



Original research

Successful reimplantation surgery after extraction of well-fixed cementless stems by femoral longitudinal split procedure

Satoshi Nagoya, MD, PhD ^{a,*}, Shunichiro Okazaki, MD, PhD ^a, Kenji Tateda, MD, PhD ^b, Ima Kosukegawa, MD, PhD ^b, Arata Kanaizumi, MD ^b, Toshihiko Yamashita, MD, PhD ^b

^a Department of Musculoskeletal Biomechanics and Surgical Development, Sapporo Medical University, Sapporo, Hokkaido, Japan

^b Department of Orthopedic Surgery, Sapporo Medical University, Sapporo, Hokkaido, Japan

ARTICLE INFO

Article history:

Received 7 August 2019

Received in revised form

19 December 2019

Accepted 13 January 2020

Available online 3 March 2020

Keywords:

Revision

THA

Longitudinal split osteotomy

Cementless stem

Extraction

ABSTRACT

Background: Well-fixed cementless stems sometimes need to be extracted in patients with complications including periprosthetic infection, stem-neck breakage, or trunnionosis. The purpose of this study was to report the clinical outcome in patients undergoing reimplantation surgery after removal of a well-fixed porous-coated cementless stem by the femoral longitudinal split (FLS) procedure.

Methods: We conducted a retrospective study and radiographic review of 16 patients who had undergone reimplantation following the FLS procedure to remove a well-fixed stem due to periprosthetic infection, stem-neck breakage, or trunnionosis. The study group consisted of 2 men and 14 women with an average age of 68.4 years. Mean follow-up was 44.6 months. The Kaplan-Meier method was used to evaluate the longevity of the stem.

Results: The average operation time was 272 ± 63 minutes and intraoperative bleeding was 420 ± 170 mL. Although postoperative dislocation occurred in 5 hips and subsidence of the stem was found in 2 hips after surgery, no progressive subsidence was observed and the clinical JOA and JHEQ scores were both improved after reimplantation surgery. Reimplantation surgery with Zweymüller-type stems revealed evidence of osseointegration of the stem without femoral fracture. Kaplan-Meier survival analysis of stem revision for any reason as the end point revealed 70.0% survival at 9 years.

Conclusions: In this study, we experienced some complications in patients with trunnionosis or periprosthetic infections. However, the FLS procedure is expected to confer successful clinical results without loosening of the reimplanted cementless stem, after safe extraction of well-fixed porous-coated cementless stems without fracture.

© 2020 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to <https://dx.doi.org/10.1016/j.artd.2020.01.004>.

Conflict of interest: Paid consultant for a company of Zimmer Biomet. Unpaid consultants for a company of Smith&Nephew, MDM. Speakers bureau/paid presentations for a company of ZimmerBiomet, Smith&Nephew.

* Corresponding author. Department of Musculoskeletal Biomechanics and Surgical Development, S1W17, Chuo-Ku, Sapporo, Hokkaido, Japan. Tel.: +81 11 611 2111.

E-mail address: nagoya@sapmed.ac.jp

<https://doi.org/10.1016/j.artd.2020.01.004>

2352-3441/© 2020 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

There have been various causes reported for revision total hip arthroplasty (THA), with loosening of implants accounting for 51.9%, dislocations 16.9%, periprosthetic infection 15.6%, periprosthetic fracture 5.5%, and/or component failure 2.1% of cases [1]. Although a loosened stem is relatively easy to remove, a cementless stem can be difficult to extract when well fixed in patients with frequent dislocation, periprosthetic infection, stem-neck breakage [2], or trunnionosis [3].

Extended trochanteric osteotomy (ETO) is a standard method for the extraction of well-fixed cementless stems [4]. In this process, the lateral femoral fragment is longitudinally opened to visualize

the whole stem, and the stem is then removed. Although in theory this method facilitates the smooth removal of the stem allowing the proximal lateral femoral fragment to be reduced to its original position with cerclage wiring at reimplantation, it involves the risk of proximal migration of the proximal femoral fragment and intraoperative fragment fracture [5]. It is therefore better to preserve the circular configuration of the proximal femur for successful revision surgery.

We previously reported a femoral longitudinal split (FLS) procedure for the removal of well-fixed extended porous-coated cementless stems with restoration of the femoral cylindrical structure [6]. The FLS procedure allowed a flexible osteotome to be inserted into the stem-femoral cortical bone interface to facilitate debonding of the stem from the bone.

As the clinical outcome of revision THA is thought to depend in part on the degree of femoral bone loss [7], we here report the clinical outcomes of patients undergoing reimplantation surgery after removal of a well-fixed porous-coated cementless stem by the FLS procedure due to neck breakage of the stem, trunnionosis, frequent dislocation, or periprosthetic infection.

Materials and methods

We conducted a retrospective study and radiographic review of 18 patients who had undergone the FLS procedure to remove a well-fixed stem at our institution between February 2007 and July 2016. As the periprosthetic infection could not be eradicated in 2 patients, 16 patients underwent reimplantation surgery after removal of a porous-coated cementless stem and were followed for more than 2 years. The study group consisted of 2 men and 14 women with an average age of 68.4 ± 10 years (range, 52 to 94 years). The average patient height was 150.7 ± 6.1 cm and body weight was 54.5 ± 6.4 kg. Approval for this study was received from the institutional review board of Medical University.

The cause for removal of the stems was trunnionosis in 7, late periprosthetic infection in 3, dislocation in 2, stem-neck breakage in 3, osteolysis in 1, and central migration of a bipolar hip replacement in 1 hip (Table 1). The average period from initial surgery to removal of the stem was 93 ± 40 months. The mean period from removal to reimplantation surgery was 3.3 ± 4.9 months, including simultaneous revision surgery and two-stage revision surgery.

Cementless stems were removed from 16 hips, 13 of which had extended porous-coated stems. Overall, 13 AML plus stems (DePuy,

Leeds, UK), 1 Replica stem (DePuy, Leeds, UK), 1 perfecta stem (Wright Medical Technology, Memphis, TN), and 1 Austin Moore-type stem (Zimmer Biomet, Warsaw, IN) were removed, with all of them found to be well fixed (Table 1). The articulation was a metal-on-polyethylene couple in all cases.

All the removed femoral heads were made of cobalt chromium, with the following sizes: $36 + 0$ mm (1), $28 + 0$ mm (3), $28 + 3$ mm (1), $28 + 6$ mm (2), $22 + 0$ mm (7), and $22 + 3$ mm (2) (Table 1). The surgery included replacement of the stem-side only or simultaneous reimplantation of the stem and acetabular components.

All stems used for reimplantation were Zweymüller-type stems, including 9 Alloclassic stems (Zimmer Biomet, Warsaw, IN), 6 SL plus MIA stem (Smith & Nephew, Memphis, TN), and 1 SL Plus stem (Smith & Nephew, Memphis, TN). With regard to the acetabular component used for reimplantation, one was conventional polyethylene, 5 were highly cross-linked polyethylene liner cemented into a well-fixed acetabular cup, 8 were revisions using a cementless cup and highly cross-linked polyethylene, and 2 were revisions using a cementless cup with constrained polyethylene. The follow-up period after revision surgery was up to 108 months, with an average period of 44.6 ± 20.5 months.

Stem extraction procedure = FLS procedure

With the patient in the lateral decubitus position, after dislocation of the hip joint through the posterolateral approach, the posterior aspect of the femur was exposed and the vastus lateralis muscle was detached from the intertrochanteric eminentia to expose the corresponding length of the femoral linea aspera to the implanted femoral stem. A Kirschner wire was used to drill multiple 2.0 mm holes longitudinally along the exposed posterior linea aspera at 1-cm intervals until the femoral stem tip, and these small holes were connected by a thin osteotome to make an FLS (Fig. 1a). Insertion of a flexible thin osteotome into the posterior, anterior, lateral, and medial aspects of the proximal femur allowed debonding of the well-fixed cementless stems (Fig. 1b). Rotation of the osteotome or using 2 osteotomes (Fig. 1c) at a point 2/3 distally along the split allowed the split to be opened. At this stage, local debonding of the osseointegrated cortical bone from the porous surface of the stem could be accomplished and simple hitting of the stem in the proximal direction with a mallet made it possible to remove the well-fixed stem. Even if this process fails to remove the stem, it is supposed that our procedure could be easily converted to an ETO. In the FLS procedure, as no large bone defects were created, cerclage wiring using Nesplon cable (Alfred, Tokyo, Japan) or metal wire placed at 3 points along the entire stem—distal to the stem tip, the middle part of the stem, and the trochanteric region of the proximal femur—was adequate to maintain the cylindrical structure of the femur to allow subsequent stem insertion.

After gentle rasping to prepare the femoral canal, Zweymüller-type stems, which have a rectangular shape on the axial plane, made of titanium alloy with a sand-blasted surface finish or Wagner-type tapered conical stems with axial splines were used for reimplantation.

Patients were kept on restricted weight-bearing for at least 3 weeks after surgery and then allowed partial weight-bearing with a crutch. Active abduction and straight-leg raises were avoided for at least 6 weeks.

Clinical and radiological evaluations

Operation time, intraoperative bleeding, complications, cause of reoperation, and postoperative period to start full weight-bearing were examined. The operation time was calculated as the total time taken during revision surgery or the extraction process plus

Table 1
Patient demographics and operative characteristics of the removed implants.

Gender	Male (2) female (14)
Mean age at removal of the stem	68.4 ± 10
Mean body height	150.7 ± 6.1 cm
Mean body weight	54.5 ± 6.4
Cause for (1 patient had multiple causes)	Trunnionosis (7) Late infection (3) Dislocation (2) Neck breakage (3) Osteolysis (1) Central migration of BHA (1)
Removed stem	AML plus stem (13) Replica stem (1) Perfecta stem (1) Austin Moore stem (1)
Removed articulation	Metal-on-poly (16)
Removed metal head size (mm)	36 (1) 28 (3) 28 + 3 (1) 28 + 6 (2) 22 (7) 22 + 3 (2)

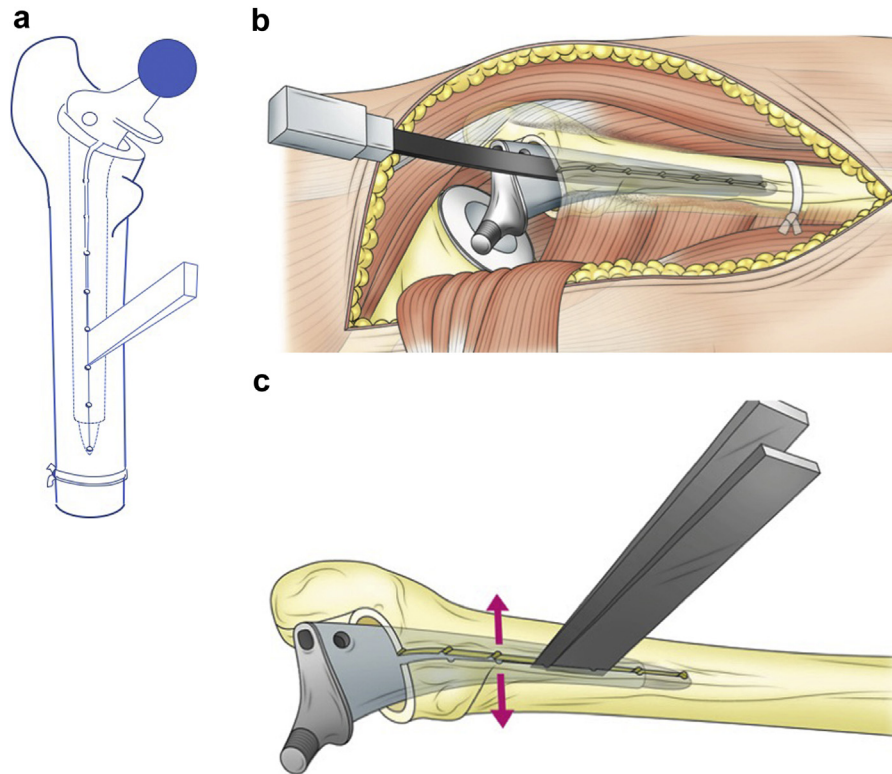


Figure 1. Osteotomy method for the femoral longitudinal split (FLS) procedure. The posterior surface of the femur was split to correspond with the length of the implanted femoral stem (a) and a flexible osteotome was inserted into posterior aspect of the femur (b) to achieve debonding of the osseointegrated cortical bone from the porous surface of the stem. The twisting and/or double osteotome insertion at a point 2/3 distal to the longitudinal split of the femur allows opening of the split portion (c). (Fig. 1 [a], [b] copyright 2017 by Medical View Co., Ltd. Reprinted with the permission of Medical View Co., Ltd.).

two-staged reimplantation surgery. Japanese Orthopaedic Association (JOA) [8] and Japanese Orthopaedic Association Hip Disease Evaluation Questionnaire (JHEQ) [9] scores were used for clinical evaluation.

To compare the length of reimplanted and extracted stems, the longitudinal distance of the femur occupied by the stem was measured radiographically. Measurement of the distance from the greater trochanter to the distal end of the stem was performed with allowance for the diameter of the metal femoral head. Stem sinking, stress shielding, radiolucent line, appearance of osteolysis, changes in the bone holes made during the extraction procedure, and changes in the femoral cortex were also investigated.

Statistical analysis

Data were collected and stored in Microsoft Excel for Mac Version 16.16.5 (Microsoft Corporation, Redmond, WA). Data analysis focused on the clinical outcome based on preoperative and postoperative data using the Wilcoxon matched-pairs signed-rank test. All descriptive data were assessed using GraphPad Prism 7 (MDF, Tokyo, Japan) statistics software.

Implant survival was defined as the time until the first revision of the implanted stem for any reason and was estimated according to Kaplan-Meier survival analysis with a 95% confidence interval (CI). The Kaplan-Meier survival analysis was performed using GraphPad Prism 7 (MDF, Tokyo, Japan) statistics software.

Results

The average operation time was 272 ± 63 minutes and intraoperative bleeding was $420 \text{ mL} \pm 170$ (260–880 mL) (Table 2). No

femoral shaft fracture or symptomatic venothrombotic embolism was observed during surgery. Partial weight-bearing started from 3 weeks postoperatively, and all cases achieved full weight-bearing under load with the use of a cane within 2 months after surgery.

Postoperative dislocation occurred in 5 hips within 2 months after surgery due to trunnionosis or periprosthetic infections, but conservative management was effective in preventing further recurrence of dislocation (Table 2).

Two patients experienced greater trochanter fracture due to falls within 3 months and 4 months after surgery, and the fracture was complicated by a dislocation in 1 patient, which was resolved with conservative therapy.

One patient treated by osteosynthesis required removal of the implant due to surgical site infection 1 month after surgery. She was successfully treated by debridement three times followed by final revision surgery. One patient required removal of the implant due to uncontrollable periprosthetic infection 37 months after initial reimplantation surgery.

The average JOA score was significantly improved from 37.6 ± 25.2 points preoperatively to 69.1 ± 13.6 points after surgery (Fig. 2a, $P < .0001$). The visual analog scale in JHEQ was significantly improved from 83.1 ± 27.6 mm preoperatively to 18.9 ± 17.0 mm postoperatively (Fig. 2b, $P = .0002$), and the total JHEQ score was significantly improved from 19.4 ± 15.6 points to 48.9 ± 13.8 points (Fig. 2c, $P = .0001$).

Radiological evaluations

To evaluate the length of the femur occupied by the stem, the distance from the tip of the greater trochanter to the distal end of the stem was measured. The preoperative average length of $158.9 \pm$

17.0 mm was an average of 6.4 ± 12.8 mm longer than that post-operatively (152.5 ± 22.1 mm) as a shorter stem was selected for reimplantation surgery (Table 3, $P = .039$).

Although a radiolucent line was found in femoral zone 1 and 7 in 6 patients, no mechanical loosening or osteolysis was observed. Subsidence of the stem by 5 and 15 mm was found in 2 patients, but no progression of subsidence was observed. Nine of 13 femurs to which a cerclage Nesplon cable was applied developed scalloping of the femoral cortical bone.

As a shorter stem was used for the reconstruction, the bone holes made during the FLS osteotomy were observed distal to the stem tip. There were no patients in whom the bone holes expanded, and the bone holes were filled with new bone in 15 of 16 patients at an average of 9 ± 3.7 months after surgery (Table 3).

There were no revisions due to mechanical loosening of the reimplanted stems. Kaplan-Meier survival analysis for re-revision of the reimplanted stems as the end point revealed a survival rate of 70.0% (95% confidence interval [CI]: 0.23–0.91) at 9 years after reimplantation (Fig. 3). The reason of the revision of 2 stems was the recurrence of periprosthetic infection that had been present prior to the index revision.

Discussion

In recent years, neck breakage [2] and trunnionosis [3] due to metal corrosion of the neck have been reported as causes leading to revision THA. Although good short-term clinical results for revision methods implanting a ceramic femoral head on the problematic trunnion of the retained stem have been reported, the long-term results remain a concern [10].

Opportunities to remove well-fixed cementless stems have been increasing [3]. However, it can be difficult to remove such stems, and various surgical techniques can be employed. There are several options for the removal of well-fixed stems by tapping with a

mallet after disruption of the bony disconnection of the stem with insertion of a K-wire or thin blade [11], ETO [4], slot femorotomy in which a bony sulcus is made in the posterior aspect of the femur [12], or posterior longitudinal split osteotomy [13].

We reported that the FLS procedure was effective in extracting well-fixed extended porous-coated cementless stems while retaining the cylindrical structure of the femur without a bone flap by inserting a flexible osteotome between the stem and the femur after FLS osteotomy [6].

It is reported that ETO is effective for removing cementless and cemented stems as well as intramedullary residual cement [4]. The principle underlying the use of ETO to remove a cementless stem with distal osseointegration is based on direct extraction by visualization of the lateral aspect of the stem through a bony flap. Slot femorotomy is indicated to remove curved anatomic stems that are fixed in the metaphysis of the femur, excluding extended porous-coated cementless stems that show relatively distal osseointegration [12]. The limited operative indications for this procedure seem to be dependent on the osteotomy line located in the proximal posterior aspect of the femur without an osteotomy line in the most proximal end of the femur. Furthermore, posterior longitudinal split osteotomy is indicated to remove fibrous ingrown or partially ingrown stems [13]. These procedures are performed without twisting and/or insertion of double osteotomes into the split allowing debonding of the well-fixed cementless stems, whereas our procedure enabled the removal of well-fixed extended porous-coated cementless stems, including 14 hips with AML plus stems. The FLS procedure used a flexible osteotome that was inserted into the posterior, anterior, lateral, and medial aspects of the proximal femur between the stem-bone interface to prevent comminuted femoral fracture. The twisting and/or insertion of double osteotomes into the split at a point 2/3 distal to the longitudinal split of the femur leads to the opening of the osteotomy line, making it easier to extract the stems following tapping with a mallet.

Table 2
Revision time, blood loss, implants, complications, and reoperation.

Case	Cause for revision	Total revision time (min)	Blood loss (mL)	Implant for femoral revision	Implant for acetabular revision	Complications	Reoperation
1	Trunnionosis	240	880	Alloclassic	Retained cup + conventional poly		None
2	Trunnionosis, stem-neck breakage	260	700	SL- Plus MIA	G7 cup + constrained ply		None
3	Periprosthetic infection	336	430	SL- Plus MIA	Reflection + XLPE	Infection recurred dislocation	Stem removed because of uncontrollable infection recurred (37 months)
4	Osteolysis	270	400	SL- Plus MIA	Retained cup + XLPE	Dislocation	None
5	Trunnionosis	260	300	Alloclassic	Continuum cup + longevity	GT fracture	None
6	Stem-neck breakage	190	480	SL- Plus MIA	Reflection cup + XLPE		None
7	Dislocation	200	265	Alloclassic	Continuum cup + longevity		None
8	Periprosthetic infection	360	350	SL Plus	R3 cup + XLPE		None
9	Trunnionosis periprosthetic infection	260	260	Alloclassic	Continuum + longevity	GT fracture infection recurred dislocation	Stem revised because of infection recurred (5 months)
10	Periprosthetic infection	430	560	Alloclassic	Trabecular metal cup + constrained poly		None
11	Trunnionosis (BHA)	220	360	SL- Plus MIA	R3 cup + XLPE		None
12	Migration of BHA	270	350	Alloclassic	Continuum cup + longevity	Dislocation	None
13	Trunnionosis	260	270	SL- Plus MIA	Retained cup + XLPE		None
14	Stem-neck breakage	300	350	Alloclassic	Retained cup + longevity	Dislocation	None
15	Trunnionosis	300	480	Alloclassic	Retained cup + longevity		None
16	Dislocation	200	320	Alloclassic	Retained cup + longevity		None
Average		272 ± 63	420 ± 170				

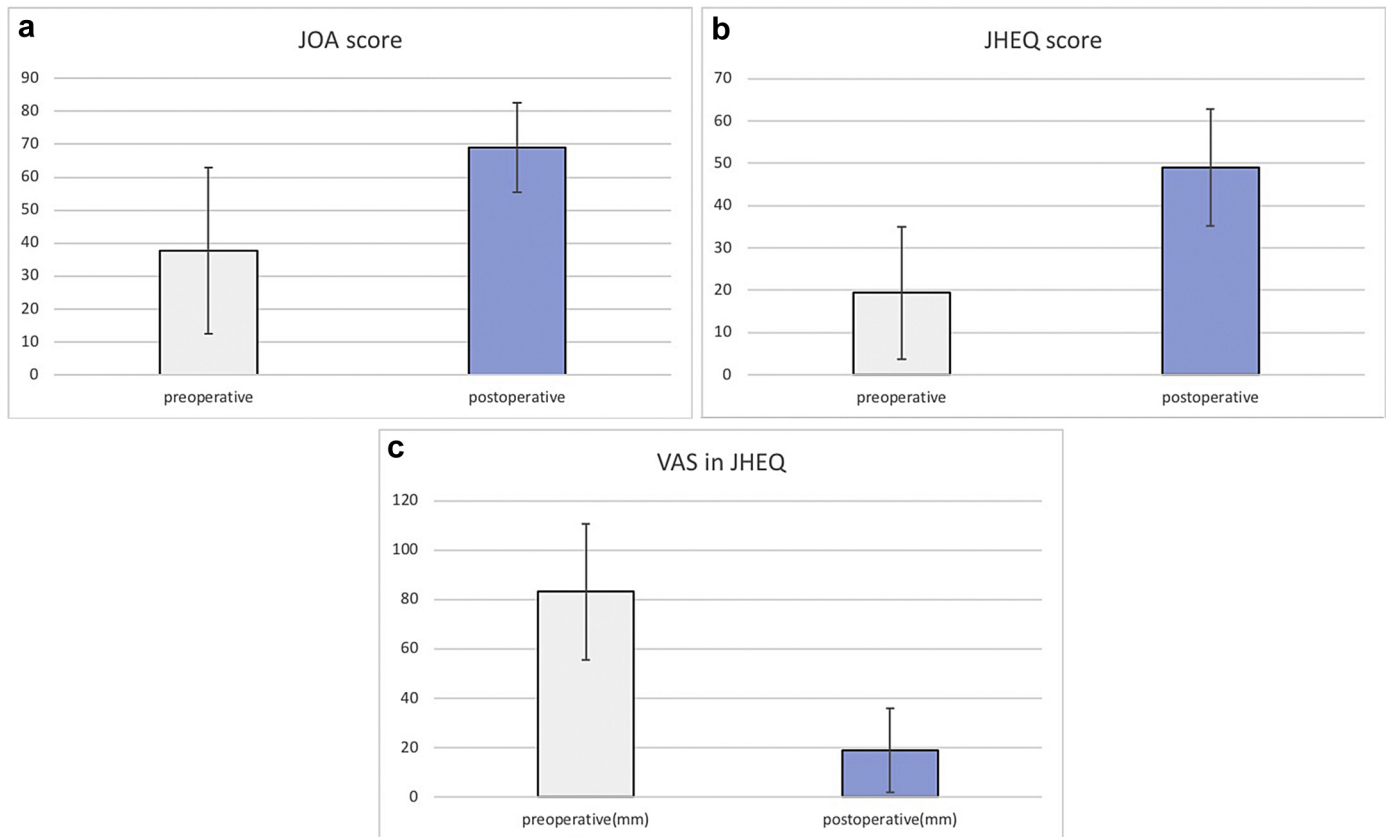


Figure 2. Clinical evaluations including the comparison of preoperative and postoperative JOA scores (a), VAS in the JHEQ scores (b), and JHEQ scores (c).

To obtain osseointegration of the implanted cementless stem in reimplantation surgery, Paprosky et al. [4] reported that a longer cementless stem was required to be press fit into the intact area of the distal femoral diaphysis for at least 4 cm, whereas rasps of a progressively increasing size were required to obtain rotational stability during reconstruction after ETO. The FLS procedure, on the other hand, allowed a shorter stem than the removed stem for reimplantation surgery (Table 3). The reason why a shorter stem is sufficient for successful reimplantation surgery is that no bone defect or flap is formed in the proximal femur and the cylindrical structure of the femur is maintained by the

cerclage wire, making it possible to ensure initial rotational stability by using a rectangular Zweymüller-type stem (Fig. 4a and b). Although we used shorter stems, the fact that the patients in this study had relatively smaller bodies in comparison to other populations (150.7 cm and 54.5 kg) might contribute to the decreased risk of femoral fracture. A longer stem may be inserted, bypassing the osteotomy line to decrease the mechanical stress applied distally to the implanted stem, especially in cases with fragile bone or femoral bone defects arising during removal of the stem. Further study will be required to clarify whether the shorter stem provides durable long-term fixation.

Table 3
Radiographic results.

Case	Final follow-up	Removed stem length (mm)	Implanted stem length (mm)	Difference in stem length (mm)	Stem sinking	Stress shielding	Radiolucent line	Split hole	Split hole-elimination time (months)
1	108	160	130	30	none	Grade 1	None	Eliminated	6
2	65	155	143	12	None	Grade 1	None	Eliminated	12
3	42	145	120	25	None	Grade 3	None	Eliminated	11
4	29	142	140	2	None	Grade 2	Zone 1,7	Eliminated	6
5	53	142	125	17	None	None	Zone 1,7	Eliminated	6
6	25	168	154	14	None	None	None	Eliminated	6
7	64	142	139	3	None	None	None	Eliminated	12
8	39	145	149	-4	None	None	None	Eliminated	12
9	46	162	187	-25	N.D.	N.D.	N.D.	N.D.	N.D.
10	35	200	200	0	None	Grade 1	None	Eliminated	10
11	36	161	159	2	None	Grade 1	Zone 1,7	Eliminated	6
12	40	185	169	16	5 mm	Grade 1	None	Eliminated	18
13	30	157	151	6	15 mm	Grade 1	Zone 1,7	Eliminated	12
14	36	178	178	0	None	None	None	Eliminated	9
15	30	144	140	4	None	Grade 1	Zone 1,7	Eliminated	6
16	36	156	156	0	None	Grade 1	Zone 1,7	Eliminated	6
Average	44.6 ± 20.5	158.9 ± 17.0	152.5 ± 22.1	6.4 ± 12.8					9 ± 3.7

N.D., not determined for removal of the stem due to infection.

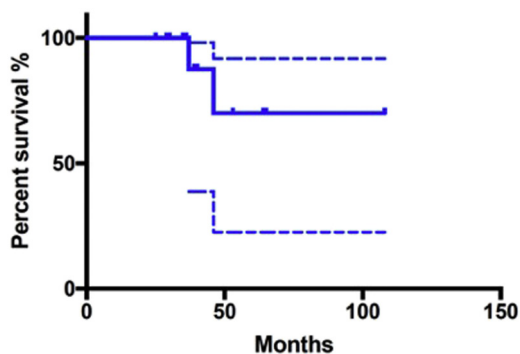


Figure 3. Kaplan-Meier survival analysis of the revised stem with revision for any reason as the end point. Dotted line indicated 95% confidence interval.

Although the bone holes generated by FLS were present at the distal end of the removed stem immediately after surgery, our results showed that the bone holes disappeared in 15 of 16 hips at an average of 9 ± 3.7 months after surgery, which appears to support the osseointegration of the implanted stem. Two hips showed stem early subsidence, but no progression was observed.

Among 13 patients treated with cerclage wiring with using Nesplon cable, 9 patients showed scalloping of the femoral cortex. It was thought that the simultaneous hoop stress from the cerclage wire and the femoral cortex on the stem resulted in local thinning of the contact area. Five of 16 patients experienced dislocation of the THA. As patients with trunnionosis and periprosthetic infection are at high risk of postoperative dislocation, we chose to treat them with a constrained polyethylene cup and did not experience postoperative dislocation. We feel it is necessary to pay attention to the risk of dislocation based on the pathology accompanying tissue necrosis and defects and to choose a construct with adequate stability to minimize the risk of dislocation.

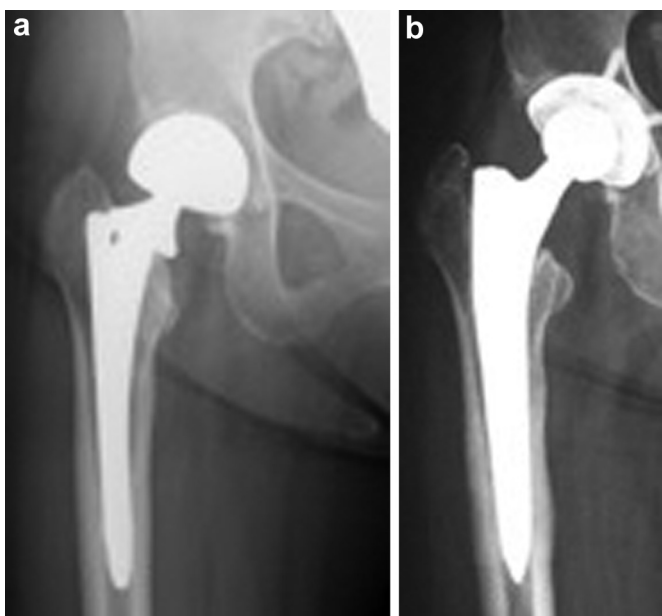


Figure 4. (a) Preoperative radiograph of a 74-year-old female patient showing a bipolar prosthesis replacement without loosening of the stem. She complained of severe right hip pain and had trunnionosis. (b) Postoperative radiograph showing a reimplanted SL-Plus MIA stem 3 years postoperatively after removal of a well-fixed stem using the FLS procedure. The relatively shorter stem was successfully fixed and no bone defect or loosening is observed.

Conclusions

In conclusion, although loosened stems are relatively easy to remove, cementless stems can be more difficult to extract when stem is well fixed in cases of stem-neck breakage or trunnionosis. We used a FLS procedure to remove well-fixed extended porous-coated cementless stems in cases of catastrophic failure. The reimplantation surgery with Zweymüller-type stems resulted in evidence of stem osseointegration without femoral fracture. In the future, as it is thought that trunnion failure of the stem-dependent early and late complications related to THA, so-called trunnionosis [3], might be increased, a surgical technique to remove well-fixed stems safely as well as allow successful reimplantation is required. We have generally used the FLS technique as required to remove well-fixed femoral stems for several years in our hospital. However, we experienced some complications including stem subsidence, and dislocations in patients with trunnionosis or periprosthetic infections. As the stem subsidence observed in 2 patients may be associated with using a shorter stem, a longer stem can be used to bypass the osteotomy line to prevent these complications. To prevent dislocations after surgery, a constrained liner may be primarily used for reimplantation in patients with trunnionosis.

The FLS procedure demonstrated successful clinical results for reimplantation surgery without loosening of the stem, after safe extraction of well-fixed porous-coated cementless stems without fracture and will allow successful reimplantation with cementless stems.

Acknowledgments

The authors thank Professor Daisuke Suzuki and Dr. Junya Shimizu for their technical support to analyze data.

References

- [1] Ulrich SD, Seyler TM, Bennett D, et al. Total hip arthroplasties. What are the reasons for revision? *Int Orthop* 2008;32(5):597.
- [2] Wodecki P, Sabbah D, Kermarrec G, Semaan I. New type of hip arthroplasty failure related to modular femoral components: breakage at the neck-stem junction. *Orthop Traumatol Surg Res* 2013;99(6):741.
- [3] Pastides PS, Dodd M, Sarraf KM, Willis-Owen CA. Trunnionosis: a pain in the neck. *World J Orthop* 2013;18(4):161.
- [4] Paprosky WG, Weeden SH, Bowling Jr JW. Component removal in revision total hip arthroplasty. *Clin Orthop Relat Res* 2001;393:181.
- [5] Mardones R, Gonzalez C, Cabanela ME, Trousdale RT, Berry DJ. Extended femoral osteotomy for revision of hip arthroplasty. Results and complications. *J Arthroplasty* 2005;20(1):79.
- [6] Nagoya S, Sasaki M, Kaya M, Okazaki S, Tateda K, Yamashita T. Extraction of well-fixed extended porous-coated cementless stems using a femoral longitudinal split procedure. *Eur Orthop Traumatol* 2015;6(4):417.
- [7] Sheth NP, Nelson CL, Paprosky WG. Femoral bone loss in revision total hip arthroplasty: evaluation and management. *J Am Acad Orthop Surg* 2013;21(10):601.
- [8] Toyama H, Endo N, Sofue M, Dohmae Y, Takahashi HE. Relief from pain after Bombelli's valgus-extension osteotomy, and effectiveness of the combined shelf operation. *J Orthop Sci* 2000;5(2):114.
- [9] Matsumoto T, Kaneuji A, Hiejima Y, et al. Japanese Orthopaedic Association Hip Disease Evaluation Questionnaire (JHEQ): a patient-based evaluation tool for hip-joint disease. The subcommittee on hip disease evaluation of the clinical outcome committee of the Japanese Orthopaedic Association. *J Orthop Sci* 2012;17(1):25.
- [10] Cooper HJ. Diagnosis and treatment of adverse local tissue reactions at the head-neck junction. *J Arthroplasty* 2016;31(7):1381.
- [11] Laffosse JM. Removal of well-fixed fixed femoral stems. *Orthop Traumatol Surg Res* 2016;102(1 Suppl):S177.
- [12] Jack CM, Molloy DO, Esposito C, Walter WL, Zicat B, Walter WK. Limited slot femorotomy for removal of proximally coated cementless stems. A 10-year follow-up of an unreported surgical technique. *J Arthroplasty* 2013;28(6):1000.
- [13] Bauze AJ, Charity J, Tsidiris E, Timperley AJ, Gie GA. Posterior longitudinal split osteotomy for femoral component extraction in revision total hip arthroplasty. *J Arthroplasty* 2008;23(1):86.