Association between open or closed reduction and avascular necrosis in developmental dysplasia of the hip
A PRISMA-compliant meta-analysis of observational studies
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Abstract
Background: The risk of avascular necrosis of the femoral head (AVN) after treatment of developmental dysplasia of the hip is associated with the method of reduction. Some authors have suggested that open reduction is a risk factor for AVN; however, this is controversial. To our knowledge, a quantitative comparison of the incidence of AVN between closed and open reduction has not been conducted.

Methods: Published studies were identified by searching PubMed, EMBASE, and the Cochrane Library up to May, 2015, focusing on the incidence of AVN after closed or open reduction for developmental dysplasia of the hip in children aged \(<\)3 years. Patients were age-matched who were treated by either closed or open reduction, but without pelvic or femoral osteotomy. Two authors independently assessed eligibility and abstracted data. Discrepancies were discussed and resolved by consensus. We pooled the odds ratios (ORs) and 95% confidence intervals (95%CIs) from individual studies using a random-effects model and evaluated heterogeneity and publication bias.

Results: Nine retrospective studies were included in this analysis. The pooled OR for comparing open reduction with closed reduction for all grades of AVN was 2.26 (95%CI = 1.21–4.22), with moderate heterogeneity (I\(^2\) = 44.7%, \(P = 0.107\)). The pooled OR for grades II to IV AVN was 2.46 (95%CI = 0.93–6.51), with high heterogeneity (I\(^2\) = 69.6%, \(P = 0.003\)). A significant association was also found for the further surgery between open and closed reduction, with a pooled OR of 0.30 (95%CI = 0.15–0.60) and moderate heterogeneity (I\(^2\) = 46.4%, \(P = 0.133\)). No evidence of publication bias or significant heterogeneity between subgroups was detected by meta-regression analyses.

Conclusion: Findings from this meta-analysis suggest that open reduction is a risk factor for the development of AVN compared with closed treatment. Future studies are warranted to investigate how open reduction combined with pelvis and/or femoral osteotomy affects the incidence of AVN.

Abbreviations: AVN = avascular necrosis of the femoral head, CI = confidence interval, DDH = developmental dysplasia of the hip, OR = odds ratio.

Keywords: avascular necrosis, developmental dysplasia of the hip, meta-analysis, open reduction
1. Introduction

Developmental dysplasia of the hip (DDH) is a spectrum of disorders in which the femoral head has an abnormal relationship to the acetabulum. This spectrum includes acetabular dysplasia without displacement, subluxation, and dislocation. DDH is the most common congenital joint disorder in the field of pediatric orthopedics, with an estimated incidence ranging from 1.4 to 35.0 per 1000 newborns.\(^1\)\(^{,}\)\(^2\) DDH is influenced by many genetic and environmental factors, such as ligamentous laxity, breech position, family history, female sex, and racial predilection. It is well known that early diagnosis and treatment can provide the best possible functional outcome. Historically, ultrasound screening in combination with clinical examination was widely used for neonatal screening in most developed countries.\(^3\)\(^,\)\(^4\) The Pavlik harness was subsequently applied in patients with DDH that was first diagnosed in infancy and achieved a success rate reaching 90\%\(^,\)\(^5\)\(^,\)\(^6\) Despite efforts to recognize and treat all cases that was subsequently applied in patients with DDH, length discrepancy, and early osteoarthritis.\(^13\)\(^\) The screening in combination with clinical examination was widely used for neonatal screening in most developed countries.\(^3\)\(^,\)\(^4\) The Pavlik harness treatment is unavoidable. Thus, further treatment such as closed or open reduction of the dislocated hip is necessary in these cases.\(^7\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(...
publication, mean patient age, mean number of follow-up years, diagnostic criteria, incidence of AVN after open or closed reduction, and quality assessment score. Quality assessments were performed according to the Newcastle–Ottawa Scale for observational studies,[42] which includes 3 aspects (total of 9 points): selection of the study groups (4 points), comparability of the study groups (2 points), and assessment of outcomes (3 points). The highest possible score was 9, and a high-quality study was defined as a study with a quality score of ≥7. We also evaluated whether the studies were adequately adjusted for potential confounders.

2.5. Data synthesis and analysis

Two-by-two tables were constructed using the data of the included studies. Odds ratios (ORs) and their 95% confidence intervals (95%CIs) were calculated from these tables. A random-effects model was used for all analyses.

Subgroup analyses were carried out on grades I to IV AVN and further surgery included studies. Odds ratios (ORs) and their 95% confidence intervals (95%CIs) were calculated from these tables. A random-effects model was used for all analyses.

Sensitivity analysis was performed by sequentially removing 1 study at a time and reanalyzing the data to determine whether any 1 study influenced the results. Heterogeneity was evaluated by the I² statistic. An I² value of >50% was considered to indicate significant heterogeneity. Begg funnel plots were created and Egger regression asymmetry tests were performed to investigate publication bias. STATA statistical software (version 12.0; StataCorp, College Station, TX) was used for the meta-analysis. All P values were two-sided with a significance level of 0.05.

3. Results

3.1. Search and study selection

In total, 108 studies were retrieved from the 3 databases: 67 articles from PubMed, 38 from EMBASE, and 3 from the Cochrane Library. A flowchart of the study selection process is shown in Fig. 1. Nine studies were included in the analysis.[23,24,26–30,39,43]

3.2. Study characteristics and quality assessment

All 9 studies were retrospective studies and included 391 hips treated by open reduction and 559 hips treated by closed reduction in patients <3 years old. AVN was classified with the Bucholz–Ogden system in 4 studies[24,26,27,39] and with the Kalanci–MacEwen system in 5. All 9 studies did not regard grade I AVN as real AVN[23,24,26–30,39,43]; the authors instead considered grades II to IV as severe AVN. Four studies described the performance of further surgery due to redislocation or residual acetabular dysplasia after successful reduction.[23,28,30,39]

Study-specific quality scores are summarized in Supplemental Table S1, http://links.lww.com/MD/B131. The quality scores ranged from 5 to 9 with a median score of 7. Because standard criteria have not been established, we considered the included studies to be of adequate quality for the analysis.

### Table 1

Characteristics of included studies.

| Author, year, and country | Mean age at reduction (mo) (range) | Mean follow-up (y) (range) | Diagnostic criteria of AVN | Open reduction Rate (%) Number | Closed reduction Rate (%) Number | Quality score |
|---------------------------|-----------------------------------|---------------------------|---------------------------|-------------------------------|-------------------------------|---------------|
| All grades of AVN         |                                   |                           |                           |                               |                               |               |
| Pospischill[39] 2012, Austria | CR 4 (1.2–10.4); OS 3.6 (0.7–7.9) | 6.8 (3.2–11.5)           | B–O                       | 20                                                           | 15                                                            | 28            | 46            | 9             |
| Firth[30] 2010, South Africa | CR 15 (2–65); OS 24 (6–117)       | 10.8 (4–26.3)             | K–M                       | 66                                                           | 56                                                            | 35            | 77            | 8             |
| Clarke[39] 2005, UK       | 11.5 (4–16)                       | ≥3 (n/va)                 | K–M                       | 50                                                           | 22                                                            | 18            | 28            | 7             |
| Segal[39] 1999, USA       | CR 6 (3–8); OS 6 (2–11)           | 5 (0.8–15)                | B–O                       | 29                                                           | 17                                                            | 34            | 38            | 7             |
| Luhmann[39] 1998, USA     | 11 (1–24)                         | 7 (n/va)                  | B–O                       | 12                                                           | 41                                                            | 4             | 112           | 8             |
| Mantam[39] 1982, USA      | 30 (n/va)                         | 14.7 (n/va)               | K–M                       | 45                                                           | 22                                                            | 24            | 59            | 5             |
| Significant AVN           |                                   |                           |                           |                               |                               |               |               |               |
| Pospischill[39] 2012, Austria | CR 4 (1.2–10.4)                 | 6.8 (3.2–11.5)           | B–O                       | 7                                                            | 15                                                            | 20            | 46            | 9             |
| Clarke[39] 2005, UK       | 11.5 (4–16)                       | ≥3 (n/va)                 | K–M                       | 14                                                           | 22                                                            | 7             | 28            | 7             |
| Luhmann[39] 1998, USA     | 11 (1–24)                         | 7 (n/va)                  | B–O                       | 5                                                            | 41                                                            | 3             | 112           | 8             |
| Camp[44] 1994, USA        | 11 (2–30)                         | 4.3 (2–14)                | B–O                       | 11                                                           | 28                                                            | 2             | 55            | 6             |
| Further surgery           |                                   |                           |                           |                               |                               |               |               |               |
| Pospischill[39] 2012, Austria | CR 4 (1.2–10.4)                 | 6.8 (3.2–11.5)           | B–O                       | 13                                                           | 15                                                            | 15            | 46            | 9             |
| Clarke[39] 2005, UK       | 11.5 (4–16)                       | ≥3 (n/va)                 | K–M                       | 18                                                           | 134                                                           | 57            | 104           | 6             |
| Luhmann[39] 1998, USA     | 11 (1–24)                         | 7 (n/va)                  | B–O                       | 41                                                           | 22                                                            | 57            | 28            | 7             |
| Mantam[39] 1982, USA      | 30 (n/va)                         | 14.7 (n/va)               | K–M                       | 42                                                           | 24                                                            | 71            | 82            | 8             |

AVN = avascular necrosis of the femoral head, B–O = Bucholz–Ogden classification, CR = closed reduction, K–M = Kalanci–MacEwen classification, n/va = not available, OS = open surgery or open reduction.
3.3. Synthesis of results and additional analysis

3.3.1. Grades I to IV AVN. The prevalence of all grades of AVN in the open reduction cohorts ranged from 12% to 66% in the 6 included studies and from 4% to 35% in the closed reduction cohorts. Analysis of the 6 studies showed a significant effect (OR = 2.26, 95%CI = 1.21–4.22) when comparing 73 cases of AVN (36%) in the open reduction group with 80 (21%) in the closed group, with moderate heterogeneity ($I^2 = 44.7\%$; $P = 0.107$) (Fig. 2).

Figure 1. Flowchart of the study selection process.

Figure 2. Forest plot (random-effects model) of the incidence of avascular necrosis of the femoral head grades I to IV between open and closed reduction. Squares indicate study-specific odds ratio (size of the square reflects the study-specific statistical weight); horizontal lines indicate 95% CIs; diamond indicates the summary relative risk estimate with its 95%CI. CI = confidence interval, OR = odds ratio.
Publication bias was not seen in the symmetrical funnel plots and was not indicated with Begg’s test \((P=0.260)\) or Egger’s test \((P=0.319)\). Sensitivity analysis was carried out by excluding 1 study at a time and reanalyzing the others. The 6 study-specific ORs ranged from a minimum of 1.93 \((95\%\text{CI}=1.62–4.79)\) after omission of the study by Firth et al.\(^{30}\) to a maximum of 2.79 \((95\%\text{CI}=1.57–4.96)\) after omission of the study by Segal et al.\(^{27}\). In the subgroup analysis, all strata showed positive associations, and there was no evidence of significant heterogeneity between subgroups in the meta-regression analysis (Table 2).

### 3.3.2. Grades II to IV AVN

Similarly, the incidence of grades II to IV AVN ranged from 5% to 57% for open reduction versus 2% to 20% for closed reduction. The meta-analysis of the 7 studies indicated that 70 patients (20%) in the open reduction cohort developed AVN compared with 38 (8%) in the closed cohort, with a significant difference \((OR=2.46, 95\%\text{CI}=0.93–6.51)\) and high heterogeneity \((I^2=69.6\%; \ P=0.003)\) (Fig. 3). There was no indication of publication bias according to Egger’s test \((P=0.710)\). Sensitivity analysis similarly indicated that the 7 study-specific ORs ranged from a minimum of 1.71 \((95\%\text{CI}=0.78–3.75)\) after omission of the study by Firth et al.\(^{30}\) to a maximum of 3.20 \((95\%\text{CI}=1.20–8.48)\) after omission of the study by Bolland et al.\(^{43}\) In the subgroup analysis, although the direction of all strata was consistent, none of them showed statistical significance in the meta-regression analysis (Table 2).

### 3.4. Further surgery

There was a statistically significant difference in the rate of further surgery between the open and closed reduction groups \((OR=0.30, 95\%\text{CI}=0.15–0.60)\), with moderate heterogeneity \((I^2=46.4\%; \ P=0.133)\) (Fig. 4). There was no indication of publication bias with Egger’s test \((P=0.734)\) or Begg’s test \((P=0.355)\).

### 4. Discussion

#### 4.1. Summary of evidence

To our knowledge, this is the first meta-analysis to evaluate the association between the treatment method for DDH and the risk of developing AVN. The findings from this meta-analysis suggest that open reduction as a risk factor for an increased incidence of AVN (both grades I-IV and grades II-IV) compared with closed reduction when restricted to <3-year-old age-matched patients with DDH. An additional analysis indicated that the rate of further surgery in the form of open reduction was much lower than the rate of closed reduction.

Although the results of the meta-regression revealed no evidence of significant heterogeneity between subgroups by age at reduction, certain differences were noted. We also found that the rates of the different AVN grades among children aged <18 months was almost half that among children aged >18 months. Meanwhile, some studies have considered that age at the time of reduction is also a risk factor for AVN. This could be partly explained by age-related aggravation of the morphologic changes of the acetabulum, femoral head, and joint capsule of DDH\(^{44–46}\) and the fact that maximal spontaneous remodeling of the dysplastic hip occurs during the first year of life.\(^{28,39,43}\) Moreover, DDH detected later in life is more likely to be treated with open reduction and lead to a higher rate of AVN. Many studies have reported that age at the time of reduction had no effect on the incidence of AVN.\(^{27,30,47–49}\) However, considering that our analysis included few studies, further research is needed to confirm whether age at the time of reduction is a risk factor for AVN.

Similarly, in the subgroup analysis of the follow-up time, we found that the OR when the follow-up time was <7 years was lower than that when the follow-up was >7 years. This was also true for the subgroup analysis of sample size. This may be explained by the fact that the development of AVN is a dynamic process. Several investigators have emphasized that certain radiographic signs of AVN may not be detected until the patient is ≥12 years of age.\(^{41,50}\) Akilapa\(^{41}\) found that studies with longer follow-up periods reported higher AVN rates than did studies with shorter follow-up periods. Therefore, we suppose that a follow-up of <7 years is not long enough to evaluate the development of AVN. The 2 studies involving larger sample sizes had longer follow-up times, which may explain the disappearance of heterogeneity and the increase in the OR. These results
should be interpreted cautiously because of the limited number of studies.

In the subgroup analysis of classification criteria, we found no significant heterogeneity by meta-regression; however, certain differences were found. The studies that used the Bucholz–Ogden classification system had younger patients, a shorter follow-up time, and a smaller sample size, which may explain the weaker association between the method and the development of AVN. However, the discrepancy between these 2 classification criteria should be further studied.

In this study, we concluded that open reduction is a risk factor for AVN compared with closed reduction in younger children. Disturbance of the blood supply of the femoral head affects the quality of hip development and maturation, leading to reduced perfusion, lack of development, ossification, and finally AVN. The excessive pressure on the femoral head and ischemic injury to the capital femoral epiphysis during hip reduction may lead to a reduced blood supply; both of these factors are considered to be involved in the developmental mechanism of AVN. Therefore, we can explain the cause of AVN in open reduction based on these 2 mechanisms. First, open reduction is invasive. The medial femoral circumflex artery is the main blood supply to the femoral head. It lies between the adductor and iliopsoas muscles and traverses the anteromedial capsule of the hip. This artery needs to be ligatured during open surgery or may be injured during capsulotomy. During capsulotomy, the acetabular labrum, ligamentum teres, and other soft tissues may be separated intraoperatively, leading to tightness of the posterolateral capsule, contracture of the external rotators, increased pressure of the joint cavity, and increased pressure on the femoral head. Because extrinsic compression of the blood vessels and excessive pressure on the femoral head may occur during joint reduction, patients who undergo repeated reduction attempts for recurrent dislocation are believed to have a higher risk of AVN. In 1 study, most patients treated by open surgery underwent failed or unstable closed reduction or severe dislocation before treatment with open reduction; this may increase the incidence of AVN and the poor prognosis to different degrees.

The current consensus is that DDH in children aged <18 months is best treated by closed reduction. However, the present analysis results show that children <3 years old who underwent closed reduction had a lower risk of development of AVN than those who underwent open reduction. In fact, controversy regarding the treatment decision in patients aged >18 months has existed for decades. Our subgroup analysis of age at the time of reduction indicated a growing tendency of the risk of AVN in children aged >18 months. Considering the limited number of included studies, however, this finding should be interpreted with caution. Future studies need to clarify with greater confidence whether open reduction increases the development of AVN. In addition, considering the matched age between the 2 groups and the comparability of our analyses, only patients <3 years old were included because the most frequent age at which open or closed reduction is performed is <3 years. In patients >3 years old, open reduction is usually used in combination with pelvic or
femoral osteotomy. Pospischill et al\[39\] concluded that open reduction with pelvic osteotomy increases the risk of AVN and that it would be relieved by femoral shortening owing to reduction of the pressure on the femoral head; this applies to older children. However, a study by Huang and Wang\[25\] showed that combined osteotomy resulted in a lower rate of AVN than did closed reduction. We did not analyze how open reduction combined with pelvic or femoral osteotomy affects the development of AVN; this requires further study.

The present study also found that the occurrence of further surgery after treatment by open reduction was much lower than that after treatment by closed reduction. A study by Pospischill et al\[39\] involving early reduction showed the smallest incidence of further surgery in the 4 included studies and similar rates for open reduction (13%) and closed reduction (15%). However, in 3 other studies\[2,26,43\] the reduction was delayed because of the presence of an ossific nucleus or patient age of >13 months, and the rate of further surgery showed a greater increase than did early reduction\[39\] (Table 1). These findings could indicate that the delayed treatment resulted in insufficient reduction and development, which could lead to redislocation and residual hip dysplasia\[26,43\] and could increase the need for secondary reconstructive operations. In addition, patients who underwent failed closed reduction constituted the majority of the open surgery cohort, which may be the reason for the lower incidence of further surgery after open reduction. Moreover, open reduction removed intra-articular obstructive factors such as hypertrophic soft tissue, ligamentum teres, and labrum, making the reduced femoral head more stable.\[23\] Although open reduction reduced the rate of further surgery, it increased the risk of AVN in our analysis; this appears to be a contradiction. Notably, however, younger children had a lower risk of AVN and further surgery. This indicates that early diagnosis and reduction is particularly important. Finally, it is necessary for future studies to analyze the association between the surgical approach and the risk of AVN or further surgery, which was not addressed in our study.

4.2. Strengths and limitations

This study had several strengths. To the best of our knowledge, this is the first meta-analysis to compare the incidence of AVN between open and closed reduction for the treatment of DDH. Moreover, it included a total of 391 hips treated by open reduction and 559 hips treated by closed reduction, which should have increased the statistical power to detect these risk factors. In addition, we performed a number of subgroup analyses to detect potential sources of heterogeneity.

Our study also contained several limitations. First, the included studies were all retrospective cohort studies; therefore, the potential study biases inherent in the original studies could not be avoided compared with a prospective study, decreasing the quality of evidence. Second, although the results of the meta-regression analyses did not show significant differences between subgroups, differences in the results and unstable heterogeneity were still observed among the stratified analyses. This cannot be fully explained by the “limited studies”; we found no good explanation for the greater heterogeneity or the disappearance of
hetereogeneity. The development of AVN may be associated with several other factors such as the present of an osisse nucleus, previous treatment, the fixed angle, and combined oestometry. However, many but not all studies adjusted for the potential confounding factors. Further studies of these factors are necessary to clearly define the occurrence of AVN. Third, significant heterogeneity and possible publication bias must be considered. There was significant heterogeneity in the pooled analysis of significant AVN ($I^2=69.66\%$, $P=0.003$), but this may be at least partially explained by differences in the study quality, study design, exposure assessment, study population, and adjustment for potential confounders. Publication bias can be a problem in any meta-analysis, but we found no statistical evidence of such bias in our analysis.

5. Conclusion

In summary, this meta-analysis has demonstrated that compared with closed treatment, open reduction without oestometry is associated with a higher risk of AVN. Especially in children <18 months of age, closed reduction should be employed as early as possible to minimize the risk of AVN. This analysis is limited to children aged <3 years, and we found that open reduction increased the risk of AVN but reduced the occurrence of further surgery. Thus, determination of which treatment method to use for children aged 18 to 36 months is unclear. This decision may be based on the degree of dislocation or intra-articular obstructive factors; further research is necessary. In addition, further studies should investigate how open reduction combined with pelvic or femoral oestometry influences the development of AVN.

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