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Original Article

Treatment of collapsed traumatic osteonecrosis of the femoral head in adolescents using non-vascularized bone grafting via the trapdoor procedure

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Abstract: Background: Traumatic osteonecrosis of the femoral head (TONFH) is the most common and severe complication after femoral neck fracture in teenagers. Despite the rapid progression of hip destruction once femoral head collapse ensues, no clear treatment exists for this condition. The purpose of this study was to evaluate the outcome of adolescents with collapsed-stage TONFH who were treated by non-vascularized bone grafting through a window at the collapsed articular cartilage, which is known as the "trapdoor procedure". Methods: We retrospectively reviewed the medical records of teenagers with TONFH who were treated with the trapdoor procedure or conservative methods between 2003 and 2013. The medical records were extracted from a database. The Harris score was obtained as a clinical evaluation, with less than 80 points defined as clinical failure. The risk of clinical failure, progression of femoral head collapse (PFHC) and secondary hip degeneration (SHD) were compared between the surgical and conservative groups using a Kaplan-Meier analysis, and multivariate Cox regression analysis was used to eliminate the effect of demographic and radiographic characteristics. Results: Seventeen teenagers treated with the trapdoor procedure and 20 teenagers treated with conservative methods were included in the study, totaling 27 boys and 10 girls. The mean age was 15.1 years (range: 13 to 18). The mean follow-up period was 44.5 months (range: 24 to 68). The rates of clinical failure, PFHC and SHD were 23.5%, 17.6% and 35.3%, respectively, in the operative group, whereas those in the conservatively treated group were 65.0%, 65.0%, and 60.0%, respectively (*log rank test: $P_{clinical\ failure} = 0.006$, $P_{PFHC} = 0.004$ and $P_{SHD} = 0.053$*). Multivariate Cox regression analysis showed that the trapdoor procedure significantly lowered the risk of clinical failure (*HR = 0.18; 95% CI: 0.05 to 0.72; P = 0.015*) and PFHC (*HR = 0.09; 95% CI: 0.02 to 0.47; P = 0.004*) compared with the conservative methods. Conclusions: The trapdoor procedure appeared effective in avoiding or forestalling the rapid progression of TONFH in teenagers and provided clinical and radiographic improvement compared with those who were treated conservatively in a short-term follow-up.

Keywords: Traumatic osteonecrosis of the femoral head, adolescent, femoral head collapse, non-vascularized bone grafting, trapdoor procedure.

Introduction

Femoral neck fracture (FNF), a rare but severe injury in teenagers, is generally induced by high-energy trauma [1-7]. A meta-analysis including 30 studies on pediatric FNF demonstrated that traumatic osteonecrosis of the femoral head (TONFH) was the most common and severe complication after pediatric FNF, with a mean incidence of 23% (203 of 893 hips) [8]. TONFH in teenagers was characterized by an extremely poor natural history with rapidly progressive hip destruction, including femoral head collapse and secondary hip degeneration (SHD) [1-3, 5, 7, 9, 10].

Femoral head collapse associated with TONFH in teenagers is often progressive, irreparable, and carries a high incidence [5, 7]. Without timely intervention, femoral head collapse is likely to lead to secondary hip degeneration and disability quite rapidly [2, 3, 10]. Vascularized bone grafting [11] and several types of femoral osteotomies [12-14] were introduced

for teenagers with TONFH at a collapsed stage. However, these operations were characterized by complex techniques that required a prolonged operative time and unclear complications at a young age, which limited their use. Although arthroplasty is an optional choice for adults with a collapsed femoral head, caution should be exercised regarding its use in teenagers due to its uncertain long-term survival rate [15, 16].

Non-vascularized bone grafting through a window at the collapsed articular cartilage, known as the "trapdoor procedure", is one widely accepted operation for osteonecrosis of the femoral head at the early post-collapse stage for adults that preserves the femoral head and is associated with a standardized surgical technique, low incidence of complications and short operative duration [17-22]. Similar satisfactory outcomes were reported in several cases of such procedures in teenagers [17]. However, considering the superior potential for bone remodeling in young patients, the successful experience of this surgery in adults was expected to be mirrored in teenagers. The aim of the present study was to evaluate the outcome of the trapdoor procedure in adolescents with TONFH who had progressed to a collapsed stage.

Materials and methods

Patients

After the approval of the Ethics Committee, a retrospective case-control study was conducted based on a database of a province-level medical center between January 2003 and January 2013. The diagnosis was confirmed by the clinical history, physical examination a nd radiological evaluation. The diagnostic radiological evaluation based on Steinberg staging system [23]. Inclusion criteria were: (1) Patients aged 13 to 18 years old with confirmed diagnosis of TONFH; (2) Patients at an early collapsed stage (Steinberg stage III, IV). (3) Patients treated with the trapdoor procedure or conservative methods. Exclusion criteria were: (1) Patients with nonunion, delayed union or hip infection after FNF. (2) Patients without a minimum of 2 years' follow-up and complete radiographic data. (3) Patients had received other treatment targeted TONFH previously.

Initially, 47 teenage patients with TONFH at an early collapsed stage were treated at our institution within the specified period. Of these patients, 7 patients without a minimum of 2 years' follow-up or without complete radiographic data were excluded. We also excluded 2 patients who had nonunion and 1 patient who had deep hip infection after FNF. Finally, thirty-seven teenagers with TONFH who underwent Trapdoor procedure (17 patients) or conservative treatment (20 patients) were included (Supplementary Table 1).

Therapeutic methods

The operative technique was consistent with the descriptions by Mont et al. [18] and Ko et al. [17]. All surgeries were performed by the same surgeon. The patients were placed in the lateral decubitus position with an incision ranging from 10 to 15 cm of anterolateral approach. Blunt dissection was performed between the tensor fascia lata and the sartorius. Subsequently, the capsule of the hip was exposed after laterally retracting the anterior two-thirds of the gluteus medius. The anterior joint capsule was split through a T-shaped incision that was sufficient for tracking the dislocation of the femoral head.

The femoral head should be dislocated anterolaterally using 2 to 4 Hohmann elevators so that the collapsed surface of the femoral head may be exposed clearly. The size of the trapdoor through the articular cartilage was normally less than 30% of the surface of the femoral head. The necrotic bone was carefully debrided by curettage and power burrs. All visible necrotic bone was cleared until a bleeding surface was evident at the base of the cavity. A bone graft of corticocancellous bone in an inverted trapezoidal shape was harvested from the iliac crest. The corticocancellous graft was applied to the cavity with surrounding firmly packed autologous or allogeneic cancellous bone. The hip was gently reduced with the trapdoor fixed by absorbable sutures.

The non-operative treatments for our patients included physical therapy and restricted weight bearing using paired crutches for more than one year. We did not use any type of anti-osteoporosis medication because of uncertain complications in adolescents. Symptomatic treatments consisted of nonsteroidal anti-

Table 1. Demographic and radiographic characteristics of teenagers with TONFH

Parameters	Total	Conservative	Operative	*p*-value
Age (mean, diagnosis of TONFH, years)	15.1	14.9	15.2	0.71[a]
Mean duration of follow-up (mean, months)	44.5	43.6	45.4	0.54[a]
Gender (n, %)				0.29[b]
Boy	27 (73.0)	16 (80.0)	11 (64.7)	
Girl	10 (27.0)	4 (20.0)	6 (35.3)	
Side (n, %)				0.29[c]
Left	23 (62.2)	14 (70.0)	9 (52.9)	
Right	14 (37.8)	6 (30.0)	8 (47.1)	
Pre-treatment Harris score (mean)	72.1	73.7	70.2	0.13[a]
JIC classification (n, %)				0.77[c]
C1	14 (37.8)	8 (40.0)	6 (35.3)	
C2	23 (62.2)	12 (60.0)	11 (64.7)	
Pre-treatment Steinburg stage (n, %)				0.21[b]
III	5 (13.5)	4 (20.0)	1 (5.9)	
IV	32 (86.5)	16 (80.0)	16 (94.1)	

TONFH, Traumatic Osteonecrosis of Femoral Head, n, number, a, Mann-Whitney test, b, Fisher exact test, c, chi square test.

inflammatory drugs (NSAIDs) or analgesics, as needed.

All patients underwent a program of rehabilitation and physiotherapy after surgery. Generally, prolonged non-weight bearing was maintained with the use of paired crutches in the first six months; during the second six months, partial weight bearing using one crutch was recommended. Then, full weight bearing was applied when the patient was free of hip pain.

Patient assessment and follow-up

The clinical and radiographic data were assessed before treatment and serially every 2 to 4 months within the first 2 years after treatment and every 6 months in the third year and subsequently. All assessments were conducted by three authors (Ziqi Li, Peng Cheng and Da Chen).

Before treatment, the clinical assessment was conducted using the Harris score. Excellent, good, fair and poor results were determined when the score was greater than 90, 80-89, 70-79 and below 70, respectively. Radiographic evaluations were performed according to the Steinberg staging system [23] and Japanese Investigation Committee (JIC) classification system [24] using radiographs in the anteroposterior and frog-leg lateral views. Although magnetic resonance imaging is a more sensitive method for measuring the necrotic lesion, the internal metal fixation interfered with the image. The Japanese Investigation Committee found a correlation between a four-group classification system (Types A, B, C1 and C2) and the progression of femoral head collapse. In this study, all the included cases were defined as Type C, in which the necrotic lesions occupy more than the medial two-thirds of the weight-bearing portion. More specifically, Type C2 lesion extending laterally to the acetabular edge showed a higher risk of collapse than Type C1 lesion. The osteonecrosis of the femoral head (ONFH) stage was determined according to the Steinberg staging system criteria: stage I was defined as a "normal radiograph with an abnormal bone scan and/or magnetic resonance images", stage II was defined as "cystic and sclerotic changes in the femoral head", and stage III was defined as "subchondral collapse without flattening". ONFH was considered to have progressed to an advanced stage with collapse of the femoral head (stage IV: A: collapse < 2 mm, B: collapse ranging from 2 to 4 mm, C: collapse > 4 mm) and the appearance of degenerative changes (stages V and VI).

During follow up, clinical failure was defined as a Harris score decreased to less than 80. Progression of femoral head collapse (PFHC) was defined as segmental collapse that had increased to more than 2 mm. The degree of

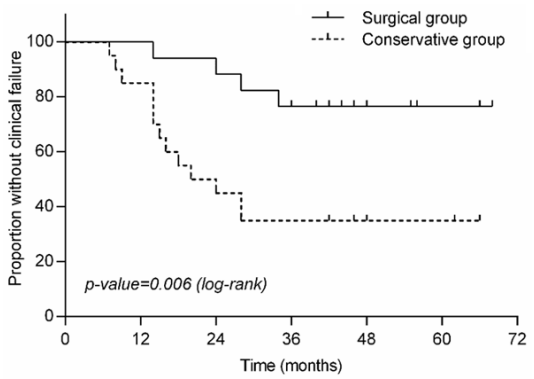

Figure 1. Kaplan-Meier estimates of the proportion of teenagers with collapsed-stage TONFH and who were free of clinical failure according to different treatments. With an endpoint of "Harris score less than 80", the overall survival rates were 35.0% (*95% CI: 23.24 to 44.45*) and 76.5% (*95% CI: 49.05 to 66.71*) in the conservatively treated and operative groups, respectively.

femoral head collapse was measured as the distance from a perfect concentric circle around the femoral head to the area of collapse in millimeters in both the anteroposterior and frog-leg lateral radiographs and by using the method of Novais et al. [25]. When the disease progressed to stage V or stage VI, secondary hip degeneration was defined.

Statistics analysis

Differences in categorical variables between two groups were calculated using the Mann-Whitney test, Fisher's exact test, or the Chi-square test. Kaplan-Meier survival analyses were used to compare the overall rates of clinical failure, PFHC and SHD. *P* value < 0.05 was used to indicate statistical significance. Cox proportional hazards models were used to test the following variables: age, gender, laterality, pretreatment Harris score, JIC classification, Steinberg stage and treatment. The variables with $P < 0.05$ were considered significant. The statistical analyses were performed using SPSS software v.19.0 (SPSS Inc., Chicago, Illinois, U.S.A.).

Results

Demographic and radiographic characteristics

In all, 27 boys and 10 girls were included in the final analysis, of which 17 were treated operatively and 20 were treated conservatively. All the included patients were followed up for more than 2 years, with a mean follow-up duration of 44.5 months (range: 24 to 68). All the patients had unilateral involvement: 23 on the left side and 14 on the right. Before treatment, no significant differences ($p < 0.05$) were observed in the demographic data, radiographic characteristics and clinical evaluations between the two groups (**Table 1**).

Clinical and radiographic assessments

The mean Harris score of the operative group was 70.2 points (range: 56 to 80) before treatment, which improved to 84.8 points (range: 66 to 94) at the last follow-up. The mean Harris score of the conservatively treated group was 73.7 points (range: 64 to 84) before treatment, which decreased to 71.4 points (range: 48 to 90) at the last follow-up. No intraoperative complications were observed. After treatment, one patient developed a superficial incision infection, which did not appear to affect the clinical and radiographic evaluations. Progression of femoral head collapse (PFHC) were found in 3 of 17 patients in surgical group and 13 of 20 in conservative group. Meanwhile, secondary hip degeneration (SHD) were found in 6 of 17 patients in surgical group and 12 of 20 in conservative group.

Kaplan-Meier survival analysis

Kaplan-Meier survival analyses of clinical failure (**Figure 1**), PFHC (**Figure 2**) and SHD (**Figure 3**) were performed between the operative and conservatively treated groups. The overall rates of clinical failure and PFHC were 23.5% and 17.6%, respectively, in the operative group, whereas those in the conservative group were 65.0% and 65.0%, respectively (*log rank test:* $P_{clinical\ failure} = 0.006$ *and* $P_{PFHC} = 0.004$). With an endpoint of SHD, the incidence of SHD in the first two years after treatment in the operative group was 17.6% (3 of 17). This rate was lower than that of the conservative group, which was 60.0% (12 of 20). The overall rate of SHD was 35.3% in the operative group and was 60.0% in the conservatively treated group ($P_{SHD} = 0.053$).

Multivariate cox regression analysis

Furthermore, we performed multivariate Cox regression analysis (**Table 2**) and found that the trapdoor procedure was associated with

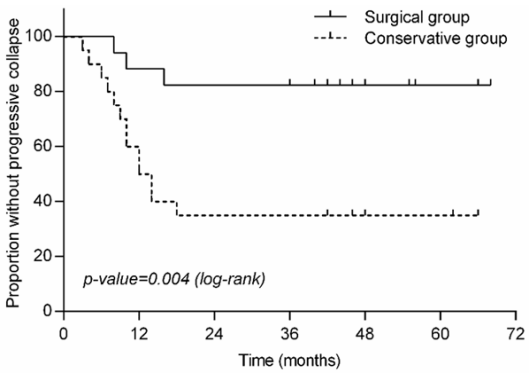

Figure 2. The Kaplan-Meier estimates of the proportion of teenagers with collapsed-stage TONFH and who were free of progression of femoral head collapse according to different treatments. The overall survival rates were 35.0% (*95% CI: 17.61 to 41.29*) and 82.4% (*95% CI: 47.71 to 68.29*) in the conservatively treated and operative groups, respectively.

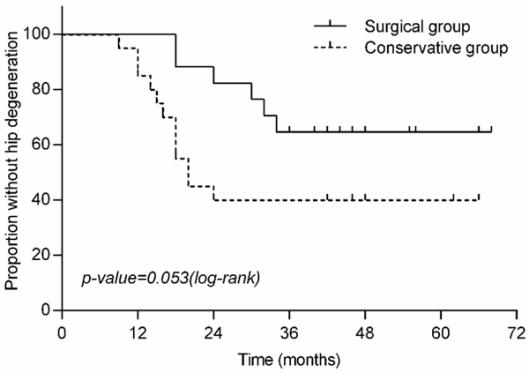

Figure 3. The Kaplan-Meier estimates of the proportion of teenagers with collapsed-stage TONFH and who were free of secondary hip degeneration according to different treatments. The overall survival rates were 40.0% (*95% CI: 25.45 to 46.95*) and 64.7% (*95% CI: 43.46 to 62.89*) in the conservatively treated and operative groups, respectively.

lower risks of clinical failure (*P = 0.015*) and PFHC (*P = 0.004*) than the conservative methods. Moreover, JIC classification was a strong predictor of clinical failure and PFHC. Type C1 was associated with significantly decreased risks of clinical failure and PFHC compared to Type C2, despite the use of treatments ($P_{clinical\ failure} = 0.006$ *and* $P_{PFHC} = 0.004$).

Discussion

Femoral head-preserving treatment of teenagers with collapsed-stage TONFH remains a challenge. Unfortunately, many teenagers with TONFH readily progress to a collapsed stage before treatment due to the extremely high risk of femoral head collapse [1-3, 5, 7, 9, 10]. Progressive femoral head collapse in teenagers with TONFH results in rapid secondary hip degeneration and disability under untreated conditions. Dhar et al. [10] reported that 8 of 9 pediatric patients with TONFH were considered to have degenerative arthritis by radiography and poor outcomes after a mean follow-up of 3 years. Inan et al. [3] observed that 6 patients sustained hip degeneration among the 11 total children and teenagers who had TONFH during a mean follow-up of approximately 3 years. Thus, timely intervention to prevent the progression of femoral head collapse is critical to improve the clinical outcome and reduce the subsequent risk of hip degeneration [26].

The trapdoor procedure has been used to avoid or delay the progression of osteonecrosis of the femoral head at an early collapsed stage, although mainly in adults [18-22, 27]. The most important finding in the current study was that, in teenagers with collapsed-stage TONFH, the trapdoor procedure provided a lower risk of femoral head collapse progression, improved clinical function, and prevented rapid hip degeneration as well during a short-term follow-up.

Revascularization and osteoclast-induced bone resorption are eventual attempts to repair the necrotic bone. However, this process typically weakens the bone structure in the necrotic lesion and results in femoral head collapse under the influence of hip joint-loading before the new bone has sufficiently formed to maintain structural integrity. To strengthen the internal structure of the femoral head and prevent the progression of femoral head collapse, non-vascularized bone grafting employing cortical bone and cancellous bone grafting with compaction following debridement of the necrotic bone has been used [19]. Three different methods of bone grafting are described: the Phemister technique via a cylindrical core from the femoral head and neck, the lightbulb technique using the femoral neck as a conduit for the harvested bone graft, and the trapdoor technique using a direct window opening in the collapsed cartilage surface [19].

In the current study, the reasons for performing bone grafting via the trapdoor technique in teenagers with collapsed-stage TONFH includ-

Table 2. Multivariate Cox Proportional Hazard Model of Survival related to CF and PFHC

	Overall Survival of CF			Overall Survival of PFHC		
	HR (95% CI)	β-value	*p*-value	HR (95% CI)	β-value	*p*-value
Age	1.10 (0.76 to 1.61)	0.10	0.62	1.09 (0.75 to 1.59)	0.09	0.65
Gender (Boy vs Girl*)	1.73 (0.29 to 10.46)	0.55	0.55	0.77 (0.15 to 3.97)	-0.27	0.75
Side (Left vs Right*)	0.79 (0.21 to 3.05)	-0.24	0.73	0.49 (0.11 to 2.07)	-0.72	0.33
Pre-treatment Harris score (Good, fair and poor*)	1.22 (0.54 to 2.79)	0.20	0.64	1.37 (0.60 to 3.10)	0.31	0.46
Pre-treatment stage (III* vs IV)	0.77 (0.14 to 4.16)	-0.26	0.77	0.99 (0.23 to 4.24)	-0.01	0.99
Treatments (Surgical vs Conservative group*)	0.18 (0.05 to 0.72)	-1.70	0.015	0.09 (0.02 to 0.47)	-2.44	0.004
JIC classification (C1* vs C2)	9.42 (1.90 to 46.70)	2.24	0.006	11.79 (2.21 to 63.04)	2.47	0.004

*, Reference group; CF, clinical failure; PFHC, progression of femoral head collapse; vs, versus; HR, hazard ratio.

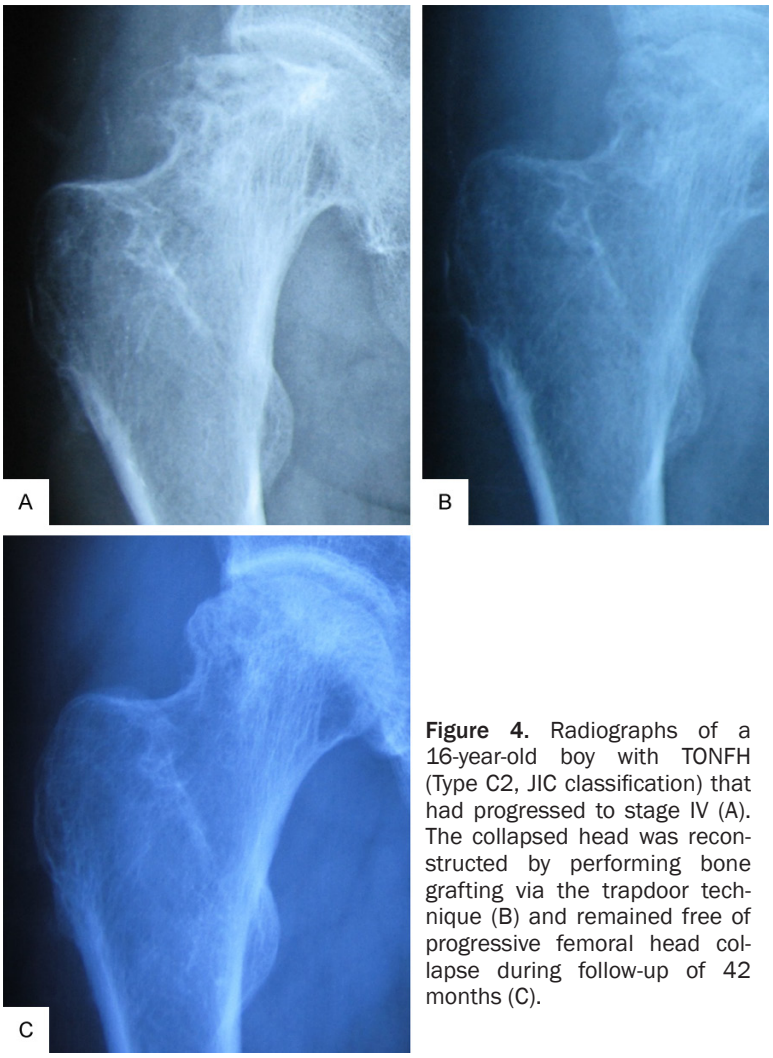

Figure 4. Radiographs of a 16-year-old boy with TONFH (Type C2, JIC classification) that had progressed to stage IV (A). The collapsed head was reconstructed by performing bone grafting via the trapdoor technique (B) and remained free of progressive femoral head collapse during follow-up of 42 months (C).

were not treated by surgical intervention as was their clinical failure rate, which was as encouraging as the rates in the published literature. Mont et al. [18] followed 30 hips treated with the trapdoor technique for at least 2 years, and improved or unchanged radiographs were found in 20 of 24 early collapsed-stage hips. Using a similar operation in teenagers with segmental collapse, Ko et al. [17] reported a similarly good outcome in a study of 13 hips with osteonecrosis. According to their results, 9 hips were classified as good, 3 as fair and 1 as poor. Using the trapdoor technique, Meyers et al. [27] evaluated the use of bone grafting in 21 patients at a post-collapse stage. Fifteen of them had successful outcomes after a minimum follow-up of 18 months. Decidedly, satisfactory clinical and radiographic improvement will be obtained when collapsed femoral head was reconstructed by performing bone grafting via the trapdoor technique (**Figure 4**).

ed: (1) a window opened in the collapsed cartilage surface provided a more direct view for completely removing the necrotic lesion and (2) bone grafting via the trapdoor technique provided direct and precise support under the collapsed lesion. Therefore, the risk of PFHC in teenagers treated by the trapdoor procedure was clearly lower than that of patients who

Notably, the frequency of secondary hip degeneration is likely to increase over a longer follow-up in the surgical group. The bone grafting of the trapdoor method presumably disrupts the integrity of the cartilaginous surface, which would then increase the risk of hip degeneration at a prolonged follow-up [19]. However, selecting an alternative to the trapdoor tech-

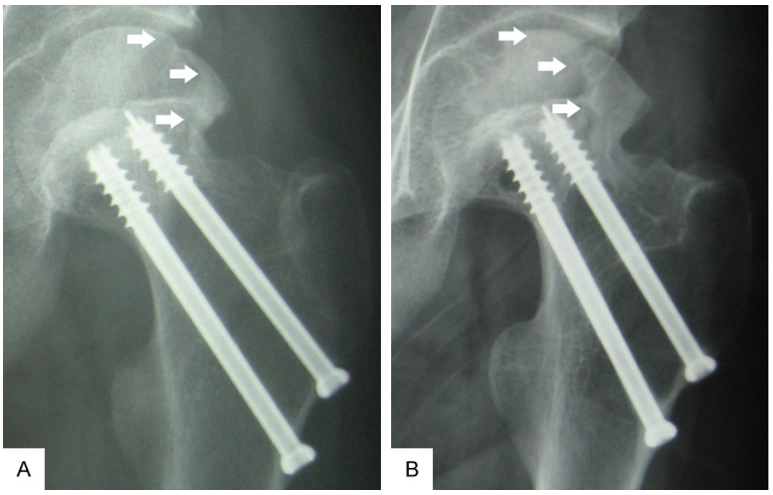

Figure 5. Radiographs of a 15-year-old boy with TONFH (Type C1, JIC classification) who was treated conservatively (A). The femoral head lesion (white arrows) decreased significantly after 12 months, meanwhile the femoral head was free of progressive collapse during follow-up (B).

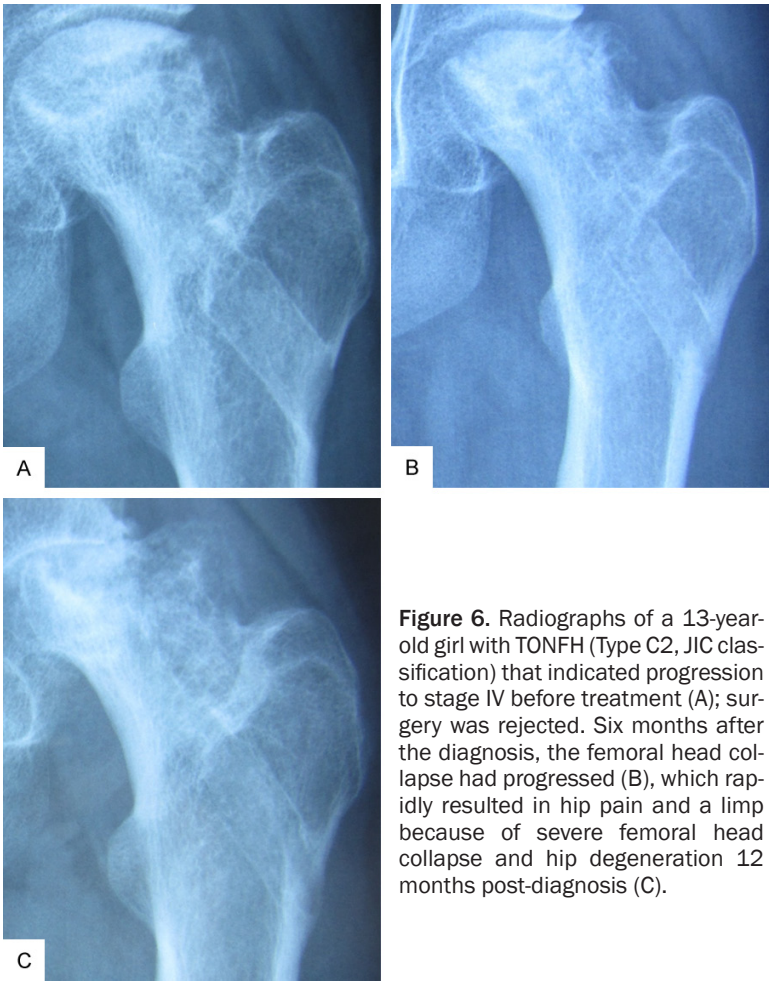

Figure 6. Radiographs of a 13-year-old girl with TONFH (Type C2, JIC classification) that indicated progression to stage IV before treatment (A); surgery was rejected. Six months after the diagnosis, the femoral head collapse had progressed (B), which rapidly resulted in hip pain and a limp because of severe femoral head collapse and hip degeneration 12 months post-diagnosis (C).

nique for teenagers when femoral head collapse has been established is difficult considering that the Phemister and lightbulb techniques showed a worse prognosis in patients at a collapsed stage. Lieberman et al. [28] reviewed 54 studies and showed that the risk of radiographic progression was 50% in post-collapse-stage patients after operations that preserved the femoral head. Of those who underwent the Phemister and lightbulb techniques, 44% were converted to THA (five studies: 74 of 168 hips) and 73% showed radiographic progression (three studies: 30 of 41 hips). Using the Phemister technique combined with core decompression (CD), after a follow-up that ranged from 2 to 14 years, Steinberg et al. [29] found that THA conversions ensued in 32% (63 of 198 hips) of patients at a pre-collapse stage and 46% (48 of 105 hips) of patients at a collapsed stage. Similarly, Wang et al. [22], who used the lightbulb technique, reported a 34.3% clinical failure rate among patients in the pre-collapse stages and a 49.3% clinical failure rate among patients in the post-collapse stages. Thus, we believed that the trapdoor procedure was more suitable for collapsed-stage patients.

All the teenagers who were diagnosed with collapsed-stage TONFH in this study were advised to undergo surgical treatment. Those who declined were instead treated by conservative methods and were included in the control group. In the current study, patients rejected surgery mostly for the reasons of study time demands, financial difficulties or concerns about surgery. A pathological study on patients younger than 13 years with femoral neck fractures

found that the necrotic area in the femoral head showed satisfactory restoration without any femoral head collapse after a non-weight bearing period of more than 1 year [30]. However, most teenagers in our study who were treated by non-weight bearing methods did not replicate their good outcomes. In the conservatively treated group, only patients with Type C1 lesions avoided PFHC after non-weight bearing and interestingly, with a rapid decrease of lesion size (**Figure 5**). In contrast, Type C2 patients showed a strong correlation with disease progression (**Figure 6**). Therefore, the JIC classification, notwithstanding its use as a predictor of prognosis with confirmed reliability in adults [24, 31], also correlated with a variable natural history in teenagers with TONFH.

Despite our encouraging results, the current study had several limitations. First, given the short duration of follow-up, the long-term outcomes of teenagers with TONFH remain unclear. Nevertheless, our results demonstrated that the trapdoor procedure, as a timely surgical intervention, halted a rapid progression of femoral head collapse and improved clinical scores, both of which are the most important short-term goal for these patients. Although the frequency of secondary hip degeneration is likely to increase over a longer follow-up, the timely surgical intervention contributed towards reversing the propensity for rapid hip destruction. Second, as a retrospective study with a small number of patients, it is difficult to design a randomized controlled trial that eliminates patient selection bias. Given the rare incidence of pediatric FNF, we have included more cases than any other published report on TONFH in children and teenagers. Third, we evaluated only the outcome of one surgical method at a single center. Evidence is insufficient to identify an optimal treatment method for teenagers with TONFH. Therefore, our results should be reconfirmed by a larger, multicenter, prospective randomized controlled trial with a prolonged follow-up.

Conclusion

In conclusion, teenagers with TONFH treated with non-vascularized bone grafting using the trapdoor technique showed a trend toward clinical and radiographic improvement compared with those treated by conservative methods in a short-term follow-up. Because no definitive treatment exists for teenagers with TONFH, this study provides value in proposing a potential treatment option with an initially good outcome.

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Disclosure of conflict of interest

None.

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References

[1] Spence D, DiMauro JP, Miller PE, Glotzbecker MP, Hedequist DJ and Shore BJ. Osteonecrosis after femoral neck fractures in children and adolescents: analysis of risk factors. J Pediatr Orthop 2016; 36: 111-116.

[2] Bali K, Sudesh P, Patel S, Kumar V, Saini U and Dhillon MS. Pediatric femoral neck fractures: our 10 years of experience. Clin Orthop Surg 2011; 3: 302-308.

[3] Inan U, Kose N and Omeroglu H. Pediatric femur neck fractures: a retrospective analysis of 39 hips. J Child Orthop 2009; 3: 259-264.

[4] Togrul E, Bayram H, Gulsen M, Kalaci A and Ozbarlas S. Fractures of the femoral neck in children: long-term follow-up in 62 hip fractures. Injury 2005; 36: 123-130.

[5] Canale ST. Fractures of the hip in children and adolescents. Orthop Clin North Am 1990; 21: 341-352.

[6] Pforringer W and Rosemeyer B. Fractures of the hip in children and adolescents. Acta Orthop Scand 1980; 51: 91-108.

[7] Ratliff AH. Fractures of the neck of the femur in children. J Bone Joint Surg Br 1962; 44-B: 528-542.

[8] Yeranosian M, Horneff JG, Baldwin K and Hosalkar HS. Factors affecting the outcome of fractures of the femoral neck in children and adolescents: a systematic review. Bone Joint J 2013; 95-B: 135-142.

[9] Canale ST and Bourland WL. Fracture of the neck and intertrochanteric region of the femur in children. J Bone Joint Surg Am 1977; 59: 431-443.
[10] Dhar SA, Ali MF, Dar TA, Sultan A, Butt MF, Kawoosa AA and Mir MR. Delayed fixation of the transcervical fracture of the neck of the femur in the pediatric population: results and complications. J Child Orthop 2009; 3: 473-477.
[11] Zhang CQ, Sun Y, Chen SB, Jin DX, Sheng JG, Cheng XG, Xu J and Zeng BF. Free vascularised fibular graft for post-traumatic osteonecrosis of the femoral head in teenage patients. J Bone Joint Surg Br 2011; 93: 1314-1319.
[12] Bartonicek J, Vavra J, Bartoska R and Havranek P. Operative treatment of avascular necrosis of the femoral head after proximal femur fractures in adolescents. Int Orthop 2012; 36: 149-157.
[13] Beris AE, Payatakes AH, Kostopoulos VK, Korompilias AV, Mavrodontidis AN, Vekris MD, Kontogeorgakos VA and Soucacos PN. Nonunion of femoral neck fractures with osteonecrosis of the femoral head: treatment with combined free vascularized fibular grafting and subtrochanteric valgus osteotomy. Orthop Clin North Am 2004; 35: 335-343, ix.
[14] Notzli HP, Chou LB and Ganz R. Open-reduction and intertrochanteric osteotomy for osteonecrosis and extrusion of the femoral head in adolescents. J Pediatr Orthop 1995; 15: 16-20.
[15] Mont MA, Seyler TM, Plate JF, Delanois RE and Parvizi J. Uncemented total hip arthroplasty in young adults with osteonecrosis of the femoral head: a comparative study. J Bone Joint Surg Am 2006; 88 Suppl 3: 104-109.
[16] Hannouche D, Devriese F, Delambre J, Zadegan F, Tourabaly I, Sedel L, Chevret S and Nizard R. Ceramic-on-ceramic THA implants in patients younger than 20 years. Clin Orthop Relat Res 2016; 474: 520-527.
[17] Ko JY, Meyers MH and Wenger DR. "Trapdoor" procedure for osteonecrosis with segmental collapse of the femoral head in teenagers. J Pediatr Orthop 1995; 15: 7-15.
[18] Mont MA, Einhorn TA, Sponseller PD and Hungerford DS. The trapdoor procedure using autogenous cortical and cancellous bone grafts for osteonecrosis of the femoral head. J Bone Joint Surg Br 1998; 80: 56-62.
[19] Pierce TP, Elmallah RK, Jauregui JJ, Poola S, Mont MA and Delanois RE. A current review of non-vascularized bone grafting in osteonecrosis of the femoral head. Curr Rev Musculoskelet Med 2015; 8: 240-245.
[20] Rijnen WH, Gardeniers JW, Buma P, Yamano K, Slooff TJ and Schreurs BW. Treatment of femoral head osteonecrosis using bone impaction grafting. Clin Orthop Relat Res 2003; 74-83.
[21] Tetik C, Basar H, Bezer M, Erol B, Agir I and Esemenli T. Comparison of early results of vascularized and non-vascularized fibular grafting in the treatment of osteonecrosis of the femoral head. Acta Orthop Traumatol Turc 2011; 45: 326-334.
[22] Wang BL, Sun W, Shi ZC, Zhang NF, Yue DB, Guo WS, Shi SH and Li ZR. Treatment of nontraumatic osteonecrosis of the femoral head using bone impaction grafting through a femoral neck window. Int Orthop 2010; 34: 635-639.
[23] Steinberg ME and Steinberg DR. Classification systems for osteonecrosis: an overview. Orthop Clin North Am 2004; 35: 273-283, vii-viii.
[24] Sugano N, Atsumi T, Ohzono K, Kubo T, Hotokebuchi T and Takaoka K. The 2001 revised criteria for diagnosis, classification, and staging of idiopathic osteonecrosis of the femoral head. J Orthop Sci 2002; 7: 601-605.
[25] Novais EN, Sankar WN, Wells L, Carry PM and Kim YJ. Preliminary results of multiple epiphyseal drilling and autologous bone marrow implantation for osteonecrosis of the femoral head secondary to sickle cell disease in children. J Pediatr Orthop 2015; 35: 810-815.
[26] Kim HKW, Larson AN, Fletcher ND, Winick N and Kim YJ. Childhood femoral head osteonecrosis. Clinic Rev Bone Miner Metab 2011; 9: 2-12.
[27] Meyers MH, Jones RE, Bucholz RW and Wenger DR. Fresh autogenous grafts and osteochondral allografts for the treatment of segmental collapse in osteonecrosis of the hip. Clin Orthop Relat Res 1983; 107-112.
[28] Lieberman JR, Engstrom SM, Meneghini RM and SooHoo NF. Which factors influence preservation of the osteonecrotic femoral head? Clin Orthop Relat Res 2012; 470: 525-534.
[29] Steinberg ME, Larcom PG, Strafford B, Hosick WB, Corces A, Bands RE and Hartman KE. Core decompression with bone grafting for osteonecrosis of the femoral head. Clin Orthop Relat Res 2001; 71-78.
[30] Maeda S, Kita A, Fujii G, Funayama K, Yamada N and Kokubun S. Avascular necrosis associated with fractures of the femoral neck in children: histological evaluation of core biopsies of the femoral head. Injury 2003; 34: 283-286.
[31] Nakamura J, Kishida S, Harada Y, Iida S, Oinuma K, Yamamoto S, Nakajima T, Takazawa M, Shigemura T, Ohtori S, Sato Y and Takahashi K. Inter-observer and intra-observer reliabilities of the Japanese ministry of health, labor and welfare type classification system for osteonecrosis of the femoral head. Mod Rheumatol 2011; 21: 488-494.

Supplementary Table 1. Original data of demographic and radiographic characteristics

NO	Groups	Age	Gender	Side	Pre clinical assessment before treatment	Post clinical assessment	JIC classification	Stage	Clinical failure	Time to clinical failure	Progressive collapse	Time to PC	Hip degeneration	Time to hd	Follow up
1	Conservative	17	Boy	Right	84	75	C1	III	Yes	15	Yes	8	Yes	15	46
2	Conservative	13	Boy	Left	68	66	C2	IV	Yes	9	Yes	3	Yes	9	48
3	Conservative	13	Girl	Right	77	70	C2	III	Yes	28	Yes	6	NO	NA	46
4	Conservative	16	Boy	Left	78	65	C1	IV	Yes	14	Yes	14	Yes	18	46
5	Conservative	15	Boy	Left	75	84	C1	IV	No	NA	NO	NA	NO	NA	42
6	Conservative	15	Boy	Left	77	82	C1	IV	No	NA	NO	NA	NO	NA	66
7	Conservative	13	Girl	Right	75	90	C1	III	No	NA	NO	NA	NO	NA	48
8	Conservative	13	Boy	Right	84	90	C1	IV	No	NA	NO	NA	NO	NA	48
9	Conservative	15	Boy	Left	71	81	C1	IV	No	NA	NO	NA	NO	NA	42
10	Conservative	16	Boy	Left	68	86	C1	IV	No	NA	NO	NA	NO	NA	62
11	Conservative	13	Girl	Left	77	52	C2	IV	Yes	7	Yes	7	Yes	12	26
12	Conservative	14	Boy	Left	65	63	C2	IV	Yes	14	Yes	10	Yes	18	42
13	Conservative	15	Boy	Left	69	72	C2	IV	Yes	24	Yes	12	Yes	24	40
14	Conservative	17	Girl	Right	74	51	C2	IV	Yes	8	Yes	4	Yes	12	40
15	Conservative	18	Boy	Left	64	48	C2	IV	Yes	14	Yes	14	Yes	20	46
16	Conservative	17	Boy	Left	76	73	C2	IV	Yes	28	Yes	10	Yes	14	28
17	Conservative	17	Boy	Right	64	52	C2	IV	Yes	16	Yes	9	Yes	16	35
18	Conservative	14	Boy	Left	83	71	C2	IV	Yes	20	Yes	12	Yes	20	36
19	Conservative	14	Boy	Left	76	73	C2	III	Yes	18	Yes	18	Yes	18	40
20	Conservative	14	Boy	Left	68	84	C2	IV	No	NA	NO	NA	NO	NA	46
21	Surgical	13	Girl	Right	80	89	C1	IV	No	NA	NO	NA	NO	NA	48
22	Surgical	15	Boy	Left	76	85	C1	IV	No	NA	NO	NA	Yes	30	46
23	Surgical	16	Boy	Left	76	94	C1	IV	No	NA	NO	NA	NO	NA	66
24	Surgical	13	Boy	Left	66	66	C2	IV	Yes	14	Yes	10	Yes	18	30
25	Surgical	14	Boy	Left	56	78	C2	IV	Yes	34	Yes	16	Yes	18	34
26	Surgical	15	Boy	Left	68	91	C2	IV	No	NA	NO	NA	NO	NA	36
27	Surgical	15	Girl	Right	71	86	C2	IV	No	NA	NO	NA	NO	NA	56
28	Surgical	14	Girl	Left	65	84	C2	IV	No	NA	NO	NA	NO	NA	46
29	Surgical	16	Boy	Right	67	73	C2	IV	Yes	28	NO	NA	Yes	32	42
30	Surgical	16	Girl	Right	71	87	C2	IV	No	NA	NO	NA	NO	NA	40
31	Surgical	17	Boy	Right	76	92	C1	IV	No	NA	NO	NA	NO	NA	44
32	Surgical	15	Boy	Left	75	83	C1	III	No	NA	NO	NA	Yes	34	48
33	Surgical	14	Girl	Left	71	90	C1	IV	No	NA	NO	NA	NO	NA	68
34	Surgical	13	Girl	Left	74	88	C2	IV	No	NA	NO	NA	NO	NA	48
35	Surgical	18	Boy	Right	60	92	C2	IV	No	NA	NO	NA	NO	NA	55
36	Surgical	18	Boy	Right	74	75	C2	IV	Yes	24	Yes	8	Yes	24	24
37	Surgical	16	Boy	Right	68	89	C2	IV	No	NA	NO	NA	NO	NA	42