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# Does Computed Tomography-Based Navigation Contribute to Achieving the Target of Intact Ratio in Surgery for Osteonecrosis of the Femoral Head? A Mean 9-Year Retrospective Study

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ABSTRACT

*Background:* This study evaluated postoperative radiological outcomes of transtrochanteric osteotomy using a computed tomography (CT)-based navigation system in patients who have osteonecrosis of the femoral head.
*Methods:* This study included 16 patients who had a mean age of 28 ± 10 years and a mean follow-up of nine ± 5 years. There were four, five, and seven patients who underwent transtrochanteric anterior rotational osteotomy, transtrochanteric posterior rotational osteotomy, and curved varus osteotomy with a CT-based navigation system to achieve an intact ratio of ≥ 34%, respectively. According to the Japanese Investigation Committee classification, 14 and two hips were stage 3A and 3B, whereas 12 and four hips were type C1 and C2, respectively. There were two types of cumulative survival rates evaluated: one based on progression to collapse and the other based on conversion to total hip arthroplasty (THA) as the end point. The intact ratio, tip-to-apex distance, femoral offset, leg length, and neck–shaft angle were calculated via radiography and compared between the THA and non-THA groups according to whether conversion to THA was required.
*Results:* Collapse occurred in two cases, whereas four cases required THA. The cumulative survival rate among those who experienced collapse and required THA was 88 and 75%, respectively. The reasons for conversion to THA in the four cases were collapse (one case), deep infection (one case), and failures at the osteotomy site (two cases). All patients had a postoperative intact ratio of ≥ 34% (mean value, 49 ± 10%). No differences in the postoperative intact ratio were found between the groups. The tip-to-apex distance was greater in the THA group (39 ± 8 mm) than in the non-THA group (28 ± 10 mm; $P = 0.04$).
*Conclusions:* Transtrochanteric osteotomy using a CT-based navigation system achieved a postoperative intact ratio of ≥ 34%. Further investigation may be necessary to reduce osteotomy site complications.
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Osteonecrosis of the femoral head (ONFH) has been identified as one of the causes of acute hip pain among young and middle-aged adult patients [1,2]. The size and location of the necrotic lesion within the weight-bearing zone of the femoral head are strongly associated with the risk of subsequent collapse, which can result in progressive hip pain, functional impairment, and joint destruction. Therefore, once collapse occurs, surgical intervention is often required, with treatment options including total hip arthroplasty (THA) or joint-preserving procedures. Although THA generally provides favorable outcomes for patients who have ONFH [3,4], it is still associated with certain complications, particularly in younger patients [5,6]—highlighting the importance of appropriate patient selection for joint-preserving procedures [7,8].

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Several joint-preserving procedures have been developed for the treatment of ONFH, including core decompression with or without bone grafting [9,10], vascularized bone grafting [11], regenerative therapies involving cells or growth factors [12], and transtrochanteric osteotomies such as curved varus osteotomy (CVO) [13,14] and transtrochanteric rotational osteotomy (TRO) [15–17]. In 1978, TRO was first introduced by Sugioka et al. [15], and subsequent studies have reported favorable clinical outcomes, supporting its recommendation for young patients who have ONFH [7,18]. On the other hand, previous studies have suggested that poor outcomes following TRO may result from intraoperative damage to the blood vessels [19]. Furthermore, cases in which the necrotic segment was not fully rotated out of the weight-bearing zone frequently required conversion to THA, indicating that insufficient rotation of the necrotic area may be a key factor contributing to surgical failure [20]. For this reason, transtrochanteric osteotomy, particularly TRO, is considered challenging [19,20]. As previously described, the intact ratio is widely used to predict postoperative outcomes following technically demanding transtrochanteric osteotomy. As illustrated in Figure 1A, it is calculated using the formula C–D/A–B. Clinical outcomes after CVO and TRO in patients who have ONFH are generally favorable when the postoperative intact ratio is ≥ 34% [1,21].

Recent studies have demonstrated that computed tomography (CT)-based navigation systems [22] and CT-guided robotic saw-cutting systems [23] can lead to favorable clinical outcomes following THA [3]. However, evidence regarding the application of computer-assisted techniques in transtrochanteric osteotomy remains limited. In particular, it is still unclear whether CT-based navigation contributes to achieving an intact ratio of ≥ 34% or improves mid-term radiological outcomes after computer-assisted transtrochanteric osteotomy [24]. Therefore, the present study aimed to investigate whether patients who have ONFH who underwent transtrochanteric osteotomy using CT-based navigation achieved an intact ratio of ≥ 34% and to evaluate mid-term (mean 9-year) radiological outcomes and cumulative survival rates.

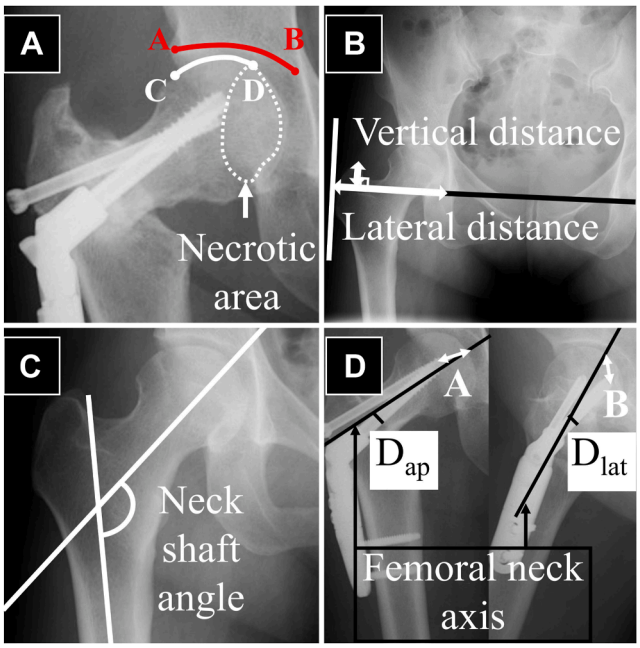



**Figure 1.** Method for the measurement of the radiological parameters. (A) Intact ratio = C–D/A–B. (B) Vertical and lateral distances. Lower limb length reduction = postoperative vertical distance − preoperative vertical distance. Lateralization of the greater trochanter = postoperative lateral distance − preoperative lateral distance. (C) Neck–shaft angle. Varus angle = preoperative neck–shaft angle − postoperative neck–shaft angle. (D) Tip-to-apex distance = A × actual diameter of femoral screw/Dap + B × actual diameter of femoral screw/Dlat.

## Material and Methods

### *Patients*

Ethical approval was obtained from the Institutional Review Board of our institution, and informed consent was obtained through an opt-out process. This retrospective study included 16 ONFH patients (eight men and eight women; mean age: 28 ± 10 years; average follow-up duration, nine ± 5 years, range, two to 18) who underwent transtrochanteric osteotomy using the OrthoMap 3D Navigation Software (Stryker, Tokyo, Japan) between August 1, 2001, and July 31, 2021, at our institution. Among the included patients, four underwent transtrochanteric anterior rotational osteotomy (ARO), five underwent transtrochanteric posterior rotational osteotomy (PRO), and seven underwent CVO with a CT-based navigation system to achieve an intact ratio of ≥ 34%. The primary surgical indication was CVO. If CVO could not achieve a sufficient intact ratio due to an extensive necrotic area, ARO or PRO was selected based on the location of the necrotic region. ONFH was associated with corticosteroid therapy in nine patients, alcohol abuse in three patients, idiopathic in three patients, and posttraumatic in one patient. According to the Japanese Investigation Committee (JIC) classification, 14 and two hips were classified as stage 3A and 3B, whereas 12 and four hips were classified as type C1 and C2, respectively. A detailed list is provided in Table 1.

### *Evaluation*

#### *Radiological Parameters and Patient Background*

Radiological assessments included the postoperative intact ratio, vertical distance, lateral distance, neck–shaft angle (both preoperatively and postoperatively), and tip-to-apex distance (TAD) (Figure 1). Lower-limb length reduction was determined by subtracting the preoperative vertical distance from the postoperative value. Lateralization of the greater trochanter was determined by subtracting the preoperative lateral distance from the postoperative value. The varus angle was calculated by subtracting the postoperative neck–shaft angle from the preoperative neck–shaft angle. Patient background variables included sex, age,

**Table 1**
Profile of Patients (n = 16).

| Variable | Score |
|---|---|
| Age (years) | 28 ± 10 |
| Men/women (n) | 8/8 |
| BMI | 22 ± 3 |
| Follow-up period (years) | 9 ± 5 |
| Etiology of ONFH (n) | |
| Associated steroid therapy | 9 |
| Alcohol abuse | 3 |
| Idiopathic | 3 |
| Posttraumatic | 1 |
| Preoperative JIC stage | |
| 3A | 14 |
| 3B | 2 |
| Preoperative JIC type | |
| C1 | 12 |
| C2 | 4 |

BMI, body mass index; ONFH, osteonecrosis of the femoral head; JIC, Japanese Investigation Committee.

**Table 2**
Comparison of Radiological Parameters and Patient Background Between the Non-THA and THA Groups.

| Variable | Non-THA Group (n = 12) | THA Group (n = 4) | *P*-Value |
|---|---|---|---|
| Radiological parameters | | | |
| Intact ratio (%) | 48.4 ± 7.1 | 49.5 ± 17.0 | 0.51 |
| Lower limb length reduction (mm) | 5.0 ± 7.3 | 6.9 ± 6.7 | 0.54 |
| Lateralization of the greater trochanter (mm) | 3.9 ± 5.8 | 3.7 ± 3.3 | 0.90 |
| Varus angle (°) | 15.1 ± 11.4 | 9.0 ± 12.3 | 0.39 |
| TAD (mm) | 28.3 ± 9.7 | 38.9 ± 8.0 | 0.04 |
| Patient background | | | |
| Age (years) | 24 ± 8.7 | 38 ± 2.4 | 0.02 |
| BMI | 21.0 ± 3.0 | 24.4 ± 3.2 | 0.11 |
| Operative time (minutes) | 274.9 ± 104.4 | 306.8 ± 37.1 | 0.23 |
| Bleeding amount (mL) | 660.1 ± 536.4 | 592.5 ± 424.0 | 1.00 |
| Hospitalization duration (days) | 62.4 ± 22.1 | 94.0 ± 46.0 | 0.11 |
| Postoperative radiographic changes | | | |
| Secondary collapse | 1 | 1 | – |
| Joint space narrowing | 0 | 0 | – |
| Complications | | | |
| Deep infection | 0 | 1 | 0.25 |
| Failures at the osteotomy site | 0 | 2 | 0.05 |

THA, total hip arthroplasty; BMI, body mass index; TAD, tip-to-apex distance.

body mass index, operative time (excluding anesthesia duration), intraoperative blood loss, and length of hospital stay. Patients were categorized into two groups based on whether they eventually required THA: the "non-THA group" and the "THA group". Differences in radiological parameters, patient background factors, and complications leading to conversion to THA were analyzed between the two groups.

*Survival Rate*

Survival rates after osteotomy were evaluated, with progression to femoral head collapse and conversion to THA as the end points. The evaluation was performed using anteroposterior and lateral hip radiography.

*Clinical Evaluation of Pain*

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores [25] were collected from the final preoperative outpatient visit and the final postoperative follow-up.

*Surgical Technique*

The surgical techniques for CVO and TRO [13,15,26] are described below:

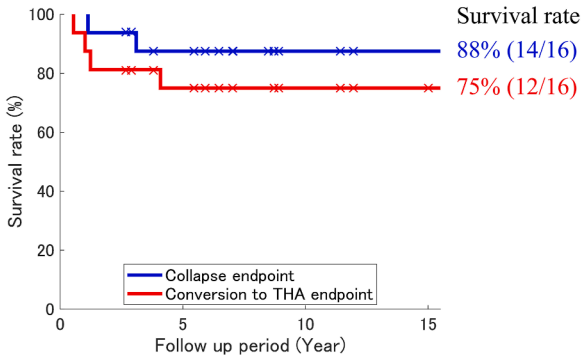



**Figure 2.** Kaplan-Meier survival curves with femoral head collapse and conversion to total hip arthroplasty (THA) as the end point. The blue line represents the curve with femoral head collapse as the end point, whereas the red line represents the curve with conversion to THA as the end point. The survival rates at 10 years were 88% (95% CI, 65 to 97) and 75% (95% CI, 51 to 90) for collapse and THA, respectively.

1. A 15-cm longitudinal incision was made with the patient in the lateral position to expose the intertrochanteric crest of the femur.
2. Two 4-mm apex half-pins were percutaneously inserted into the distal one-third of the femoral diaphysis, and a reference marker was fixed to the femur using these pins.
3. The surface points of the patient's femur were matched with the preoperative CT-based femoral surface model, and femoral registration was performed using the navigation system.
4. After femoral registration, the 3-mm tip of the Kirschner wire was identified using a calibration tool. Several wires were then inserted into planes running parallel to the preoperatively planned osteotomy planes, with the wires inserted from the dorsal side of the trochanter toward the ventral side.
5. Osteotomy was performed using a reciprocating saw.
6. After varus and rotational adjustments, alignment with the preoperatively planned proximal bone fragment was confirmed, and the fragment was fixed.
7. Fixation was performed using either the adjustable angle Hip Screw (Kyocera, Japan) or the F System (Mizuho Co., Japan). For TRO, additional screws or pins were used to secure the greater trochanter.

*Data Analyses*

Radiological parameters in both groups were compared using the Mann–Whitney *U* test. The incidence of complications in both groups was compared using Fisher's exact test. Survival rates, with femoral head collapse and THA as end points, were estimated using the Kaplan–Meier method. In both analyses, differences were considered significant when the *P*-value was <0.05. All statistical

**Table 3**
Comparison of WOMAC Scores Between Preoperative and Postoperative Assessments.

| WOMAC Scores | Preoperative Average (Range) | Final Follow-Up Average (Range) | *P*-Value |
|---|---|---|---|
| Total (96 points) | 41.6 ± 21.7 (10 to 68) | 5.7 ± 6.4 (0 to 19) | 0.02 |
| Pain (20 points) | 8.9 ± 3.9 (3 to 14) | 1.5 ± 2.3 (0 to 7) | 0.02 |
| Stiffness (8 points) | 4.3 ± 3.0 (0 to 8) | 0.8 ± 1.2 (0 to 3) | 0.03 |
| Function (68 points) | 28.4 ± 15.3 (7 to 49) | 3.4 ± 4.4 (0 to 14) | 0.02 |

WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

analyses were performed using JMP Pro (version 17; Statistical Analysis System Institute Japan Inc., Cary, North Carolina) and MATLAB (version 24.2; The MathWorks, Natick, Massachusetts).

## Results

### *Comparison of Radiological Parameters and Patient Background Between the Two Groups*

Details of the comparison of radiological parameters and patient background are summarized in Table 2. Among the radiological parameters, a postoperative intact ratio of ≥34% was achieved in all patients. The intact ratio was 48.4 ± 7.1% (range, 37.7 to 61.5) in the non-THA group and 49.5 ± 17.0% (range, 36.0 to 74.3) in the THA group, with no difference observed between the two groups ($P = 0.47$). Values for lower limb length reduction, lateralization of the greater trochanter, and varus angle are also presented in Table 2, and no differences were found for these parameters. In contrast, the TAD was greater in the THA group than in the non-THA group ($P = 0.04$). Regarding patient background and complications, the THA group was older than the non-THA group ($P = 0.02$). No differences were found in the remaining background parameters.

### *Survival Rates*

During the follow-up period, two cases progressed to collapse, resulting in a survival rate of 88% (95% confidence interval [CI], 65 to 97) with collapse as the end point. Meanwhile, four cases required conversion to THA, with a survival rate of 75% (95% CI, 51 to 90) using THA conversion as the end point (Figure 2). Causes of conversion to THA included collapse in one case, deep infection in one case, and failure at the osteotomy site in two cases.

### *Clinical Evaluation of Pain*

The details of the WOMAC scores are presented in Table 3. Overall, and across all subcategories, pain was relieved at the final follow-up.

## Case Report

### *Case 1*

A 29-year-old woman was diagnosed with ONFH associated with corticosteroid therapy. Preoperative radiography and magnetic resonance imaging (MRI) showed JIC stage 3A and type C2. The patient was treated with CVO, achieving a postoperative intact ratio of 38%. She exhibited a favorable course, with no femoral head collapse or other complications, 5 years after surgery (Figure 3).

### *Case 2*

A 26-year-old man was diagnosed with ONFH associated with alcohol abuse. Preoperative radiography and MRI showed JIC stage

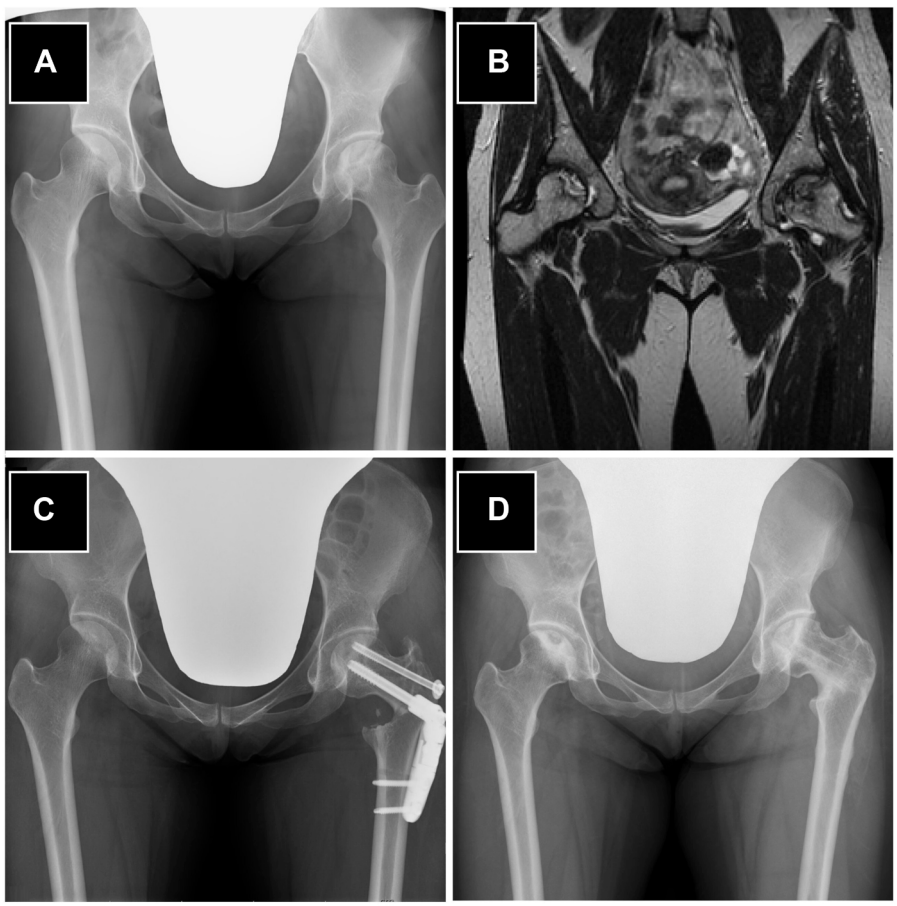



**Figure 3.** Case 1. A 29-year-old patient who had osteonecrosis of the femoral head associated with corticosteroid therapy. (A) Preoperative hip radiography. (B) Preoperative hip magnetic resonance imaging. (C) Postoperative hip radiography. (D) Hip radiography 5 years after surgery.

3B and type C2. The patient was treated with PRO. His postoperative intact ratio was 48%. The patient exhibited a favorable course with no femoral head collapse or other complications 9 years after surgery (Figure 4).

*Case 3*

A 37-year-old woman was diagnosed with ONFH associated with corticosteroid therapy. Preoperative radiography and MRI showed JIC stage 3A and type C1. The patient was treated with ARO. Her postoperative intact ratio was 46%. This patient experienced progression to femoral head collapse 3 years after surgery, resulting in conversion to THA (Figure 5).

## Discussion

*Summary of This Study*

This study showed that transtrochanteric osteotomy using a CT-based navigation system achieved a postoperative intact ratio of ≥ 34% in all cases. Further investigation may be necessary to reduce complications of the osteotomy site.

## Survival Rate and Intact Ratio

Table 4 summarizes previous studies on transtrochanteric osteotomy [17,21,24,27–30]. Numerous reports have indicated that the intact ratio is closely associated with the survival rate following transtrochanteric osteotomy. A study demonstrated that the survival rate after TRO, using femoral head collapse as the end point, was significantly higher in patients who had a postoperative intact ratio of ≥ 34% [21]. Another study evaluated the survival rate after TRO using both progression to femoral head collapse and conversion to THA as end points and found that a postoperative intact ratio ≥ 33.6% significantly improved survival outcomes [27]. Moreover, a study reported that a postoperative intact ratio ≥ 39.2% in patients who underwent ARO was associated with reduced joint space narrowing [31]. These findings collectively support the notion that the intact ratio is a critical determinant of postoperative survival following transtrochanteric osteotomy. Atsumi et al. [29] reported a 4-year follow-up study of 46 patients who underwent TRO, demonstrating a survival rate of 78% when collapse was used as the end point. Previous studies have reported cases in which the intact ratio was ≤ 34% [17,21,27]. However, all cases in the current study achieved a postoperative intact ratio of ≥ 34%, which may be attributed to our use of a CT-based navigation system.

*Clinical Course*

A THA is a widely used surgical treatment for ONFH [1]. However, concerns remain regarding complications such as aseptic loosening, high dislocation rates, and limited long-term durability, particularly in younger patients [5,7,32]. Therefore, bone-preserving procedures are often recommended in this population. Indeed, existing evidence suggests that CVO and TRO have

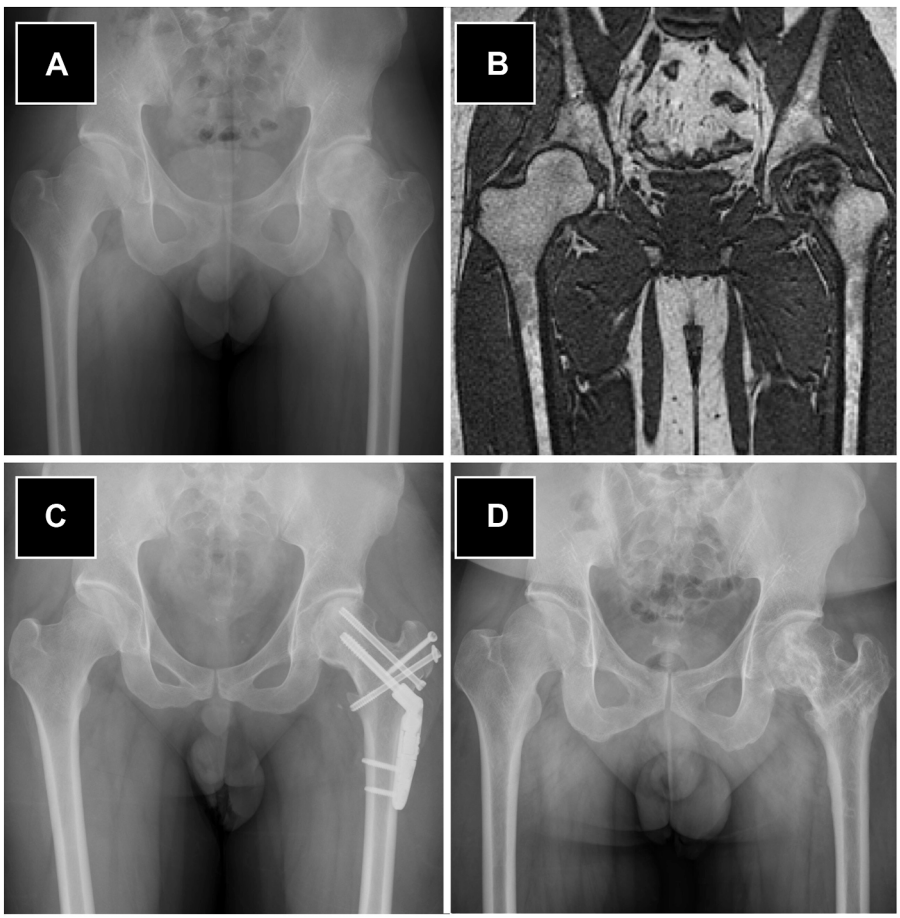



**Figure 4.** Case 2. A 26-year-old patient who had osteonecrosis of the femoral head associated with alcohol abuse. (A) Preoperative hip radiography. (B) Preoperative hip magnetic resonance imaging. (C) Postoperative hip radiography. (D) Hip radiography 9 years after surgery.

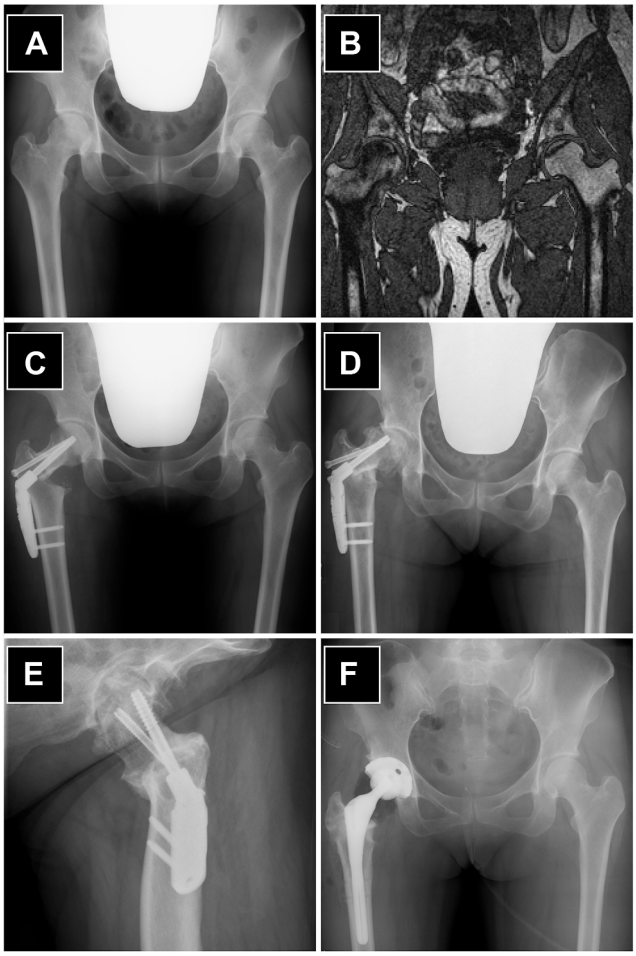



**Figure 5.** Case 3. A 37-year-old patient who had osteonecrosis of the femoral head associated with corticosteroid therapy. (A) Preoperative hip radiography. (B) Preoperative hip magnetic resonance imaging. (C) Postoperative hip radiography. (D) Antero-posterior hip radiography 3 years after surgery. (E) Lateral hip radiography 3 years after surgery. (F) Conversion to total hip arthroplasty.

achieved more favorable outcomes than core decompression, pedicle bone grafting, or fibular bone grafting [7]. Several studies have investigated the survival rates associated with transtrochanteric osteotomy. Morita et al. [17] reported 109 cases of TRO, excluding two early conversions to THA. Among the remaining cases, two patients (1.8%) developed deep infections, and six (6%) experienced failure at the osteotomy site. Using Cox regression analysis, they identified an Association Research Circulation Osseous stage >3A [33] and age > 40 years as significant risk factors for radiological failure, including progression to collapse. Conversely, another study analyzing survival in 65 patients (71 hips) who underwent ARO with an average follow-up of 11 years found that age was not associated with postoperative collapse [34]. In the present study, one patient (6%) developed a deep infection, and two patients (13%) experienced failure at the osteotomy site. Regarding patient background, the THA group was older and had a higher TAD than the non-THA group. A previous study reported that a higher TAD is associated with postoperative complications in trochanteric fracture surgery [35]. These findings suggest that, in the context of transtrochanteric osteotomy, an increased TAD may also be a contributing factor to osteotomy site failure.

### *Computer-Assisted Surgery for Hip Disease*

The current study demonstrated that computer-assisted transtrochanteric osteotomy was successfully performed, achieving a postoperative intact ratio of $\geq$ 34% in all cases. Computer-assisted surgery (CAS) represents a significant technological advancement in orthopaedics. A substantial number of studies have demonstrated the efficacy of computer-assisted THA for hip disorders. These favorable outcomes are not exclusive to hip osteoarthritis; they have also been demonstrated in THA for patients who have ONFH [3]. However, only a few studies have investigated the outcomes of computer-assisted transtrochanteric osteotomy [24,26]. Of these studies, one investigated the bone fragment rotational angle and movement error between preoperative three-dimensional planning and postoperative CT in eight patients (eight hips) who underwent TRO and CVO for ONFH, reporting a rotational angle error within five degrees and a movement error within four mm [26]. Another one investigated the short-term outcomes of a spherical varus rotational osteotomy performed on eight patients (nine hips) using a CT-based navigation system, with an average follow-up period of 21 months [24]. Meanwhile, the current study investigated the mid-term radiological outcomes of 16 patients (16 hips) who underwent TRO and CVO using a CT-based navigation system, with an average follow-up period of 9 years.

### *Potential Limitations*

This study has several potential limitations. The sample size was relatively small compared to previous studies [17,21,30], which may have limited the ability to detect significant parameter differences between the two groups. In addition, there was a difference in age between the groups, resulting in nonequivalent patient backgrounds. In addition, this study did not compare procedures performed with and without CT-based navigation. This limitation is primarily due to the small number of patients eligible for transtrochanteric osteotomy, making it challenging to collect a matched cohort under standardized conditions. However,

**Table 4**
Previous Reports on Survival Rates and Intact Ratio.

| Authors (Ref.) | Follow-Up Periods (Years) | Number of Hips (n) | Procedure | Navigation System | Survival Rates (Collapse) | Survival Rates (THA) | Intact Ratio (Range) % |
|---|---|---|---|---|---|---|---|
| Morita et al. [17] | 18 | 111 | TRO | – | 78 | 71 | 55.0 (0 to 90.0) |
| Miyanishi et al. [21] | 14 | 125 | TRO | – | 78 | – | 44.0 (0 to 100) |
| Sonoda et al. [27] | 12 | 28 | TRO | – | 93 | 79 | 48.6 (15.0 to 88.5) |
| Lee et al. [28] | 7 | 156 | CVO/TRO | – | 79 | 86 | – |
| Atsumi et al. [29] | 5 | 46 | TRO | – | 78 | 91 | – |
| Hamanishi et al. [30] | 6 | 53 | CVO | – | 96 | 98 | 51.7 (36.5 to 67.2) |
| Watnabe et al. [24] | 2 | 9 | SVRO | + | 100 | 100 | 74.0 (57 to 77) |
| This study | 9 | 16 | CVO/TRO | + | 88 | 75 | 48.6 (36.0 to 74.3) |

THA, total hip arthroplasty; TRO, transtrochanteric rotational osteotomy; CVO, curved varus osteotomy; SVRO, spherical varus rotational osteotomy.

previous studies on TRO and CVO without CAS have included cases with postoperative intact ratios ≤ 34%. In contrast, all cases in the present study achieved an intact ratio ≥34%, suggesting that using CAS may have contributed to reducing the number of outliers with suboptimal postoperative alignment. Furthermore, there are only a few reports on transtrochanteric osteotomy performed with CAS, and most focus on short-term outcomes. In contrast, our study includes 16 cases with a follow-up period of up to 9 years, providing valuable insight into mid-term outcomes. We plan to collaborate with other institutions to increase the number of cases and strengthen the evidence through further investigations.

*Future Directions*

As part of our future plans, we hope to continue performing femoral osteotomy using a CT-based navigation system to increase the number of patients. In addition, we hope to collaborate with other hospitals to establish a control group that did not undergo surgery using a CT-based navigation system for comparative analysis.

## Conclusions

Transtrochanteric osteotomy using a CT-based navigation system achieved a postoperative intact ratio of ≥ 34% and may have contributed to preventing collapse. However, certain challenges appear to persist at the osteotomy site. Further investigation may be necessary to reduce complications after transtrochanteric osteotomy.

## CRediT authorship contribution statement

**Ryo Higuchi:** Writing – original draft, Investigation. **Kazuma Takashima:** Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Keisuke Uemura:** Writing – review & editing. **Seiji Okada:** Supervision. **Nobuhiko Sugano:** Supervision. **Hidetoshi Hamada:** Writing – review & editing, Supervision.

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