Core Decompression Prevents Progression of Asymptomatic Type C Osteonecrosis of Femoral Head According to the Japanese Investigation Committee Classification: A Retrospective Study

Qiu-ru Wang, MD¹, Jing-jing An, MM², Wan-li Zhang, MM², Zhou-yuan Yang, MD¹, Xin Zhao, MD¹, Peng-de Kang, MD, PhD¹

¹Department of Orthopaedics Surgery and ²Public Laboratory Technology Center, West China Hospital, Sichuan University, Chengdu, China

Objective: To evaluate whether core decompression could prevent progression of asymptomatic type C osteonecrosis of the femoral head (ONFH) according to the Japanese Investigation Committee (JIC) classification.

Methods: This retrospective cohort study included 124 hips (117 patients) with asymptomatic type C ONFH. Seventy-one hips (67 patients) received core decompression (core decompression group) and 53 hips (50 patients) received no surgical treatment (control group). Clinical and radiological follow-up was conducted at 6 and 12 months, then annually until 5 years. Clinical outcomes were evaluated in terms of the Oxford hip score and UCLA Activity Level rating. Radiological outcomes were evaluated using X-ray and magnetic resonance imaging. Survival analysis was performed based on collapse of the femoral head as the first endpoint and total hip arthroplasty (THA) as the second endpoint.

Results: There were no significant differences in clinical outcomes between the core decompression group and the control group within 2 years after surgery. Patients in the core decompression group had significantly better Oxford hip score and UCLA Activity Level from year 3 to the end of follow-up (P < 0.05). In year 5, the absolute difference in Oxford hip score (5.3 points) exceeded the reported minimal clinically important difference (MCID, 5.2 points). In years 3–5, the absolute difference in UCLA Activity Level rating (0.95 points, 0.95 points, and 0.99 points, respectively) exceeded the reported MCID (0.92 points). By 5-year follow-up, significantly fewer patients in the core decompression group had experienced femoral head collapse (40.8% vs 62.3%, P = 0.011) or received THA (26.8% vs 45.3%, p = 0.022).

Conclusions: Core decompression can prevent progression of asymptomatic type C ONFH according to the JIC classification, leading to better medium-term hip function and activity levels than no surgical treatment. Core decompression is recommended for early intervention against asymptomatic type C ONFH.

Key words: Asymptomatic; Core decompression; Femoral head collapse; Joint-preserving surgery; Osteonecrosis of the femoral head

Address for correspondence Peng-de Kang, PhD, MD, Department of Orthopaedics, West China Hospital, Sichuan University, 37# Wainan Guoxue Road, Chengdu 610041, Sichuan, China Tel: +862885422426; Fax: +86 28 85423438; Email: kangpengd@163.com
Qiuru Wang and Jingjing An contributed equally to this work and should be regarded as first co-authors.
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**Introduction**

Osteonecrosis of the femoral head (ONFH) frequently occurs in patients between 20 and 50 years of age, and can have a major impact on daily activities and socioeconomic status. Many cases of osteonecrosis are diagnosed following the gradual onset of hip or groin pain, while asymptomatic disease is typically discovered in the contralateral hip of a patient with one symptomatically affected hip, or during prospective screening of at-risk populations.

Treatment of asymptomatic ONFH is controversial. Some surgeons recommend “watchful waiting,” especially for patients with small- or medium-sized lesions, as they believe that only some lesions will progress to symptomatic disease or collapse of the femoral head. In contrast, other surgeons believe that many asymptomatic patients will eventually progress to symptomatic disease or collapse of the femoral head. Some surgeons therefore suggest femoral head-preserving surgical procedures to delay disease progression and reduce the risk that total hip arthroplasty (THA) will be needed later.

The Japanese Investigation Committee (JIC) classification establishes four stages and three types for describing the location and stage of osteonecrotic lesions in the femoral head (Figure 1). The types of ONFH differ according to the location of lesions (how much of the weight-bearing surface contains lesions): type A indicates that such lesions occupy up to medial one-third of the surface; type B, up to medial two-thirds; or type C, more than medial two-thirds. A recent survey of 505 hips from 310 patients according to the JIC classification suggested that type A or B ONFH requires no further treatment because such lesions rarely progress, with 5-year collapse rates of 0% for type A and 7.9% for type B. Type C ONFH, in contrast, may warrant joint-preserving surgery because the large, laterally located lesions have a 5-year collapse rate of 58.3%. Therefore, early diagnosis and intervention in asymptomatic patients with type C ONFH is important.

Joint-preserving surgeries for early stage ONFH mainly include core decompression, various types of osteotomy, and vascularized and non-vascularized bone grafting. Bone grafting and osteotomy are unsuitable for patients with asymptomatic ONFH because of the invasiveness of the procedures and associated complications. Instead, core decompression may be suitable for asymptomatic ONFH. The purposes of this study were: (i) to assess whether core decompression can prevent progression of asymptomatic type C ONFH according to the JIC classification; (ii) to compare medium-term clinical outcomes between patients who underwent core decompression surgery or not; (iii) to compare medium-term radiological outcomes between patients who underwent core decompression surgery or not.

**Methods**

This retrospective cohort study was approved by the Clinical Trials and Biomedical Ethics Committee of our institution. The requirement for written informed consent was waived because all patients, upon admission, provided consent for their anonymized clinical data to be analyzed and published for research purposes.

**Patients**

Patients treated at our hospital between September 2008 and March 2016 were screened for inclusion in this retrospective analysis. Inclusion criteria for the study were (i) diagnosis with unilateral or bilateral asymptomatic ONFH, which was defined as absence of clinical symptoms in the affected hip(s); (ii) diagnosis with stage 1 or 2 and type C ONFH according to the JIC classification: (iii) treatment with core decompression or no surgery; (iv) complete electronic medical records; and (v) follow-up for at least 2 years.

Patients were excluded if they had traumatic ONFH, rheumatoid arthritis, ankylosing spondylitis, or other immune disease.

Clinicodemographic data on age, sex, body mass index, and affected side were recorded. The proportion of patients with bilateral hip involvement, Oxford hip scores and UCLA scores were compared between patients who underwent core decompression surgery or not.

**Fig. 1** The types of Japanese Investigation Committee Classification. Type A: The osteonecrotic lesions present only in the medial one-third, or less of the weight bearing surface. Type B: The osteonecrotic lesions present in the medial two-thirds, or less of the weight bearing surface. Type C: The osteonecrotic lesions span more than the medial two-thirds of the weight bearing surface. Type C is subdivided into two types: type C1, the osteonecrotic lesions do not exceed the acetabular edge; and type C2, the osteonecrotic lesions exceed the acetabular edge.
Activity Level at diagnosis, etiology of ONFH, and JIC classification (stage and type) were also recorded. All these variables were compared between the groups.

**Surgical Procedure**

All core decompression surgeries in this study were performed by two experienced senior surgeons at our institution. Patients underwent surgery in the supine position under general anesthesia. A guide pin was inserted into the lateral cortex of the femur and directed towards the proximal part of the femoral neck. The alignment of the guide pin was checked under C-arm fluoroscopy guidance to ensure that the pin was centered in the femoral head at the appropriate depth. Then the guide pin was removed and a Steinmann pin with a diameter of 4 mm was advanced into the lesion under fluoroscopic guidance. At least 5 mm of subchondral bone was retained. Simple depression was performed; necrotic tissue was not removed, nor was the core canal bone grafted. Patients with bilateral asymptomatic ONFH in the core decompression group received simultaneous, bilateral core depression.

For the first 3 weeks after discharge, patients were maintained at toe-touch weight-bearing with two crutches. Then patients were advanced to partial weight-bearing for the next 3 weeks using a crutch in the opposite hand. At 6 weeks after surgery, patients began to bear full weight if they were able, but they were told to avoid strenuous exercise and jumping. Patients who received bilateral core depression were instructed to be particularly careful during recovery.

**Outcomes**

Patients were required to visit the institution for follow-up at 6 and 12 months, then annually until 5 years.

**Clinical Outcomes**

**Oxford Hip Score**

The Oxford hip score was used to evaluate pain and function of the hip. The score ranges from 0 to 48, with higher scores suggesting better outcome.

**UCLA Activity Level**

The UCLA Activity Level was used to assess limb function and activity on a scale of 1–10, where 1 indicates “completely inactive: dependent on others and cannot leave residence” and 10 indicates “regular participation in impact sports such as jogging, tennis, skiing, acrobatics, ballet, heavy labor, or backpacking.”

In the case of patients who underwent THA during follow-up, their Oxford hip scores and UCLA Activity Level before THA were included in that year’s assessment, and they were not included in subsequent assessments of Oxford hip scores or UCLA Activity Level.

**Radiographic Outcomes and Survival Analysis**

Anteroposterior view radiography and magnetic resonance imaging were performed at each follow-up to evaluate radiological outcomes. Survival analysis was conducted in which the first endpoint was collapse of the femoral head, defined as stage 3 ONFH according to the JIC classification, and the second endpoint was THA, which was performed on patients who experienced groin pain so severe that it seriously affected daily life.

**Statistical Analysis**

All data were reported as mean and standard deviation, unless indicated otherwise. The normality of data was assessed using the Shapiro–Wilk test. The Student’s t test was used for continuous variables with normal distribution, while the Mann–Whitney U test was used for variables with non-normal distribution. The chi-squared test was used for categorical variables. Probability values less than 0.05 were considered statistically significant.

### TABLE 1 Baseline data of patients

| Parameter               | Control group | Core decompression group | Statistical value | P value |
|-------------------------|---------------|--------------------------|-------------------|---------|
| Number of hips          | 53            | 71                       |                   |         |
| Number of patients      | 50            | 67                       |                   |         |
| Age (years)             | 39.0 ± 9.7    | 38.6 ± 9.8               | 0.210             | 0.834*  |
| Weight (kg)             | 64.6 ± 7.8    | 64.7 ± 9.6               | −0.084            | 0.933*  |
| Height (m)              | 1.66 ± 0.06   | 1.64 ± 0.08              | 0.889             | 0.376*  |
| Body mass index (kg/m²) | 23.5 ± 2.5    | 23.9 ± 2.7               | −0.687            | 0.493*  |
| Sex (male/female)       | 41/12         | 55/16                    | <0.001            | 0.989†  |
| Target side (right/left)| 26/27         | 39/32                    | 0.420             | 0.517†  |
| Bilateral hip involvement (yes/no) | 6/47 | 8/63                     | <0.001            | 0.993‡  |
| JIC classification (stage 1/2) | 14/39 | 19/52                    | 0.002             | 0.966‡  |
| JIC classification (type C₁/C₂) | 25/28 | 24/47                    | 2.269             | 0.132‡  |
| Etiology of ONFH        |               |                          | 1.655             | 0.437†  |
| Alcohol-induced         | 33            | 36                       |                   |         |
| Steroid-induced         | 14            | 24                       |                   |         |
| Idiopathic              | 6             | 11                       |                   |         |
| Baseline OHS            | 43.8 ± 2.3    | 44.2 ± 1.9               | 0.645†            |         |
| Baseline UCLA score     | 6.8 ± 1.1     | 6.8 ± 1.0                | 0.734†            |         |

JIC, Japanese Investigation Committee; ONFH, osteonecrosis of femoral head; OHS: Oxford hip score; UCLA, University of California Los Angeles; * Student’s t test.; † Pearson’s chi-squared test.; ‡ Mann–Whitney U test.
TABLE 2 Postoperative clinical outcomes

| Outcome                  | Control group       | Core decompression group | P value* |
|--------------------------|---------------------|--------------------------|----------|
| Oxford hip score         |                     |                          |          |
| 6 months                 | 42.0 ± 2.5          | 42.5 ± 1.8               | 0.227    |
| 1 year                   | 40.3 ± 4.2          | 41.4 ± 2.8               | 0.064    |
| 2 years                  | 39.2 ± 4.2          | 39.9 ± 3.5               | 0.479    |
| 3 years                  | 37.7 ± 4.9          | 39.5 ± 3.2               | 0.007    |
| 4 years                  | 35.9 ± 5.5          | 37.7 ± 5.7               | 0.005    |
| 5 years                  | 30.2 ± 7.1          | 35.5 ± 6.8               | <0.001   |
| UCLA score               |                     |                          |          |
| 6 months                 | 6.60 ± 0.84         | 6.70 ± 0.88              | 0.586    |
| 1 year                   | 6.36 ± 0.86         | 6.30 ± 0.78              | 0.560    |
| 2 years                  | 6.14 ± 0.98         | 5.96 ± 0.69              | 0.060    |
| 3 years                  | 4.79 ± 0.92         | 5.74 ± 0.73              | <0.001   |
| 4 years                  | 4.43 ± 0.70         | 5.38 ± 0.87              | <0.001   |
| 5 years                  | 3.76 ± 0.76         | 4.75 ± 1.06              | <0.001   |

UCLA, University of California Los Angeles; * Mann–Whitney U test.

TABLE 3 Survival analysis

| Outcome                                         | Control group (n = 53) | Core decompression group (n = 71) | Statistical value | P value |
|-------------------------------------------------|------------------------|-----------------------------------|-------------------|---------|
| Collapse of the femoral head (n, %)             |                        |                                   | 6.452             | 0.011*  |
| 1 year                                          | 3 (5.7)                | 1 (1.4)                           |                   |         |
| 2 years                                         | 7 (13.2)               | 3 (4.2)                           |                   |         |
| 3 years                                         | 12 (22.6)              | 7 (9.9)                           |                   |         |
| 4 years                                         | 19 (35.8)              | 15 (21.1)                         |                   |         |
| 5 years                                         | 33 (62.3)              | 29 (40.8)                         |                   |         |
| Receiving total hip arthroplasty (n, %)          |                        |                                   | 5.284             | 0.022†  |
| 1 year                                          | 2 (3.8)                | 1 (1.4)                           |                   |         |
| 2 years                                         | 4 (7.5)                | 2 (2.8)                           |                   |         |
| 3 years                                         | 8 (15.1)               | 4 (5.6)                           |                   |         |
| 4 years                                         | 13 (24.5)              | 9 (12.7)                          |                   |         |
| 5 years                                         | 24 (45.3)              | 19 (26.8)                         |                   |         |

*n values refer to hips; * Life-table method; † Kaplan–Meier method with log-rank test.

Fig. 2 Survival analysis based on femoral head collapse. The difference was statistically significant, P value = 0.011 (Life-table method)
analyzed using histograms and quantile-quantile plots. Inter-group differences in continuous, normally distributed data were assessed using Student’s t test. Differences in categorical data were assessed using Pearson’s chi-squared test or Fisher’s exact probabilities test. Differences in ordinal, skewed data were assessed using the Mann–Whitney U test. Femoral

Fig. 3 Survival analysis based on the need for total hip arthroplasty. The difference was statistically significant, \( P \) value = 0.022 (Kaplan–Meier method with log-rank test)

Fig. 4 Radiographs of one patient in the core decompression group. The patient was a 45-year-old man, with alcohol-induced osteonecrosis of femoral head (ONFH). (A, B, and C) X-ray images and (D, E, and F) MRI before surgery. The patient had symptoms in the right hip and no symptoms in the left hip when ONFH was diagnosed. The left hip was diagnosed as stage 2 and type C2 ONFH according to the Japanese Investigation Committee Classification.
head collapse survival analysis was performed using the life-table method, since the exact timing of femoral head collapse was unknown. In contrast, the timing of accepting THA was clear, so survival analysis for this outcome was performed using the Kaplan–Meier method, and groups were compared using the log-rank test. All statistical analyses were performed using SPSS 26.0 (IBM, Chicago, IL, USA). Differences were considered statistically significant when \( P < 0.05 \).

**Results**

**Enrolled Patients**

Based on the study inclusion criteria, 71 hips (67 patients) were included in the core decompression group and 53 hips (50 patients) in the control group (Table 1). The two groups did not differ significantly in demographic characteristics at baseline, the proportion of patients with bilateral hip involvement, Oxford hip scores or UCLA Activity Level at baseline, etiology of ONFH, or JIC classification.

Three patients in the control group were lost to follow-up: one in year 3 and two in the year 4. Five patients in the core decompression group were lost to follow-up: three in year 3, one in year 4, and one in year 5.

**Clinical Outcomes**

**Oxford Hip Score**

There was no significant difference in Oxford hip score between the two groups within 2 years after surgery (Table 2). However, patients in the core decompression group had significantly better Oxford hip scores than control patients in year 3 (37.7 ± 4.9 vs 39.5 ± 3.2, \( P = 0.007 \)), year 4 (35.9 ± 5.5 vs 37.7 ± 5.7, \( P = 0.005 \)), and year 5 (30.2 ± 7.1 vs 35.5 ± 6.8, \( P < 0.001 \)). In year 5, the absolute difference in Oxford hip score (5.3 points) exceeded the reported minimal clinically important difference (MCID) of 5.2 points.

**UCLA Activity Level**

There was no significant difference in UCLA Activity Level between the two groups within 2 years after surgery (Table 2). However, patients in the core decompression group had significantly better UCLA Activity Levels in year 3 (4.79 ± 0.92 points).

Fig. 5 (A, B, and C) X-ray images of the same patient shown in Figure 4, taken on the first day after surgery. The patient accepted core decompression on the left side, as well as femoral head and neck fenestration combined with compacted autograft on the right side. (D, E, and F) X-ray images at 24 months after surgery.
The absolute difference in UCLA Activity Level exceeded the reported MCID of 0.92 points\textsuperscript{22,23} in year 3 (0.95 points), year 4 (0.95 points), and year 5 (0.99 points).

Radiographic Outcomes and Survival Analysis
During the 5-year follow-up, the core decompression group showed a significantly lower rate of femoral head collapse than the control group (40.8\% vs 62.3\%, $P = 0.011$) and a lower rate of THA (26.8\% vs 45.3\%, $P = 0.022$), based on survival analysis (Table 3, Figs 2 and 3). Among patients who required THA during follow-up, the control group underwent the procedure earlier (40.8 $\pm$ 15.2 vs 45.5 $\pm$ 12.9 months, $P = 0.250$), but the difference did not reach statistical significance. Representative radiographs of one patient in the core decompression group are shown in Figs 4–6.

Discussion

Main Findings of this Study
The present study found that patients with asymptomatic type C ONFH who underwent core decompression surgery or non-surgical treatment showed no significant difference in function or daily activity level within 2 years after the intervention. From year 3 until at least year 5, however, patients who underwent core decompression showed significantly better hip function and activity levels. In addition, patients who received core decompression showed significantly smaller rates of femoral head collapse or THA during 5-year follow-up.

Reason Why We Chose Core Compression
Several surgical treatments have been described for patients with pre-collapsed ONFH, including various types of osteotomy, vascularized or non-vascularized bone grafting, and core decompression\textsuperscript{14,24,25}. At present, there is no gold standard for surgical treatment of asymptomatic ONFH. Core decompression is a well-established treatment of pre-collapsed ONFH that can reduce intraosseous hypertension and restore blood supply to the necrotic area\textsuperscript{26}. It is recommended as suitable for asymptomatic ONFH because it is minimally invasive, simple, and associated with few complications\textsuperscript{18}.

Core Decompression can Prevent Progression of Asymptomatic Type C ONFH and Provide Better Medium-Term Radiological Outcomes
As a relatively common disease in younger and active patients, ONFH is one of the major causes of disability\textsuperscript{1,2}. ONFH is usually asymptomatic in early stages. Whether
patients with asymptomatic ONFH should be treated with conservative treatment or hip-preserving surgery is controversial\textsuperscript{27,28}. Some surgeons recommend surgery only for symptomatic ONFH patients\textsuperscript{29}, while others suggest joint-preserving surgery for asymptomatic and symptomatic patients\textsuperscript{14,24}. Comparison of collapse rates in patients with different types of ONFH highlight the importance of early diagnosis and intervention in asymptomatic patients with type C ONFH. For example, one review of studies that followed patients for an average of 21–103 months reported collapse rates of 8.6% (6/70) for type A, 18.9% (20/106) for type B, and 59.4% (120/202) for type C\textsuperscript{3}. Another review of studies involving 505 hips reported 5-year collapse rates of 0% for type A, 7.9% for type B, and 58.3% for type C\textsuperscript{13}. The high collapse rate for type C ONFH prompted us to examine asymptomatic patients with that condition in the present study. We found a 5-year collapse rate of 62.3% in the control group, similar to that in the abovementioned reviews. The collapse rate was substantially lower in our core decompression group (40.8%), as was the 5-year rate of THA. These observations indicate that core decompression can prevent progression of asymptomatic type C ONFH.

Core Decompression Can Provide Better Medium-Term Clinical Outcomes

In the present study, core decompression began to benefit hip function from year 3 onwards. Patients in the core decompression group had significantly better Oxford hip scores from year 3 until year 5, and the absolute difference in Oxford hip score exceeded the MCID in year 5. From year 3 until year 5, patients in the core decompression group also showed improvement in UCLA Activity Level exceeding the corresponding MCID. This suggests that core decompression can improve the quality of life of patients with asymptomatic type C ONFH in the medium term.

Nevertheless, patients in the core decompression group did not show better hip function within the first 2 years. This may be because asymptomatic ONFH progresses slowly in the early stage. All patients in our study, regardless of whether they received core decompression or not, showed relatively good hip function soon after diagnosis. In contrast to our results, a study of core decompression for patients with ONFH associated with sickle cell disease found that decompression led to significantly better Merle d’Aubigné–Postel functional scores than conservative treatment as early as 1 and 3 years later\textsuperscript{30}. The difference between our results and that study may reflect differences in how quickly asymptomatic or symptomatic ONFH progresses.

Core decompression has been widely reported as an effective treatment for pre-collapse ONFH\textsuperscript{14,15}, and the present study suggests that it is also effective for asymptomatic type C ONFH. Our results contrast with those from a prospective study comparing asymptomatic and symptomatic hips in 31 patients who had bilateral ONFH but only one symptomatic hip\textsuperscript{37}. After the patients underwent simultaneous bilateral core decompression and bone grafting, the two types of hips showed similar rates of THA (32%–42%) and time until THA (13–15 months) during mean follow-up of 32.6 months. Those investigators concluded that core decompression may not benefit patients with asymptomatic ONFH, especially when it is bilateral, and so surgery on such patients should be performed only when symptoms arise. The different conclusions in that study and ours may reflect that those researchers included asymptomatic ONFH of types A–C, whereas we included only type C. In any case, our results should be verified and extended in large, prospective, randomized studies.

The Significance and Limitations of this Study

This study found that core decompression can prevent progression of asymptomatic type C ONFH, potentially making it an effective intervention against the high natural collapse rate of this condition. In this way, core decompression may be a good way for clinicians to intervene early in asymptomatic cases of type C ONFH, as recommended in previous studies\textsuperscript{3,13}. Our results should be interpreted with caution in light of several limitations. First, our sample was small, and patients selected their treatment rather than being randomized to receive it. Second, we did not blind assessors to patient treatment. Third, we did not control for potential effects of alcohol consumption or hormone exposure dose, which can increase risk of femoral head collapse\textsuperscript{31,32}. However, the etiological composition did not differ significantly between the two groups. This may reduce the bias caused by the reason. Fourth, we relied on the Oxford hip score to evaluate pain and function of the hip. We did not evaluate groin pain systematically, nor did we explore a potential relationship between groin pain and femoral head collapse. Fifth, our study classified patients by the location, not size, of the necrotic lesion. Further studies are needed to validate our results when patients are stratified by lesion size or other factors. Sixth, our follow-up was relatively short, preventing us from observing long-term outcomes of core decompression on asymptomatic type C ONFH. Lastly, if a patient already had a THA on one side, they would likely be more willing to have THA sooner, which may also have biased the outcomes.

Conclusions

Core decompression can prevent progression of asymptomatic type C ONFH according to the JIC classification, leading to better medium-term hip function and activity than no surgical treatment. We recommend early intervention with core decompression in asymptomatic patients with type C ONFH.

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References

1. Sun W, Li G, Gao F, Shi Z, Zhang T, Guo W. Recombinant human bone morphogenetic protein-2 in dermbriderm and impacted bone graft for the treatment of femoral head osteonecrosis. PLoS One, 2014, 9: e100424.
2. Fukushima W, Fujii M, Kudo T, Tamakoshi A, Nagai M, Hirota Y. Nationwide epidemiologic survey of idiopathic osteonecrosis of the femoral head. Clin Orthop Relat Res, 2010, 468: 2715–24.
3. Mont MA, Zywiel MG, Mark GR, McGrath MS, Delanois RE. The natural history of untreated asymptomatic osteonecrosis of the femoral head: a systematic literature review. J Bone Joint Surg Am, 2010, 92: 2165–70.
4. Aronow M, Zelzicf S, Leslie D, Velosa JA, Ginsburg WW, Ehrman RL. Clinically occult avascular necrosis of the hip in systemic lupus erythematosus. J Rheumatol, 1997, 24: 2318–22.
5. Cheng EY, Thongtrangan I, Laor A, Saleh KJ. Spontaneous resolution of osteonecrosis of the femoral head. J Bone Joint Surg Am, 2004, 86: 2594–9.
6. Nam KW, Kim YL, Yoo JJ, Koo KH, Yoon KS, Kim HJ. Fate of untreated asymptomatic osteonecrosis of the femoral head. J Bone Joint Surg Am, 2008, 90: 477–84.
7. Bradley JK, Morey BF. The natural history of the silent hip in bilateral atraumatic osteonecrosis. J Arthroplasty, 1993, 8: 383–7.
8. Herrigou P, Poignard A, Nogier A, Manicom O. Fate of very small asymptomatic stage I osteonecrotic lesions of the hip. J Bone Joint Surg Am, 2004, 86: 2589–93.
9. Goker B, Block JA. Risk of contralateral avascular necrosis (AVN) after total hip arthroplasty (THA) for non-traumatic AVN. Rheumatol Int, 2006, 26: 215–9.
10. Hungerford DS. Treatment of osteonecrosis of the femoral head: everything’s new. J Arthroplasty, 2007, 22: 91–4.
11. Lieberman JR, Engstrom SM, Meneghini RM, SooHoo NF. Which factors influence the progression of the osteonecrotic femoral head. Clin Orthop Relat Res, 2012, 470: 525–34.
12. Sugano N, Atsumi T, Ohzono K, Kubo T, Hotokebuchi T, Takaoka K. The 2001 revised criteria for diagnosis, classification, and staging of idiopathic osteonecrosis of the femoral head. J Orthop Sci, 2002, 7: 601–5.
13. Kuroda Y, Tanaka T, Miyagawa T, Kawai T, Goto K, Tanaka S, et al. Classification of osteonecrosis of the femoral head: who should have surgery. Bone Joint Res, 2019, 8: 451–8.
14. Mont MA, Cherian JJ, Sierra RJ, Jones LC, Lieberman JR. Nontraumatic osteonecrosis of the femoral head: where do we stand today? A ten-year update. J Bone Joint Surg Am, 2015, 97: 1604–27.
15. Chughtai M, Piuozzi NS, Kliopas A, Jones LC, Goodman SB, Mont MA. An evidence-based guide to the treatment of osteonecrosis of the femoral head. Bone Joint J, 2017, 99-B: 1267–79.
16. Sugioya Y, Yamamoto T, Transtrochanteric posterior rotational osteotomy for osteonecrosis. Clin Orthop Relat Res, 2008, 466: 1104–9.
17. Haminishi M, Yasunaga Y, Yamasaki T, Morii R, Shoji T, Ochi M. The clinical and radiographic results of intertrochanteric curved varus osteotomy for idiopathic osteonecrosis of the femoral head. Arch Orthop Trauma Surg, 2014, 134: 305–10.
18. Hungerford DS, Jones LC. Asymptomatic osteonecrosis: should it be treated? Clin Orthop Relat Res, 2004, 429: 124–30.
19. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. J Bone Joint Surg Br, 1996, 78: 185–90.
20. Zahiri CA, Schnaaidzepo T, Szuszczewicz ES, Armitz HC. Assessing activity in joint replacement patients. J Arthroplasty, 1998, 13: 890–5.
21. Yeo M, Goh GS, Chen JY, Lo NN, Yeo SJ, Liow M. Are Oxford hip score and Western Ontario and McMaster universities osteoarthritis index useful predictors of clinical meaningful improvement and satisfaction after Total hip arthroplasty. J Arthroplasty, 2020, 35: 2458–64.
22. Ford MC, Hellman MD, Kazarian GS, Clohisy JC, Nunley RM, Barrack RL. Five to ten-year results of the Birmingham hip resurfacing implant in the U.S.: a single Institution’s experience. J Bone Joint Surg Am, 2018, 100: 1879–87.
23. SooHoo NF, Li Z, Chenok KE, Bozic KJ. Responsiveness of patient reported outcome measures in total joint arthroplasty patients. J Arthroplasty, 2015, 30: 176–91.
24. Moya-Angeler J, Gianakos AL, Villa JC, Ni A, Lane JM. Current concepts on osteonecrosis of the femoral head. World J Orthop, 2015, 6: 590–601.
25. Wang Q, Li D, Yang Z, Kang P. Femoral head and neck fenestration through a direct anterior approach combined with compacted autograft for the treatment of early stage nontraumatic osteonecrosis of the femoral head: a retrospective study. J Arthroplasty, 2020, 35: 652–60.
26. Lee MS, Hsieh PH, Chang YH, Chan YS, Agrawal S, Ueng SW. Elevated intraosseous pressure in the intertrochanteric region is associated with poorer results in osteonecrosis of the femoral head treated by multiple drilling. J Bone Joint Surg Br, 2008, 90: 852–7.
27. Hsu JE, Winby T, Shah RP, Garino JP, Lee GC. Prophyllactic decompression and bone grafting for small asymptomatic osteonecrotic lesions of the femoral head. Hip Int, 2011, 21: 672–7.
28. Kumpf R, Tresvicka T. Avascular osteonecrosis of the hip in the adult: current evidence on conservative treatment. Clin Cases Miner Bone Metab, 2015, 12: 39–42.
29. Min BW, Song KS, Cho CH, Lee SM, Lee KJ. Untreated asymptomatic hips in patients with osteonecrosis of the femoral head. Clin Orthop Relat Res, 2008, 466: 1087–92.
30. Mukisi-Mukaza M, Manicom O, Alexis C, Bashoun K, Donkerwolcke M, Burny F. Treatment of sickle cell disease’s hip necrosis by core decompression: a prospective case-control study. Orthop Traumatol Surg Res, 2009, 95: 498–504.
31. Zalavras CG, Lieberman JR. Osteonecrosis of the femoral head: evaluation and treatment. J Am Acad Orthop Surg, 2014, 22: 455–64.
32. Pijnenburg L, Feiten R, Javier RM. A review of avascular necrosis, of the hip and beyond. Rev Med Intemte, 2020, 41: 27–36.