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PAEDIATRICS

Rates and risk factors for failure of reduction in closed reduction in developmental dysplasia of the hip: a systematic review and meta-analysis

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- *Objective*: In developmental dysplasia of the hip (DDH), concentric reduction of dislocated hips cannot be achieved by closed reduction in many cases, and open reduction is required ('failure of reduction'). The incidence of cases requiring open reduction and the significance of risk factors for unsuccessful reduction remain unclear. We investigated the overall rate and the risk factors for failed closed reduction in DDH.
- *Methods*: We followed the Cochrane recommendations in our systematic review and meta-analysis. We performed a systematic search in three medical databases to identify all studies reporting on pediatric patients with hip dislocation in DDH on 2 July 2022. Eligible studies reported on the rate of failure in children younger than 36 months. We calculated odds ratios (ORs) with 95% CIs from two-by-two tables (event rate in risk group, event rate in non-risk group).
- *Results*: We identified 13 316 studies and included 62 studies (5281 hips) for failure rate and 34 studies (3810 hips) for risk factor analysis. The overall rate of failure in closed reduction was 20%. The risk of failure of reduction increased with the grade of dislocation and was significantly higher for high dislocations (group 0–24: IHDI 4 vs IHDI 2 OR: 17.45, CI: 9.26–32.92; Tönnis 4 vs Tönnis 2 OR: 14.67, CI: 1.21–177.37; Graf IV vs Graf III OR: 3.4, CI: 2.27–5.09). Male gender was also a significant risk factor (OR: 2.27, CI: 1.13–4.56) in group 0–36.
- *Conclusion*: Higher grade dislocations and male gender are significant risk factors for failure of reduction in closed reduction in hip dislocation in DDH.

Keywords: closed reduction; DDH; developmental dysplasia of the hip; hip dislocation

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Introduction

Hip dislocation in developmental dysplasia of the hip (DDH) is one of the most important and most investigated topics in pediatric orthopedics. However, its management remains a challenge in everyday practice. Unsuccessful reduction, redislocation, avascular necrosis of the femoral head, and residual dysplasia are the main reasons for secondary surgery and poor long-term outcomes.

The treatment of hip dislocation is based on the principle of a step-by-step approach (Fig. 1). However, the treatment protocol varies between countries and different institutes. The age of the child significantly influences which treatment method is chosen first: in several countries, under the age of 6 months conservative treatment with abduction orthosis is preferred (1, 2), between 6 months and 18–24 months of age, mainly closed reduction is performed or attempted (1, 3, 4), and over 18–24 months of age, open reduction is the method of choice with or without additional osteotomy (1, 5, 6). However, as the risk of failure and development of complications with conservative treatment with abduction orthosis increases with age (7), in other countries closed reduction is the primary treatment at a younger age, even from 6 weeks (8).

Other factors, such as the grade of dislocation, also influence the treatment. In some institutions, closed reduction is the first-line treatment under the age of 6 months in high dislocations (7, 9), although in other institutions, closed reduction is performed in all decentered hips (Graf D, III, IV) even under the age of 6 months (10). However, complications are common with this treatment scheme. Concentric reduction of dislocated hips cannot be achieved in 0–55% of cases in conservative treatment with abduction orthosis (7, 11), in 1–54% of cases in closed reduction (10, 12), and in 0–29% of cases in open reduction (13, 14) (failure of reduction). In addition, the most severe complication of the treatment, avascular necrosis of the femoral head is common too; the overall rate of clinically significant avascular necrosis is 10% in closed reduction (15) and 20% in medial open reduction (16).

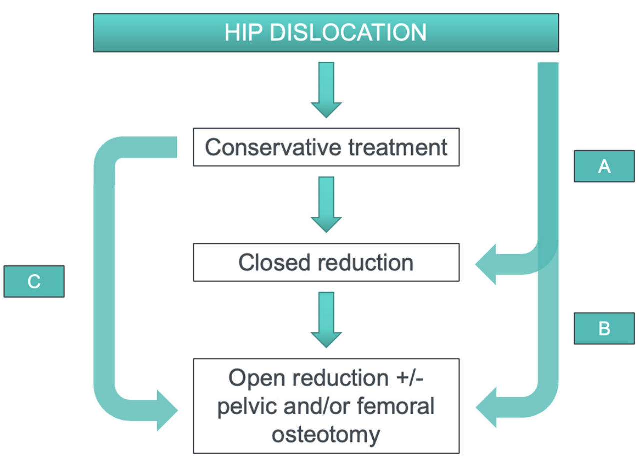

Figure 1

The stepwise treatment regimen for hip dislocation in DDH. Different factors (A, B, C) influence the next step of treatment in various treatment protocols. (A) Age over 6 weeks (8), age over 6 months (1), Graf IV. grade (7, 9), all decentered hips (10). (B) Open reduction: age over 12 months (5), age over 18 months (1), age over 24 months (6), obstructions to reduction on arthrogram (69). Open reduction and pelvic and/or femoral osteotomy: age over 12 months (62), age over 18 months (1,5). (C) age over 12 months (1), obstructions to reduction on arthrogram (59, 62, 69).

Therefore, our aim is to identify the risk factors where the treatment protocols are likely to fail and to select cases where it is worth skipping the next step of the treatment and proceeding to the next step if there the chances of unsuccessful reduction, avascular necrosis and further surgery are lower. In light of these results, a more personalized treatment method can be chosen, resulting in fewer unnecessary interventions, less avascular necrosis, and better functional outcomes. In this study, which is the first systematic review and meta-analysis investigating the failure of reduction in the treatment of hip dislocation in DDH, we analyzed the overall rate and the risk factors for failure of reduction in patients with DDH treated with closed reduction.

Methods

We conducted our systematic review and meta-analysis according to the PRISMA 2020 guideline (17) (see Supplementary Table 1, see section on supplementary materials given at the end of this article) and the Cochrane Handbook (18). We registered the protocol of the study on PROSPERO and we fully complied with it.

Eligibility criteria

We formulated our research question using the PICO framework. Eligible studies reported on (P) patients under the age of 36 months with hip dislocation in DDH. We included cohort studies, case-control studies, and randomized controlled trials that provided data on the rate of failure of closed reduction, with a series of minimum of ten hips to minimize the bias of small samples. We defined failure of reduction in closed reduction as the need for open or repeated closed reduction with or without additional pelvic and/or femoral osteotomy. We did not evaluate pelvic or femoral osteotomies without open or repeated closed reduction for residual dysplasia or subluxation as a failure of closed reduction. In studies with data on different risk factors, we evaluated the rate of failure of reduction (O) in the presence (I) and absence of risk factors (C).

We excluded reviews, case reports, and conference abstracts, data on patients with a history of

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unsuccessful closed or open reduction, and to reduce clinical heterogeneity, studies involving only patients representing a small patient group (e.g. male patients, irreducible dislocations). We also excluded studies in which the closed reduction was performed by arthroscopy, or without general anesthesia/sedation (including techniques by gradual traction and spontaneous or manual reduction, i.e. Petit–Morel and FACT-R techniques). However, we did not exclude studies in which closed reduction was performed under general anesthesia following preliminary traction. We also excluded studies in which only the hip spica cast was applied under general anesthesia, but not the reduction.

A minimum follow-up period was not defined in our study as a long follow-up was not required to evaluate the rate of failure in some treatment steps (intraoperative failure, postoperative failure). Studies with partially duplicated cohorts were also excluded unless they contained sufficient independent information to use both cohorts. Where appropriate data were analyzed only once.

Information sources and search strategy

We conducted the systematic search in three databases: Embase, MEDLINE (via PubMed), and Cochrane Central Register of Controlled Trials (CENTRAL) on 2 July 2022. The following search key was used during the systematic search: hip and (dislocation or luxation or dislocated or dysplasia or displacement or DDH) and (reduce or reduction or reposition). No filters were applied during the search. In addition, the reference list of eligible studies was also searched.

Selection process

The selection was performed by two independent review author groups after the removal of duplicates by title, abstract, and full text, based on pre-defined criteria. For the selection, the Endnote 20 reference manager software (Clarivate Analytics) was used. Disagreements were discussed, and if consensus could not be reached, a third independent review author was involved in the decision.

Data collection process and data items

Data were collected from the eligible articles by two authors independently. In the case of disagreement, a third author was involved in making a consensus. The following data were extracted: first author, the year of publications, study population, study period, study site (country), study design, demographic data of the patients, follow-up time after closed reduction, failure types (intraoperative, postoperative failure, failed reduction, redislocation, overall failure; Table 1), failure rates for different risk factors, and information to assess the risk of bias in the studies.

Study risk of bias assessment

Two authors performed the risk of bias assessment independently with the help of the Quality in Prognostic

Table 1 Types of failure of reduction in closed reduction. The number of failed hips/all hips is shown in parentheses. See also Supplementary Figures 17 and 18. The rate of overall failure is not the sum of the primary and secondary failure rates.

		Failure rate*	
Failure type	**Description**	**Group 0–24†**	**Group 0–36‡**
Intraoperative failure	The closed reduction attempt was not successful, and an open reduction was performed either under the same or separate anesthesia (irreducible or unstable hips).	24% (279/1056)	23% (302/1172)
Postoperative failure	The closed reduction was found to be successful in the operating room, but the postoperative x-ray, CT, or MRI scan showed failure within the first 48 h/1 week after reduction.	7% (69/882)	8% (79/964)
Failed reduction (primary failure)	The closed reduction failed either intraoperatively or a failure was detected on the postoperative imaging scans. The rate of failed reduction includes both intraoperative and postoperative failure rates.	13% (177/1283)	15% (211/1399)
Redislocation (secondary failure)	After a primary successful closed reduction (proved by postoperative imaging methods) the reduced femoral head redislocated during or after the postoperative immobilization period.	8% (155/1861)	8% (184/2141)
Overall failure	The closed reduction failed either primarily or secondarily. The overall failure rate includes the rate of failed reduction and the rate of redislocation.	20% (377/1618)	21% (661/2452)

*Weighted data; †All included studies with failure rates under 24 months of age (3, 4, 6, 8, 9, 10, 12, 13, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 39, 41, 43, 44, 45, 46, 47, 49, 50, 51, 52, 55, 56, 57, 58, 60, 61, 62, 64, 66, 68, 69, 70, 71, 72, 73); ‡All included studies with failure rates under 36 months of age (3, 4, 6, 8, 9, 10, 12, 13, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73).

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Studies (QUIPS) tool (19). As a result, a consensus was reached in the case of disagreements. Specific methodological details are described in Supplementary Table 2.

Synthesis methods

We performed the quantitative analysis of the risk factors when dichotomous data were available in 3 independent cohorts. Other risk factors were evaluated using narrative analysis.

All statistical analyses were performed with R (R Core Team 2020, v4.0.3) using the meta (v5.2.0) and dmetar (v0.0.9000) packages. We calculated pooled odds ratios (ORs) with 95% CIs from two-by-two tables (failure rate in risk group, failure rate in non-risk group). The DerSimonian–Laird method was applied with a random-effects model. We used forest plots to represent pooled and individual study results.

I^2 and χ^2 tests were used to assess the statistical heterogeneity with a P-value < 0.1 as a threshold for a statistically significant difference. We could not perform a publication bias analysis because of the low number of studies. Besides heterogeneity, a P-value < 0.05 was considered statistically significant. Subgroup analyses were performed using data found in the studies for five failure types of reduction and two different age groups (group 0–24, group 0–36).

Results

Search and selection

A total of 13 316 studies were identified by our search, of which 62 studies could be included in the quantitative analysis (Fig. 2). Of the 62 studies, we identified 28 studies (9, 10, 13, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44) that included data only on failure rates, and 34 publications (3, 4, 6, 8, 12, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73) that included data on both rates and risk factors for failure of reduction.

Basic characteristics of included studies

Table 2 summarizes the baseline characteristics of the included studies with data on risk factors.

Of the 34 publications with risk factors, 6 were prospective and 28 were retrospective descriptive studies. Twenty-seven articles provided data on risk factors for one type of failure, one publication provided data on risk factors for two types of failure, and six articles provided data on risk factors for three types of failure.

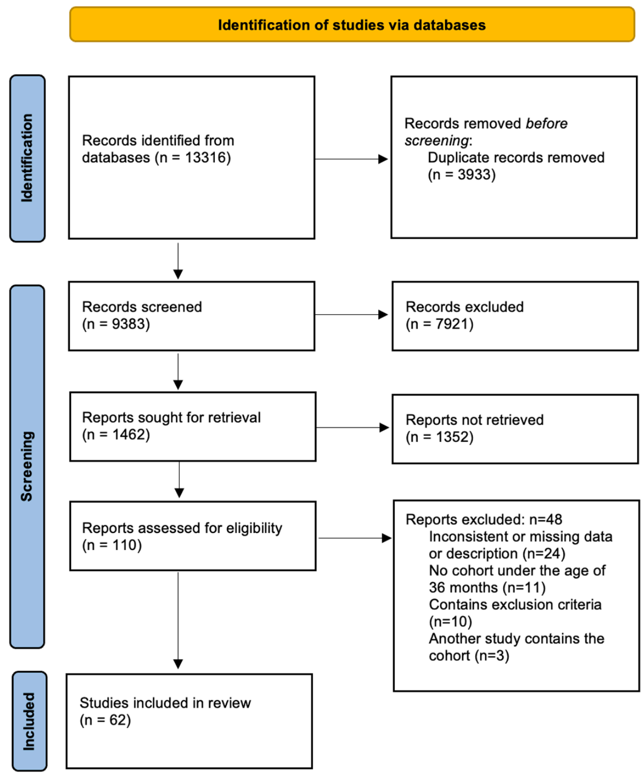

Figure 2

PRISMA 2020 flowchart representing the study selection process.

Of these 34 studies, 23 included information only on patients aged 0–24 months (Table 2). In four articles we were able to collect data on one cohort aged 0–24 months and another one aged 0–36 months (47, 51, 55, 68). Seven other studies included pool data on patients aged 0–36 months (48, 53, 54, 59, 63, 65, 67). Patients over 36 months were excluded from these studies (50, 51, 55).

For further statistical analysis, we formed two groups in the pool of the 34 studies with risk factors: group 0–24 included 27 cohorts with patients aged 0–24 months, and group 0–36 included 34 cohorts with patients aged 0–36 months (Table 2). The total number of patients included in our study was 2839 (3810 hips). The average number of patients was 92 (15–385), the age of the patients was 0–36 months, and the follow-up time was 0 months–27.7 years (Supplementary Table 3).

Failure rate

Based on the time of failure of reduction, we identified three failure types (intraoperative failure, postoperative failure, and redislocation) and two additional types of data for failure rates (failed reduction and overall failure). Table 1 summarizes the failure rates for each failure type and for the different age groups. The overall failure rate for closed reduction was 20% under the age

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Table 2 Basic characteristics of studies included in risk factor analysis.

Reference	Study design	Number of Patients*	Number of Hips	Age† (months)	Age group‡	Follow-up period (months)§	Failure type	Significant risk factors
Alassaf (45)	CSS	104	164	15.6 (5–24)	1	1.5 (N/A)	Failed reduction	- Higher age ($P = 0.01$) - IHDI grade 4 vs 2 ($P = 0.001$) - Decreased acetabular index ($P = 0.02$)
Arneill *et al.* (46)	RS	54	67	6 (3.93–12.07)	1	49 (19–89)	Overall failure	- Shorter length of time spent in harness - Graf 4
Bachy *et al.* (47)	PS	29	34	9.7 (2.1–33.9)	1	N/A (18–76)	Postoperative	
		31	36		2			
Barakat *et al.* (48)	PS	20	29	18.3 (9–36)	2	21 (18–24)	Overall failure	
Bhaskar *et al.* (49)	RS	15	17	9.5 (6–16)	1	28 (24–36)	Redislocation	
Danielsson (50)	PS	68	71	7 (2–22)	1	10.9 (5.5–17.5)	Intraoperative, redislocation, overall failure	
Daoud *et al.* (51)	RS	13	20	26 (18–36)	1	48 (32–65)	Failed reduction, redislocation, overall failure	
		25	35		2			
Elerson *et al.* (52)	PS	96	115	13 ± 5.7	1	> 12	Overall failure	
Elghobashy *et al.* (53)	RS	49	65	24 (9–30)	2	4.2 (3–11) years	Overall failure	- Increasing FAZ (femoro-acetabular zone) grade ($P = 0.001$)
Fleissner *et al.* (54)	RS	68	79	8 (1–36)	2	41.1 (12–120)	Redislocation	- Obstructive limbus ($P = 0.001$)
Forlin *et al.* (55)	RS	56	65	13 (3–31)	1	62 (24–151)	Redislocation	
		60	71		2			
Huang & Wang (56)	RS	16	17	17 ± 5.4	1	> 24	Failed reduction, redislocation, overall failure	
Jones *et al.* (12)	RS	19	28	6 (3–10)	1	48 (12–102)	Overall failure	
Kubo *et al.* (8)	RS	104	132	3 ± 2	1	2 (+/−1)	Postoperative, redislocation	
Li *et al.* (57)	RS	385	440	16 ± 4.9	1	37.4 (24–117)	Failed reduction	
Li *et al.* (58)	RS	276	308	15.3 (6–23.9)	1	41.9 (24–127)	Redislocation	- Tönnis grade 3–4 ($P = 0.027$)
Mitani *et al.* (59)	RS	N/A	38	N/A (12–31)	2	14 (10–21) years	Redislocation	- Interposed limbus
Morris *et al.* (60)	RS	N/A	104	13 ± 4.68	1	16.9 ± 3.8‖ years	Intraoperative	- IHDI grade 4 ($P < 0.001$)
Murray *et al.* (61)	RS	30	35	6 (0.75–16.5)	1	> 20	Failed reduction	
Pospischill *et al.* (62)	RS	64	78	4 (1.2–10.4)	1	6.3 (5.2–7.2) years	Intraoperative	
Ramo *et al.* (63)	RS	N/A	235	N/A (6–36)	2	N/A (48-) in 131 hips	Overall failure	- Tönnis grade (3-)¶ 4 (Pp = 0.0028) - IHDI grade (3-)¶ 4 (Pp = 0.0000)
Sankar *et al.* (64)	PS	78	87	8 (1–20)	1	22 (12–36)	Failed reduction, redislocation, overall failure	- Irreducible hips on clinical and/or US exam (Ortolani neg dislocation) (initial success, $P = 0.006$) - High reduction grade on arthrogram ($P < 0.001$)
Schoenecker *et al.* (65)	RS	32	38	23 (18–35)	2	104 (36-)	Failed reduction, redislocation, overall failure	

(Continued)

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Table 2 Continued.

Reference	Study design	Number of Patients*	Number of Hips	Age† (months)	Age group‡	Follow-up period (months)§	Failure type	Significant risk factors
Senaran *et al.* (66)	RS	21	35	3 (1–7)	1	36 (12–78)	Failed reduction, redislocation, overall failure	
Sucato *et al.* (67)	RS	299	342	11 (2–33)	2	10.4 (2–27.7) years	Overall failure	- Tönnis grade 4 ($P = 0.001$)
Talathi *et al.* (3)	PS	154	166	8.7 ± 4.1	1	N/A	Overall failure	- Graf 4 ($P = 0.003$) - Less femoral head coverage ($P = 0.01$) - Male gender ($P = 0.04$) - Irreducible hips (Ortolani neg) ($P = 0.01$) - IHDI grade 3–4 ($P = 0.002$)
Tennant *et al.* (4)	RS	120	133	9 (4–24)	1	N/A (5-) years	Overall failure	- Bilateral dislocations - Patients ≤ 12 months ($P < 0.04$) - Tönnis grade 4 ($P < 0.003$)
Tennant *et al.* (6)	RS	29	58	7 (3–13)	1	6.5 (3–12)‖ years	Overall failure	- Tönnis grade 4 (in bilateral dislocations)
Terjesen & Horn (68)	RS	49	52	13 (3–33)	1	15.7 (13–21)‖	Overall failure	- Age over 12 months ($P = 0.026$)
		N/A	46		2			
Ucpunar *et al.* (69)	RS	53	65	8.1 ± 1.4	1	4.2 ± 1.5 years	Overall failure	
Yilar *et al.* (70)	RS	218	302	7 (3–17)	1	26 (12-)	Redislocation	- Absence of ossific nucleus ($P = 0.048$)
Yu *et al.* (71)	RS	22	25	10 (3–18)	1	N/A	Postoperative	
Yuan *et al.* (72)	RS	173	187	15.4 ± 4.4	1	N/A (12–36)	Failed reduction	- Age higher than 14.5 months ($P = 0.023$) - Poor delineation of the labrum or acetabular surface on arthrogram ($P < 0.001$), medial dye pool (mdp) distance ≥ 6 mm ($P < 0.001$)
Zhang *et al.* (73)	RS	107	156	13 (4–28)	1	6.7 ± 0.8‖ years	Redislocation	- IHDI grade 4 ($P = 0.004$) - walking ($P = 0.011$)

*In different age groups, if any; †Average age in months (range or S.D.); ‡Group 1: 0–24 months; group 2: 0–36 months; §Average follow-up period in months (range or mean ± S.D.); ‖Age at final follow-up; ¶The respective grade 3 was also a significant risk factor in the publication, but the *P* value was not reported.
N/A: not available; CSS, cross-sectional study; PS, prospective study; RS, retrospective study.

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of 24 months. The highest failure rate was found in the intraoperative subgroup (24%). Publications did not consistently describe all types of failure of reduction.

Intraoperative failure

The closed reduction attempt is not successful (irreducible or unstable hips) and an open reduction is performed either under the same or a separate anesthesia. The rate of intraoperative failure was 24% in group 0–24.

Postoperative failure

The closed reduction was found to be successful in the operating room, but failure is detected during the postoperative x-ray, CT, or MRI scan in the first 48 h after reduction. The rate of postoperative failure was 7% in group 0–24.

Failed reduction (primary failure)

The closed reduction is failed either intraoperatively or a failure is detected on the postoperative imaging scans. The rate of failed reduction includes the intraoperative and postoperative failure rate. The rate of failed reduction was 13% in group 0–24.

Redislocation (secondary failure)

After a primary successful closed reduction (proved by postoperative imaging methods), the reduced femoral head redislocates during or after the postoperative immobilization period. The rate of redislocation was 8% in group 0–24.

Overall failure

The closed reduction is failed either primarily or secondarily. The rate of overall failure includes the rate of failed reduction and the rate of redislocation. The rate of overall failure was 20% in group 0–24.

Risk factors of failure

In the 34 publications, we found data on 71 potential risk factors for gender, different age subgroups, anamnesis, previous treatment, laterality, clinical exam, ultrasound and x-ray findings, soft tissue release, and arthrogram findings (Supplementary Table 4). We analyzed the risk factors separately for all five types of failure data (intraoperative failure, postoperative failure, failed reduction, redislocation, and overall failure) and for the pooled data set, based on the principle that if one treatment step fails, the whole treatment will also fail. We analyzed each data set both in group 0–24 and group 0–36. A total of 136 forest plots were made during our analysis. Forest plots by different failure types, age groups, and risk factors are shown in Fig. 3 and Supplementary Figures 1–16.

Group 0–24

We found that the risk of failure of reduction in closed reduction was significantly higher in IHDI 4 grade dislocations compared to IHDI 2 and IHDI 3 grade (OR: 17.45, CI: 9.26–32.92 and OR: 2.52, CI: 1.22–5.19), in IHDI 3 grade dislocations compared to IHDI 2 grade (OR: 5.00, CI: 2.04–12.23), in Tönnis 4 grade dislocations compared to Tönnis 2 grade (OR: 14.67, CI: 1.21–177.37), in Tönnis 3 grade dislocations compared to Tönnis 2 grade (OR: 3.10, CI: 1.15–8.36), and in Graf 4 grade dislocations compared to Graf 3 grade (OR: 3.4, CI: 2.27–5.09) (Fig. 3A).

However, the overall rate of unsuccessful reduction was lower in Graf 4, Tönnis 4, and IHDI 4 grade dislocations than the rate of successful reduction (43%, 36% and 33% failed, respectively). We also found that the risk of failure in closed reduction was significantly lower in low dislocations regardless of the classification system: in IHDI grade 2 compared to IHDI grade 3–4 dislocations (OR: 0.09, CI: 0.05–0.18), and in Tönnis grade 2 compared to Tönnis grade 3–4 dislocations (OR: 0.22, CI: 0.12–0.42) (Fig. 3A). No significant risk factors for failure of reduction were found in the different failure types, in any age groups, and for gender, laterality, bilateral dislocations, presence of ossific nucleus, and previous treatment including preoperative traction and abduction brace treatment.

Group 0–36

As for group 0–24, high-grade dislocation was also a significant risk factor in group 0–36 (IHDI 4 vs 2 and 3, IHDI 3 vs 2, Tönnis 4 vs 2, Tönnis 3 vs 2 grade). Additionally, the risk of failure was also higher for Tönnis 4 grade dislocations compared to Tönnis 3 grade (OR: 3.37, CI: 1.37–8.27) (Fig. 3B). We also found that the male gender was a significant risk factor for failed reduction treatment step (OR: 2.27, CI: 1.13–4.56) in this group (see Supplementary Figure 8).

Risk of bias assessment

The results of the risk of bias assessment are presented in Supplementary Table 2. The studies included in our meta-analysis mostly had a low risk of bias, with a proper description of the prognostic factors and outcome measures. However, in some cases, only a few prognostic factors were analyzed; therefore, the study's confounding effect of the study was considered moderate.

Discussion

Although several studies identified risk factors for failure of reduction in closed reduction of the dislocated hip in DDH (Table 2), these data were sometimes controversial, their clinical relevance was not obvious,

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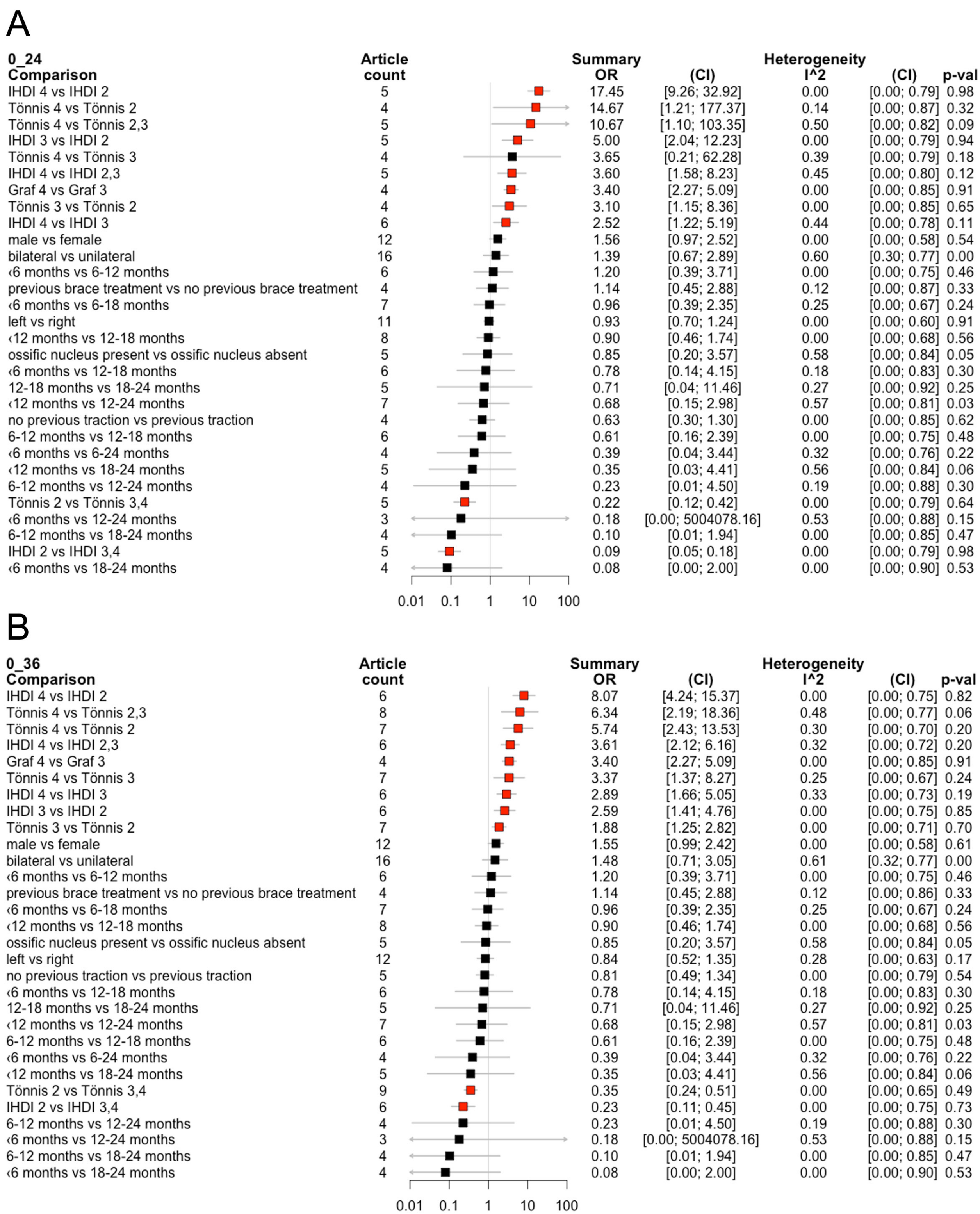

Figure 3

Summary forest plots in group 0–24 (Figure 3A) and group 0–36 (Figure 3B). The risk of failure in closed reduction is significantly higher in high dislocations and significantly lower in low dislocations (red dots, significant results; black dots, non-significant results).

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and the results only slightly influenced treatment protocols. In our study, which is the first systematic review and meta-analysis of risk factors for failure of reduction in the treatment of hip dislocation in DDH, the overall rate of failure was 20%. We also identified significant risk factors: the rate of failure of reduction significantly increased with the grade of dislocation, and the rate of failed reduction was significantly higher in male patients. However, no significant correlation was found between the failure rate of closed reduction and the following factors: age, laterality, unilateral or bilateral dislocations, absence of ossific nucleus of the femoral head, previous brace treatment, and preoperative traction.

Significant risk factors

Gender

Only Talathi described a significant correlation between the male gender and failed closed reduction previously (3). In our meta-analysis, the risk of failed closed reduction was significantly higher in male patients in group 0–36 (odds ratio: 2.27), and there was a non-significant trend for failure in group 0–24 (odds ratio: 1.56, CI: 0.97–2.52).

Grade of dislocation

Several studies found that the rate of failure was significantly higher in high-grade (Graf 4, IHDI 4, Tönnis 4) dislocations (3, 4, 6, 45, 46, 57, 60, 63, 65, 67, 73), but in one study (48) the rate of failure was lower in high (IHDI IV) dislocations. However, the rate of failure of reduction in high dislocations was not known. In our meta-analysis, we also found that the failure rate was significantly higher in high dislocations.

Graf classification (ultrasound)

Graf 4 grade hip dislocation was a significant risk factor for failure in two studies (3, 46). However, Tschauner found that in Graf 4 dislocations open reduction was needed only if these hips were missed in the first weeks after birth (10). In our meta-analysis, the odds of failure in closed reduction were 3.4 times higher in Graf 4 hips compared to Graf 3 grade dislocations in group 0–24 and the average failure rate was 43% in Graf 4 dislocations (Supplementary Figures 19 and 20).

IHDI classification (X-ray)

In three studies the rate of failure significantly increased with increasing IHDI grades (3, 45, 63). In other studies, IHDI grade 4 dislocation was a significant risk factor for redislocation (73) or overall failure (60). In the study by Ramo, the rate of unsuccessful closed reduction of IHDI 4 grade hips was higher (56.4%) than that of successful closed reduction (63). Other studies did not find a significant correlation (64, 72). In our study, the odds of failure in closed reduction significantly increased with increasing IHDI grades and was 17.45 times higher in IHDI 4 hips compared to IHDI 2 grade dislocations under 24 months of age. The average failure rate was 33% in IHDI 4, 16% in IHDI 3, and 2% in IHDI 2 dislocations (Supplementary Figures 19 and 20).

Tönnis classification (x-ray)

In three studies the rate of failure significantly increased with Tönnis grade for either redislocation (30) or overall failure (63, 65). In two other studies, a Tönnis grade 4 dislocation was a significant risk factor for failure (4, 67). In the study by Tennant, 94% of the bilateral Tönnis grade 4 dislocations failed closed reduction (6). In our study, the odds of failure significantly increased with increasing Tönnis grades and was 14.67 times higher for Tönnis 4 hips compared to Tönnis 2 grade dislocations. The average failure rate was 36% in Tönnis 4, 12% in Tönnis 3, and 6% in Tönnis 2 dislocations (Supplementary Figures 19 and 20). The slight difference in statistical analysis between IHDI and Tönnis classification (IHDI 4 was a significant risk factor for failure compared to IHDI 3 but Tönnis 4 was not compared to Tönnis 3 in group 0–24) may be explained by the reproducibility of classification systems, there was a nonstatistically significant better agreement for the IHDI versus the Tönnis classification in the study by Ramo (63).

Non-significant risk factors

In our meta-analysis, we found no significant correlation between the rate of failure of reduction and the following risk factors.

Age

The age of the child is one of the main factors that significantly influence the treatment of a dislocated hip (see Fig. 1). Several studies described a significant correlation between age and failure rate in closed reduction treatment, but the results were controversial. Older age was a significant risk factor in several studies (45, 65, 72, 74), but younger age (≤12 months) was also a significant risk factor in one study (4).

Based on the included studies, we could investigate 12 different potential risk groups regarding failure: age at baseline exam, age at reduction, <6 months, <12 months, <24 months, 6–12 months, 12–18 months, 18–24 months, 6–18 months, 12–24 months, 24–36 months, 6–24 months (see Supplementary Table 4). Based on this, we performed subgroup analyses in 13 different age-group pairs, both in group 0–24 and in group 0–36 (see Fig. 3A and B), and we also performed a subgroup analysis for patients aged < 24 months compared to patients aged 24–36 months. We also investigated whether age influences the risk for failure in different treatment steps (intraoperative failure, postoperative failure, redislocation).

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In total, we performed 44 subgroup analyses to determine if the child's age influences the risk for failure of reduction. However, we did not find any significant correlation between age and the failure rate of closed reduction.

Ossific nucleus of the femoral head

Only Yilar found a significant correlation between the presence of the femoral head ossific nucleus and a lower rate of redislocation (70). Other studies found no significant correlation (4, 49, 64, 72).

Previous conservative treatment

Previous Pavlik harness treatment did not significantly affect the failure rate in several studies (3, 4, 64). However, in the study by Arneill (46), 48% of patients also failed closed reduction after a failed conservative treatment.

Unilateral–bilateral dislocations

Tennant described a significantly higher failure rate in bilateral cases (at least one hip failed in 46%, and both hips failed in 31%) (4). In addition, Arneill also published a high (62%) failure rate in bilateral cases (46). Other studies (3, 45, 64, 70, 72) did not find any significant correlation between unilateral and bilateral cases.

Prereduction traction

In our meta-analysis, we investigated studies in which closed reduction was performed under general anesthesia either with or without preliminary traction. However, studies with gradual traction, where the reduction of the dislocated femoral head was not performed under general anesthesia (i.e. Petit–Morel and FACT-R techniques (76, 77, 78, 79)), were excluded, as the process of reduction is different from closed reduction under general anesthesia, and the results are not comparable.

Although patients with a fixed dislocation were more likely to undergo preoperative traction in the study by Sucato (67), no difference was found in the risk of failure of reduction between traction and non-traction groups, for any age groups either in reducible or irreducible dislocations (67). In two studies, traction also did not influence the risk of failure either in dislocations with lower Tönnis grades or in dislocations with higher Tönnis grades (57, 67). Other studies did not find a significant correlation between failure risk and the application of preoperative traction or the length of traction in irreducible dislocations (52, 64, 68).

In five studies, we found data on the failure rates of patients treated with and without preliminary traction (52, 56, 57, 64, 67). In our meta-analysis, we found no significant correlation between preliminary traction and failure rate of closed reduction.

Risk factors with insufficient data for statistical analysis

We performed statistical analysis of the risk factors when data were available in at least 3 independent cohorts. There were insufficient data available in the publications for further quantitative analysis of other risk factors.

Irreducible dislocations

In preoperatively irreducible (Ortolani neg) dislocations the rate of failure was significantly higher in two studies (3, 64), and in the study by Sankar, failure was identified as an intraoperative failure (64).

Adductor tenotomy

In the multicenter study by Sankar, an adductor tenotomy was performed in 85% of the patients, and there was no significant relationship between adductor tenotomy and failure of reduction (64). However, there was a non-significant trend toward fewer adductor releases in hips that failed initial reduction (64).

In the study by Ucpunar, 33% of the patients required adductor tenotomy to achieve a stable reduction and to ensure a minimum 30° safe zone and/or at least 45° hip abduction in 90° hip flexion. The need for adductor tenotomy was one of the main predictors of the possible secondary surgery in this study (69). In the study by Tennant, soft tissue release (adductor tenotomy or adductor+psoas tenotomy) was performed in 73% of the hips, and no significant correlation was found between failure of reduction and soft tissue release (4).

Intraoperative arthrogram

Obstructions to reduction on arthrogram and an unstable hip after initial closed reduction are indications for transition to an open reduction during closed reduction surgery (62). Several studies investigated the role of intraoperative arthrogram findings related to the failure of reduction (54, 59, 64, 72). Although several significant risk factors for failure were identified in the arthrogram (reduction grade (64), poor delineation of the labrum or acetabular surface, medial dye pool (MDP) distance ≥ 6 mm (72), obstructive limbus (54)), none of these risk factors had data in three different cohorts to perform a quantitative analysis in our study. However, inverted labrum was not a significant risk factor in the study by Yuan (72).

Spica cast immobilization, postoperative splint

Only Sankar published data on the failure rate regarding the length of postoperative spica cast immobilization (64). 90% of the hips received a hip spica cast for a median of 12 weeks (4–30 weeks), and 10% directly received a Denis Browne splint for a median of 26 weeks

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(9–53 weeks). Of those treated with spica casting, 68% of hips also received postcasting abduction orthosis. In this study, no significant correlation was found between the length of spica cast immobilization and failure rate.

Femoral anteversion, acetabular anteversion

In the study by Hong, statistically significantly increased femoral anteversion angle was found in Tönnis 3 and 4 types of hip dislocations (80). However, the rate of redislocation was not influenced by femoral anteversion values in this study in patients treated by closed or open reduction.

Increased femoral and acetabular anteversion angles were also found in hip dislocation in other studies (81, 82), but no other statistical analysis was performed if femoral or acetabular anteversion influences the rate of failure in closed reduction. However, these anatomical changes might influence the success of closed reduction and the need for additional surgery.

Failure rates and risk factors of failure in different treatment steps

We identified three types of failure in closed reduction (intraoperative failure, postoperative failure, and redislocation) and two additional types of data for failure rates (failed reduction and overall failure). Some important risk factors for the different treatment steps have been described previously. In terms of intraoperative failure, only preoperatively irreducible dislocations were found to be a risk factor (64). No significant risk factors were found for postoperative failure. However, several risk factors were described for redislocation: IHDI grade 4 (73), higher Tönnis grades (58), obstructive limbus (54), and walking ability (73). In addition, a lower rate of redislocation was described in the presence of the ossific nucleus of the femoral head (70). In the study by Sankar, redislocation occurred at a median of 4 months following an initially successful reduction (64).

In our meta-analysis, the intraoperative failure, postoperative failure, and redislocation rates in group 0–24 were 24%, 7%, and 8%, respectively. In our quantitative analysis, we found only the male gender to be a significant risk factor for failure of a specific treatment step (failed reduction).

Combination of risk factors

The failure of reduction seems multifactorial. Several risk factors have been described, but none of these alone causes failure in the majority of the patients. However, there are data that the incidence of failure is higher due to multiple risk factors. For example, in the study by Tennant, the rate of failure was 4 times higher in bilateral Tönnis 4 hips compared to bilateral Tönnis 2 and 3 cases (94% vs 23%), almost all bilateral Tönnis 4 grade hips failed (6). Talathi found that the odds of failure were 2.5 higher in IHDI grade 4 hips compared to IHDI 3 hips, 3.3 times higher in patients with negative Ortolani sign but in the presence of both risk factors for failure, the odds of failure were 4.4 times higher (3).

Strengths and limitations

Our study has several strengths: this is the first systematic review and meta-analysis of risk factors for failure of reduction in hip dislocation treatment. We followed a pre-defined and registered protocol during our study and applied a rigorous methodology. As a result, we included a high number of publications, and a large number of patients could be enrolled. We also performed a detailed quantitative analysis with a high amount of data. Furthermore, we were able to identify high-risk patient groups.

As for the limitations of this work, publications did not consistently investigate and define the different failure groups, and the treatment protocol slightly varied across the articles. Furthermore, other complications and long-term results were not assessed in this study.

Conclusion

The overall rate of failure of reduction in closed reduction is 20% and most failures occur intraoperatively. The risk of failure of reduction increases with the grade of dislocation and is significantly higher for high dislocations, regardless of the classification system. In addition, the risk of failure of reduction is significantly lower in lower dislocations. Male gender was a significant risk factor for failed reduction in group 0–36. No significant correlation was found between any age group, preoperative traction, unilateral or bilateral dislocations, presence of femoral head ossific nucleus, previous conservative treatment, and failure of reduction.

Implications for practice and research

The benefit of implementing scientific results immediately has been previously proved (83, 84). Surgeons should be aware that there is a high risk of failure of reduction in closed reduction in high dislocations. In these cases, especially in combination with other risk factors such as irreducible dislocation, obstruction to reduction on arthrogram and male gender, or in bilateral high dislocations achieving and maintaining a stable concentric reduction by closed means is more difficult, and transition to an open reduction after an attempted closed reduction, or redislocation is more likely to be expected. However, based on our results further prospective data collection and analysis should be performed to better understand

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the role of other risk factors such as age, irreducible dislocation, preoperative traction, adductor tenotomy, intraoperative arthrogram findings, and anatomical changes of the dislocated hip joints.

Supplementary materials

This is linked to the online version of the paper at https://doi.org/10.1530/EOR-24-0007.

ICMJE Conflict of Interest Statement

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the study reported.

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Ethical statement

No ethical approval was required for this systematic review with meta-analysis, as all data were already published in peer-reviewed journals. No patients were involved in the design, conduct or interpretation of our study. The datasets used in this study can be found in the full-text articles included in the systematic review and meta-analysis.

Author contribution statement

GD: conceptualization, formal analysis, writing – original draft; SV: conceptualization, project administration, methodology, writing – review and editing; CS: conceptualization, formal analysis, visualization, writing – review and editing; GA: conceptualization, formal analysis, visualization, writing – review and editing; PH: conceptualization, funding acquisition, writing – review and editing; AP: writing – review and editing, data curation; KB: writing – review and editing, data curation; CV: conceptualization, data curation, writing – review and editing; GS: conceptualization; supervision; writing – original draft. All authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript.

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