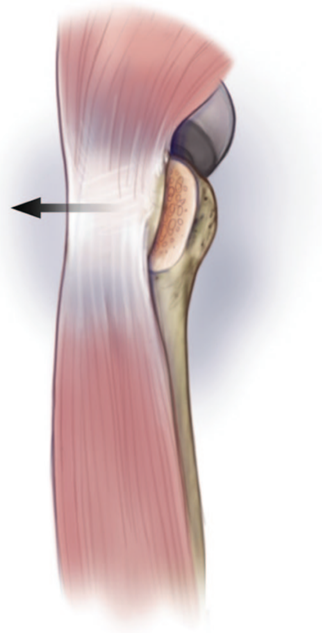

Fig. 1B The resulting trochanter fragment can be slid anteriorly or posteriorly to facilitate exposure.
Source. Adapted from Cleveland Clinic Foundation Images.

Outcomes

Aseptic loosening

TSO can be performed in cases requiring acetabular and/or femoral stem revision for loosening. The technique allows excellent acetabular exposure, especially in the revision setting where scar tissue may limit limb motion and obstruct visualization. Multiple studies suggest that most patients achieve osseous union after surgery. Langlais et al[12] reported the results of a series of 94 consecutive patients undergoing revision THA with revision of both femoral and acetabular components for aseptic loosening. They found that 96% of all patients in the series achieved union after TSO including 95% of patients (18/19) with septic loosening and 100% of patients (32/32) with major femoral osteolysis. Two patients in this series required reoperation for trochanter nonunion, while two other patients required revision for recurrent aseptic loosening. Lakstein et al[13] reported a similar rate of union (98%, 81/83); however, this series included a number of revisions performed for septic cases (6%, 5/83). Chen et al[14] performed a study of 46 hips undergoing extended TSO, which involves a more extensive posterolateral surgical exposure. The number of patients presenting for aseptic loosening was 93% (43/46). One patient was lost to follow-up. Among the remaining patients, the rate of union was 98% (44/45). On the other hand, León et al[15] reported on 113 modified TSO and 73 extended trochanteric

Table 1. Rates of union after trochanteric slide osteotomy (TSO)

Study	Indication	*N*	Union
Chen et al[14]	Aseptic	46	97.8% (44/45)
Langlais et al[12]	Aseptic	94	95.7% (90/94)
Lakstein et al[13]	Aseptic	83	95.2% (79/83)
León et al[15]	Aseptic	113	84.1% (95/113)

osteotomies and found a lower rate of union for the modified TSO cohort (84%, 95/113). This group performed a logistic regression analysis to identify risk factors for greater trochanter migration greater than 1 cm, a potential sequela of nonunion. They found that osteotomies less than 10 cm were at risk for trochanter migration. Among osteotomies less than 10 cm, they found that a distal cerclage wire below the lesser trochanter may be a protective factor against greater trochanter migration. A limitation of this analysis was that it was performed using a mixed cohort of hips receiving both TSO and ETO. Union rates after TSO are summarized in Table 1.

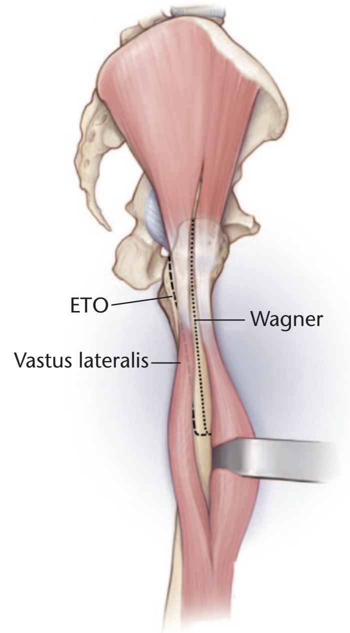

Fig. 2 A visual comparison of the tissue planes utilized during an extended trochanter osteotomy versus a Wagner osteotomy.
Source. Adapted from Cleveland Clinic Foundation Images.

Extended trochanter osteotomy

Technique

The final fragment in ETO has a proximal pole defined by the greater trochanter, a posterior border defined by the linea aspera, and anterior border developed with scoring holes using a drill or osteotome, and the distal pole in defined by a horizontal cut in the diaphysis of the femur.[3,5,16] The exact location of the distal cut is left to the discretion of the surgeon, but prior work suggests a minimum length of 10 cm and a typical length between 12–15 cm.[15] ETO is typically utilized in surgeries performed through a posterolateral approach. The osteotomy is typically utilized in cases of a well-fixed stem, significant cement in the canal, femoral remodelling, and sometimes prior to hip dislocation for safe access. The posterior border of the linea aspera is first exposed through release of the gluteus medius and exposure of the elevation of the vastus lateralis (Fig. 2). The osteotomy is performed in three phases: direct osteotomy of a posterior limb, transverse cut, and drill-hole or osteotome scoring of the anterior border. Options for a cutting instrument include a thin-saw for less bone removal and a high-speed pencil-tip burr for creating rounded corners. The distal cut is initiated at the proximal greater trochanter and carried to the level of the pre-determined transverse cut. The transverse cut is then performed. Ideally, the transverse cut will include no more than one third the circumference of the femoral diaphysis (Fig. 3). The distal anterior limb is scored with the oscillating saw 1–2 cm above the level of the transverse cut. The proximal anterior limb is scored by passing an oscillating saw between the prosthetic neck and medial

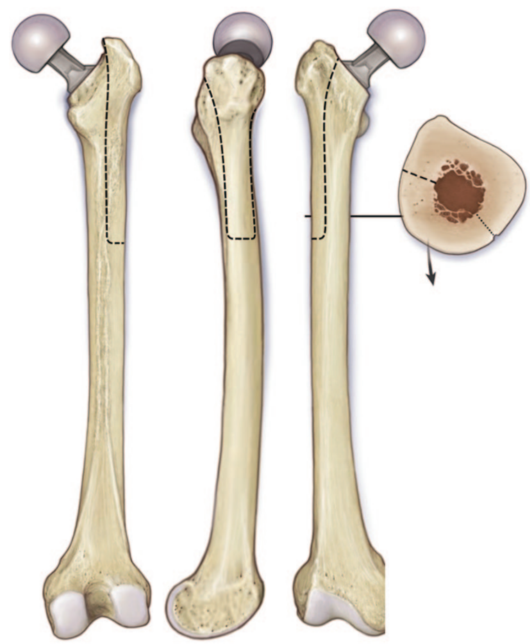

Fig. 3 A schematic representation of cuts made during an extended trochanter osteotomy.
Source. Adapted from Cleveland Clinic Foundation Images.

trochanter. A series of scoring holes are then developed between the proximal and distal extent of the anterior limb using either a drill or osteotome. At this stage, the fragment has a well-defined posterior border, a scored anterior border, and a distal pole that is well defined with a transverse cut. A series of curved osteotomes are inserted underneath the posterior border and the fragment is retracted anteriorly. Cables and wires are both fixation options after extended trochanter osteotomy (ETO).

Outcomes

Aseptic loosening

ETO performed during aseptic revision THA has been well described, with a survival rate greater than 90%.[17–23] Miner et al[24] conducted a large retrospective study of 166 revision hip arthroplasties performed with ETO over 6 years. The minimum clinical and radiographic follow-up was two years (range 2–7.5 years) and the indication for revision was aseptic loosening in the majority of cases (78.9%,131/166). There was a re-operation free survival of 89.8% (149/166). The rate of union was 98.2% (163/166). There were two nonunions (1.2%), including one patient who was revised for aseptic loosening of femoral and acetabular components and one malunion (0.6%) in a patient with femoral component loosening. Mardones et al[25] reported the results of 75 revision arthroplasties performed at a single centre in which 69/75 hips (92%) were revised for aseptic loosening. They reported that overall 99% (73/74) of osteotomies healed, 92% (68/74) healed with no migration, and 7% (5/74) healed with less than 5 mm of migration. The single case of nonunion (1%) healed after re-operation. There was a 5.4% (4/74) rate of fragment fracture, 75% (3/4) occurred intra-operatively, and 25% (1/4) occurred post-operatively. Most recently, León et al[15] reported that 98.6% (72/73) of patients receiving an ETO achieved union. The mean length of osteotomy in this series of patients receiving ETO was 14.8 cm (range, 8–23 cm) and the mean number of cerclage wires placed distal to the lesser trochanter was 2.6 (range, 0–5). It is notable that a minority of revisions in this series were performed for septic indications (1.4%, 1/73). Union rates after ETO are summarized in Table 2.

Table 2. Rates of union after extended trochanter osteotomy (ETO)

Study	Indication	*N*	Union
Miner et al[2$]	Aseptic	166	98.2% (160/163)
MacDonald et al[19]	Aseptic	44	91.1% (41/45)
Mardones et al[25]	Aseptic	75	98.6% (73/74)
Tulic et al[18]	Aseptic	25	100% (25/25)
King et al[22]	Aseptic	45	97.8% (44/45)
Charity et al[21]	Aseptic	18	100% (18/18)
Wronka et al[20]	Aseptic	108	93.5% (101/108)
León et al[15]	Aseptic	73	98.6% (72/73)
Morshed et al[30]	Septic	13	100% (13/13)
Levine et al[73]	Septic	23	95.7% (22/23)
Lim et al[28]	Septic	23	86.4% (19/22)
Petrie et al[26]	Septic	102	94.1% (96/102)

Periprosthetic joint infection

Most studies assessing the use of ETO in two-stage revision are single-centre retrospective cohort studies. Overall, it appears that utilization of metallic hardware for ETO fixation at the first stage may not appear to increase rates of failure relative to comparison groups[26] and that the approach can be successfully used for treatment of periprosthetic joint infection (PJI).[27–29] Morshed et al[30] conducted a single-centre, retrospective review of 13 patients who underwent two-stage revision with ETO at the first stage with subsequent antibiotic-impregnated cementer spacer with delayed osteotomy fixation in chronically infected THAs. Most patients (77%, 10/13) achieved infection-free survival. Healing occurred in all patients within six months. The average follow-up was 39 months (range 26–68 months). Reasons for failure included recurrent infection in 15% of patients (2/13) and aseptic failures in 23% of patients (3/13). Petrie et al[26] performed a single-centre retrospective review of 102 patients who required two-stage revision for infection between 1997 and 2014. All patients received an ETO during the first stage of implantation. There were no significant differences in survivorship ($p > 0.05$) and the mean follow-up period in the standard stem group was five years six months (range, 107 days–15 years) versus 5.7 years (range, 56 days–14.4 years) in the long-stem group. Overall, patients achieved resolution of infection in 97% of cases.

Transfemoral (Wagner) osteotomy

Technique

The transfemoral approach differs from the ETO in terms of circumferential magnitude and orientation. The ETO typically incorporates a third of the diameter (Fig. 3) of the femoral shaft whereas the transfemoral approach uses half the diameter of the femoral shaft (Fig. 4). Typically, the cuts forming the long-limbs of an ETO are made in the sagittal plane.[31] The osteotomy forming the long-limbs of a transfemoral approach are made in alignment with the coronal plane producing an 'open book' with a femoral fragment on one side and prosthesis on the other side. Similar to the ETO, the location of the transverse cut, and thus the length of the final fragment, is left at the discretion of the attending surgeon.

The direct lateral approach provides optimal exposure and access for the osteotomy. The vastus lateralis is split with an incision carried from the proximal extent of the muscle to distal of the planned transverse cut (Fig. 2). A pen or electrocautery are then used to define the lateral limb of the osteotomy fragment. An oscillating saw is then utilized to trace the pre-defined path from proximal to distal. A pencil-tipped burr is used to make the transverse cut. The medial limb of the osteotomy can be created

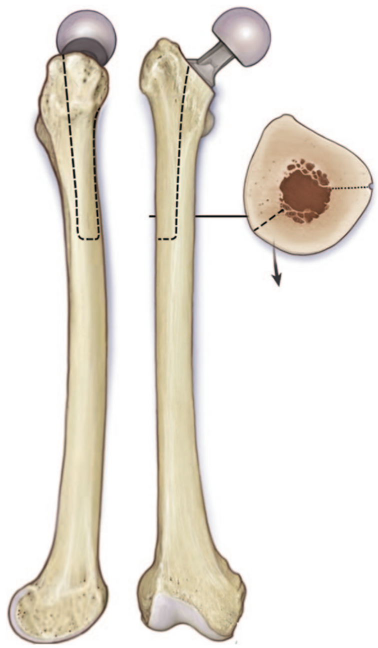

Fig. 4 A schematic representation of cuts made a Wagner osteotomy.
Source: Adapted from Cleveland Clinic Foundation Images.

directly with an oscillating saw. This works particularly well in cases involving a flat femoral stem. The medial aspect of the femur can alternatively be scored using osteotomes and levered open. This technique may be more appropriate for wide-diameter, cylindrical stems.

Outcomes

Aseptic loosening

Wagner originally described a transfemoral approach utilizing a non-modular stem and chisel perforation for all limbs of the osteotomy; however, this technique had high rates of stem subsidence and nonunion. Fink et al[32] reported higher rates of union using an osteotomy technique that employed selective use of an oscillating saw and curved, modular components. Radiographic evaluation after one year showed a 98.5% (67/68) rate of osteotomy union. While most hips in this series (54%, 37/68) were performed for aseptic loosening, it is notable that 21% (14/68) of cases involved a periprosthetic fracture. De Menezes et al[33] reported a similar improvement in Harris Hip Scores, from 45.2 points (standard deviation 14.02 points) pre-operatively to 83.4 points (standard deviation 11.86 points) at final follow-up of five years (standard deviation 1.64 years) in their series of 100 patients undergoing aseptic revisions.[33] Causes for revision THA in this series included aseptic femoral component loosening (40%, 40/100) and revision of an acetabular component for aseptic loosening (30%, 30/100) among other aseptic causes. There were nine dislocations in the series. There were four cases of stem complications requiring revision. Radiographic engagement of the femoral stem with the femoral cortex at the level of the isthmus was classified as complete engagement or 'three-point' (incomplete) fixation. There were 21 patients with 'three-point fixation' and all four cases of stem revision involved incomplete cortical engagement. The authors suggested that a long femoral stem and short osteotomy flap were risk factors for three-point fixation and thus increased the risk of revision. Binary logistic regression suggested that both utilization of a long stem and short osteotomy flap were risk factors for this finding. These findings have been replicated in a series of 12 patients (8/12 patients with femoral component loosening) reported by Nozawa et al[34] who found radiographic evidence of hip sinking in 17% (2/12) of patients but no other complications, though it is notable that one patient in this series was treated for periprosthetic fracture and it was not specified whether this was the patient who suffered the complication. Union rates after TFO are summarized in Table 3.

Table 3. Rates of union after the transfemoral approach (Wagner osteotomy)

Study	Indication	*N*	Union
Fink et al[32]	Aseptic	68	98.5% (67/68)
De Menezes et al[33]	Aseptic	100	95.0% (95/100)
Nozawa et al[34]	Aseptic	12	100% (12/12)
Fink et al[35]	Septic	76	98.7% (75/76)

Periprosthetic joint infection

Fink and Oremek[35] reported on a series on 76 patients with a minimum 24 months of follow-up undergoing two-stage revision for periprosthetic fracture who underwent a femoral osteotomy during removal of a well-fixed femoral component in the first stage, who then underwent subsequent osseous flap opening during the second stage. Cerclage wiring was used for the first stage of revision. The rate of recurrent infection was 6.6% (5/76); mean follow-up was 51.2 months (minimum 24 months, maximum 118 months). Subsidence occurred in 6.6% (5/76) of patients and dislocation occurred in the same proportion of patients. During re-operation, the osseous flap fractured in 11.8% (9/76) of cases but all flaps healed without further intervention. The authors concluded that cerclage wires did not lower rates of infection-free survival.

Trochanteric osteotomy fixation

Steel wire

Wire fixation was first introduced as an alternative to fixation-free trochanter osteotomy, and early studies suggest that it can effect union in more than 80% of cases.[3,36,37] A biomechanical study of wire fixation found that use of a larger diameter wire with a knot twist or square knot twist offered optimal fixation.[38] Potential disadvantages of wire fixation include potential trochanteric pain, implant failure due to fatigue, or failure due to infection at the site of wires.[39]

Cable fixation

Early cable fixation was associated with high rates of osteolysis due to debris propagation.[3] Kelley and Johnston[40] raised concerns about generation of particle debris in primary total hip arthroplasties performed with a trochanter osteotomy. Hop et al[41] found that use of braided cable without a plate system was associated with more wear, osteolysis, and acetabular loosening and proposed metal debris as a potential mechanism for these outcomes. However, in an uncomplicated osteotomy with adequate residual femoral bone stock of the ETO fragment, authors have advocated fragment fixation with two or three appropriately tensioned and locked cables.[42] In a cadaveric study, Schwab et al[43] compared ETO fixation with two versus three cables. Nine cadavers were randomized to either the two or three-cable fixation group after ETO and implantation of a full coat stem. The authors found no statistically significant difference between the two or three-cable group in peak force, stiffness, angular displacement, axial displacement, or axial displacement.[43]

Cable plate system

Modern systems have addressed some of these shortcomings and now the choice between cables and cable plate fixation is controversial. Sheridan et al[44] found lower rates of mean migration ($p < 0.05$), superior Harris Hip Scores ($p < 0.05$), and superior radiographic outcomes as assessed using the Beals and Tower classification ($p < 0.05$) among patients undergoing fixation with plate systems versus cables alone. On the other hand, Kim et al[45] found that several patients in their series required plate removal due to symptomatic hardware.

Dall and Miles first introduced a trochanter cable-grip system which provided additional anchoring points for cables in order to reduce rates of cable fraying.[46] The technique capitalizes on the superior strength of cables, while reducing rates of fraying and debris generation that have been associated with aseptic loosening. Dall and Miles first evaluated their system in a four-year series of 321 hips and their initial results suggested a disengagement rate of 1.6% (5/321) and a breakage rate of 3.1% (10/321).[46] Although later studies have suggested slightly higher rates of fraying than this seminal article, excellent rates of osseous union continue to be reported.[45,47]

Technical factors that reduce the success of this fixation method may include varus malalignment greater than 6 degrees,[48] loosening of the femoral component,[48] placement of cables around the medial cortex of the femur rather than a drill hole, and use of steel rather than vitallium cables.[49–51] Potential disadvantages of the Dall–Miles cable-grip system include plate fractures, cable fragmentation, bone resorption, and trochanteric tenderness/bursitis which occurs in a minority of patients.[52,53] Tension-band fixation has also been described for the treatment of intra-operative inter-trochanteric fracture as well as a previous trochanter osteotomy nonunion; however, results in the published literature are currently sparse.[54–56]

Polymer cable-grip-plate system

Although newer cable-plate and steel-wire systems have improved function and minimized complications from early generation systems,[57] there is still concern about metal breakage and soft tissue irritation[58] especially when utilized concomitantly with plates and screws. Metal breakage has been reported to occur in up to 28%[36,59–61] of hips fixed with steel wires and up to 43%[46,51,53,62] of those fixed with cable systems, respectively. Cable fraying and fragmentation and wire breakages may contribute to trochanteric nonunion rates after the use of steel wires (0.4–21%)[36,59–61] and cables (1.5–38%).[46,51,53,62]

Non-metallic polymer cable systems (Supercable® System, Kinamed Inc., Camarillo, CA) have garnered interest due to their ability to provide early fixation strength to allow for osteotomy or fracture healing without the potential complications from dissimilar metal wear.[63,64] In a biomechanical in vitro study, Ménard et al[65] described cable tension immediately after cable application and crimping and found significant tension loss with crimping in all designs but more noticeably with multifilament cobalt-chromium cables (up to 52%) versus non-metallic cables (up to 46%). Berend et al[64] reported 81% success (22/27 revision THAs) with grip-plate fixation with polymer cables at average 2.5 year follow-up. At short-term follow-up, the authors reported improved Harris Hip Scores (HHS) and Lower Extremity Activity Scale (LEAS) scores ($p < 0.005$).

Polymer cable fixation also has the potential to avoid complications unique to cobalt-chromium, including progressive resorption, loosening, metallic debris, higher nonunion rates increased polyethylene wear, osteolysis and component loosening.[63–65] Future higher-quality studies with longer-term follow-up are needed to explore the longevity and viability of polymer cables in the setting of ETO fixation and revision THA.

Polyethylene fibre cable

Ultra-high molecular weight polyethylene (UHMWPE) fibre cable is a soft, flexible material that has been conventionally used to bind metal rods to bone in spine fusion surgeries given its superior tensile and fatigue strength with minimal abrasion properties.[66] In an animal model study, Oe et al[67] found UHMWPE fibre cable tensile strength to be similar to that of metal wires, but significantly superior in its fatigue strength properties. Furthermore, the authors described ease of removal with minimal surrounding tissue biological reactivity. In a multi-institutional study, Jingushi et al[68] reported on 85 patients who had undergone procedures with greater trochanteric osteotomies (50 THAs and 35 hip osteotomies). The osteotomized greater trochanter was reattached using UHMWPE fibre cables (NESPLON® Cable System, Alfresa Pharma Corporation, Osaka, Japan). At a minimum one-year follow-up, nonunion of the osteotomy site occurred in 4.7% of patients overall (2/35 hip osteotomy and 2/50 THAs) with minimal displacement less than 2 mm. The authors concluded that UHMWPE fibre cable was a viable option for greater trochanter fixation. However, studies with longer-term follow-up are needed to assess its in vivo safety profile and long-term viability.

Suture fixation

The use of absorbable sutures for ETO fixation during revision THA has also been utilized to further avoid the pitfalls of metal wires and cables. Suture loops consisting of eight strands have been reported to have a breaking strength greater than 1,000 Newtons.[69] Landsmeer et al[69] first described the method to make a strong suture cord using number 2 Vicryl® (Ethicon, Bridgewater, New Jersey). The authors suggest tying four strands of number 2 Vicryl together at both ends with a single knot. While one knot is held with forceps, the other is placed in the power chuck of a drill. The drill is turned on to allow rotation while maintaining tension until a tight helix is created. The suture cord is augmented with four additional suture strands. Kuruvalli et al[70] retrospectively reviewed 20 patients who underwent revision THA with an ETO that was fixed using the aforementioned suture cord technique. At a mean 2.2-year follow-up, bony union occurred in 95% (19/20) of patients and fibrous union in one asymptomatic patient. Proximal migration of the osteotomy fragment (5 mm) was noted in one patient who had bony union. The authors suggested that suture cord fixation provides a secure fixation while maintaining the vascular supply to the osteotomy site. It further avoids complications associated with metal wires/cables and other non-metallic fixation systems.

Number 5 FiberWire® (Arthrex, Naples, Florida) cerclage has also been reported with biomechanically similar resistance to prosthetic subsidence and bony stability compared to metal cerclage systems.[71] Although the FiberWire cerclage system has Food and Drug Administration (FDA) approval for trochanteric reattachment after osteotomy following hip arthroplasty,[72] there are no studies, to our knowledge, that report on its efficacy. The current literature on FiberWire cerclage focuses on its use in revision total shoulder arthroplasty periprosthetic fractures and implant stabilization.[71] Future studies are needed investigating the utility of the FiberWire cerclage system on trochanteric osteotomy stability, healing, and comparison with conventional absorbable suture cords that have been previously reported.

Summary

Trochanter osteotomies facilitate access and exposure in revision total hip arthroplasty. TSO allows acetabular component revision in the presence of a well-fixed stem. The ETO and transfemoral approaches provide greater exposure and have safely been performed for stem revision in septic revisions as well as aseptic revisions due to loosening, component malposition, and periprosthetic fracture.

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ICMJE CONFLICT OF INTEREST STATEMENT

AS declares no conflict of interest relevant to this work.
AFK reports consultancy, payment for lectures including service on speakers bureaus, payment for development of educational presentations for and stock/stock options in Zimmer Biomet and DePuy Synthes; and royalties from Innomed, all outside the submitted work.
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