REVIEW ARTICLE

Early Versus Delayed Treatment for Gartland Type III Supracondylar Humeral Fractures in Children: A Systematic Review and Meta-analysis

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Abstract

Purpose The timing of treatment for Gartland type III supracondylar fractures has been an area of contention as it was previously thought to be a surgical emergency. The aim of this systematic review and meta-analysis is to clarify whether there is a difference in perioperative outcomes between early and delayed treatment for Gartland type III supracondylar humeral fractures in children.

Methods Literature search and study selection were performed according to the PRISMA process. The early surgery (ES) and delayed surgery (DS) groups were defined by the authors of each study included, based on the time to surgery. The primary outcome was the risk of conversion to open reduction. The secondary outcome was perioperative complication risks.

Results A total of 14 studies met the eligibility criteria ($n = 1263$ patients), of which 665 (52.7%) patients had undergone early surgery, while 598 (47.3%) had delayed surgery. On meta-analysis, there was no significant difference between ES and DS for the outcome of open reduction conversion risk. There was also no significant difference for the secondary outcomes of post-operative compartment syndrome, iatrogenic nerve injury, vascular injury, and surgical site infection.

Conclusion Despite the limitations in the literature, evidence exists to support the notion that a delayed approach to the surgical treatment of Gartland type III supracondylar humeral fractures in children does not result in an increased risk of converting to open reduction and perioperative complications.

Keywords Gartland type III fractures · Supracondylar humeral fractures · Paediatrics · Systematic review · Meta-analysis

Introduction

Supracondylar humeral fractures in paediatrics are injuries frequently encountered in the trauma and orthopaedics department, accounting for 16% of all paediatric fractures and 60% of all paediatric elbow fractures [1]. The injury occurs most commonly in children between the ages of 5 and 7 on their non-dominant side, as a result of falling onto an outstretched hand with the elbow in full extension, causing an extension-type supracondylar fracture [2, 3]. The severity of the injury is defined by the Gartland classification, and whether the patient has vascular or neurological compromise; type I fractures are non-displaced, type II fractures are displaced with an intact posterior cortex, and type III are completely displaced fractures with no cortical contact [4].

The timing of treatment for Gartland type III supracondylar fractures has been an area of contention. It was previously thought to be a surgical emergency, with delays resulting in an increased risk of compartment syndrome secondary to swelling, as well as an increased difficulty in achieving adequate closed reduction and subsequently the need for conversion to open reduction [2]. A systematic review, Loizou et al. [5], helped solidify this opinion as it concluded that delaying treatment of Gartland type III fractures more than 12 h resulted in an increased rate of conversion to an open technique for reduction [5]. On the other hand, a more recent systematic review, Farrow et al. [6], challenges this notion as it established that a delay in treatment by up to 3 days for

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all closed Gartland type II and III supracondylar fractures, in the absence of vascular compromise, did not significantly increase the risk of conversion to open reduction or the risk of complications [6].

Given the contrasting findings in each systematic review, it is still somewhat unclear whether Gartland type III fractures should be treated as an orthopaedic emergency which warrants overnight treatment or whether it can be delayed, a decision which is very surgeon dependent. Furthermore, the COVID-19 pandemic has added strain on the healthcare systems across the globe. This has increased issues with theatre capacity and availability, and along with the need for COVID testing prior to theatre has resulted in more trauma cases being treated later than usual.

The aim of this systematic review is to clarify whether there is a difference in the perioperative outcomes between early and delayed treatment for Gartland type III supracondylar fractures in children.

Materials and Methods

Literature Review

A systematic review and meta-analysis were performed to assess the perioperative outcomes of early surgery (ES) versus delayed surgery (DS) for Gartland type III supracondylar humeral fractures in children. All relevant articles were identified using the MEDLINE/PubMed and EMBASE database search for the period from 1942 to November 2021. In addition, Google Scholar search engine was used to ensure retrieval of all related articles to the study. All electronic searches were conducted before November 2021. The study selection process was done according to the PRISMA process (Preferred Reporting Items for Systematic reviews and Meta-Analyses) [7]. The study protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) prior to commencement of data extraction (Registration Number CRD42021289759).

Eligibility Criteria

Studies were only included in the review if they had: (1) made comparison between early and delayed surgery of Gartland type III supracondylar humeral fractures in children, (2) assessed for the primary outcome mentioned below, and (3) been retrospective or prospective non-review research articles.

Studies were excluded if they: (1) included Gartland type I or II fractures, and Gartland type III data could not be extracted separately for the primary outcome mentioned below, (2) included supracondylar fracture cases that warrant emergency intervention; vascular compromise, etc., (3)

were not in English or English-translated, or (4) were non-comparative studies.

Comparator Groups

The early surgery (ES) and delayed surgery (DS) groups were classified by the authors of each study included, based on the time to surgery. The ES group consists of the patients who underwent surgery before a specific time defined by the authors of that study, while the DS group included the patients who underwent surgery after that specified time. If the study has divided the time to surgery into more than two groups, then the earliest group will be added to the ES cohort and the remaining later groups will be combined into one set and added to the DS cohort for our systematic review and meta-analysis.

Outcome Measure

The primary outcome was to assess the risk of conversion to open reduction in the event of failed closed reduction. The secondary outcome was to assess perioperative complication risks including: (1) compartment syndrome, (2) iatrogenic nerve injury, (3) vascular injury, and (4) surgical site infection.

Quality Assessment

The Risk of Bias in Non-Randomised Studies-Interventions (ROBINS-I) tool was utilized to assess the risk of bias in the studies included [8]. Furthermore, the quality of evidence for each outcome was assessed using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach for systematic reviews and meta-analysis [9]. This was performed by one reviewer (GI), and then checked by another reviewer (WK), with any disagreements discussed with the third reviewer (MI).

Statistical Analysis

A meta-analysis was conducted using the outcomes from studies that met the eligibility criteria and had sufficient homogeneity with regards to population, intervention, and study design. Review Manager 5.4 software was used for the data analysis. The I-squared statistic (I^2) and Chi-square (χ^2) tests were used to determine statistical heterogeneity within the meta-analyses. For dichotomous outcomes, a random-effects model and Mantel–Haenszel statistical method were utilized for all analyses. The risk difference (RD) values were calculated to measure the outcome effect. In all analyses, a p value < 0.05 represented statistical significance. All analysis results are reported in the text as risk difference

(RD), 95% confidence intervals (CI), *p* value, and sample size (*n*).

Results

Studies Selection

The five studies incorporated in the previous version of the review, Loizou et al. [5], were included in our study [10–14]. A total of 594 studies were identified from the literature search after filtering out duplicate articles. Out of these, 34 studies were selected for full-text review, of which nine new studies were found to meet the eligibility criteria, in addition to the five studies in the previous version of the review. Thus, a total of 14 studies were selected for our study [10–23] (Fig. 1). A total of 1263 patients with Gartland type III fracture have been included in these studies, of which 665 (52.7%) patients had undergone early surgery, while 598 (47.3%) had delayed surgery. From the 14 studies included, two were prospective cohort designs, while the remaining were retrospective cohort designs. Five of the studies included both Gartland types II and III in their study. However, since it was possible to separately extract the Gartland type III data for the primary outcome, these studies were included in our systematic review and meta-analysis (Table 1).
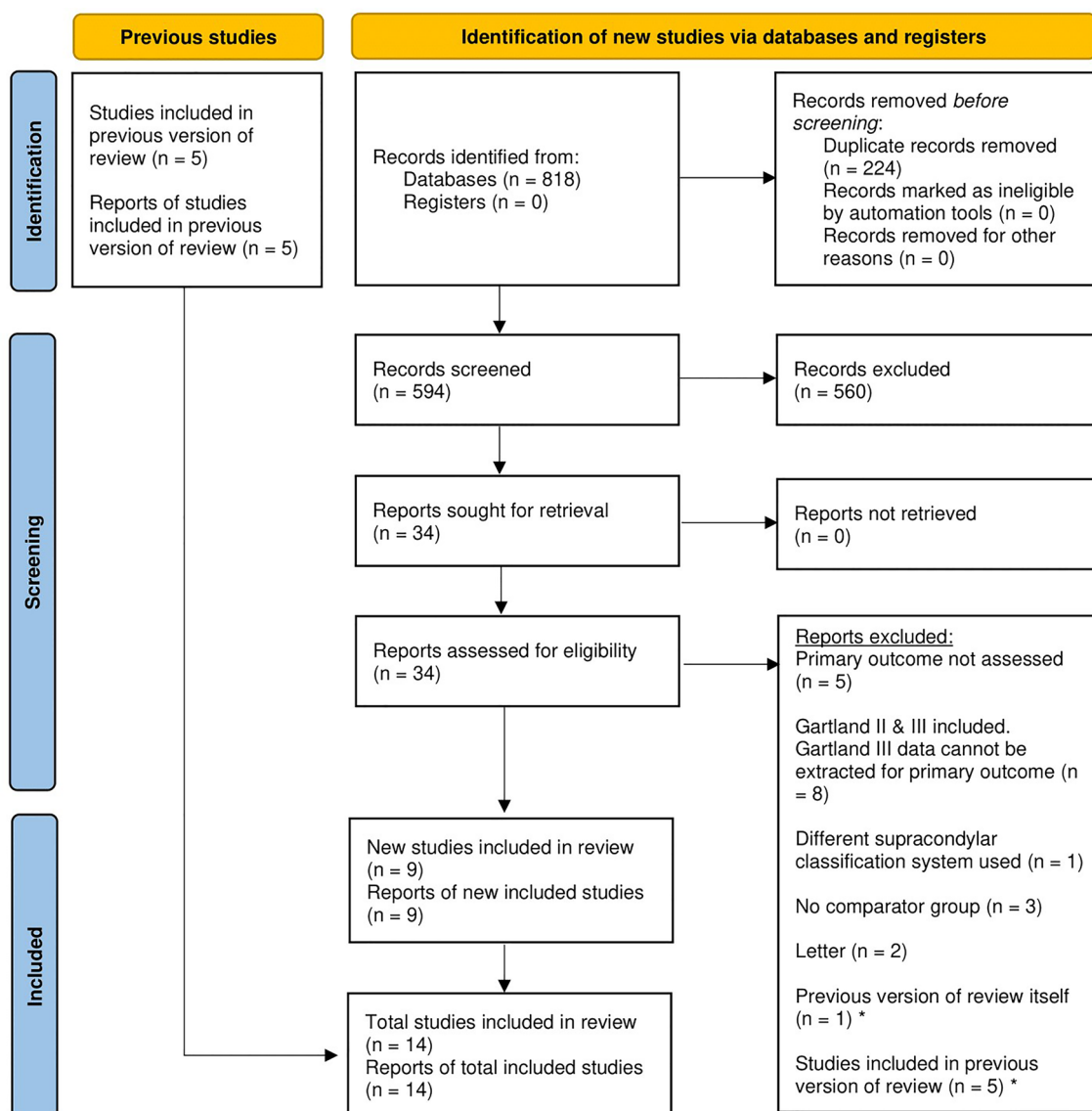
Fig. 1 PRISMA flow diagram. *PRISMA* Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Asterisk indicates the previous version of review = Loizou et al. [5]

Table 1 Summary of characteristics of the studies included

Author (year)	Study design	Patients, n	Gender, (male/female)	Mean age, (years)	Mean time to surgery (hours)	Mean duration of surgery (min)	Early and delayed surgery defining time (hours)
Iyengar et al. (1999) [10]	RC	58	N/A	ES: 6.3, DS: 5.7	N/A	N/A	ES: < 8 h from injury, DS: > 8 h from injury
Gupta et al. (2004)[a] [11]	RC	69	N/A	N/A	N/A	N/A	ES: < 12 h from injury, DS: > 12 h from injury
Carmichael et al. (2006)[a] [12]	RC	21	ES: 9/7, DS: 3/2	ES: 5.3, DS: 6.4	N/A	N/A	ES: < 8 h from injury, DS: > 8 h from injury
Sibinski et al. (2006) [13]	RC	77	ES: 25/18, DS: 16/18	ES: 6.4, DS: 6.8	ES + DS: 11	ES: 63, DS: 60	ES: < 12 h from injury, DS: > 12 h from injury
Walmsley et al. (2006) [14]	RC	171	ES: 70/56, DS: 18/27	ES: 6.4, DS: 5.8	ES: 3.3, DS: 9.6	N/A	ES: < 8 h from presentation, DS: > 8 h from presentation
Yildirim et al. (2009) [15]	PC	190	ES + DS: 129/61	ES + DS: 7.4	ES + DS: 32	N/A	ES: < 15 h from injury, DS: > 15 h from injury[b]
Bales et al. (2010)[a] [16]	PC	42	N/A	N/A	ES + DS: 19	ES: 53.1, DS: 50.3	ES: < 21 h from presentation, DS: > 21 h from presentation
Murnaghan et al. (2010) [17]	RC	87	N/A	N/A	ES: 5.7, DS: 17.9	ES: 32.6, DS: 31.7	ES: < 8 h from injury, DS: > 8 h from injury
Han et al. (2011) [18]	RC	86	ES: 24/16, DS: 30/16	ES: 7.2, DS: 7.6	N/A	N/A	ES: < 12 h from injury, DS: > 12 h from injury
Schmid et al. (2015)[a] [19]	RC	199	N/A	N/A	N/A	N/A	ES: < 6 h from injury, DS: > 6 h from injury[b]
Khabiri et al. (2016) [20]	RC	24	ES: 5/3, DS: 10/6	ES: 4.8, DS: 5.0	N/A	N/A	ES: < 24 h from injury, DS: > 24 h from injury
Kwiatkowska et al. (2018) [21]	RC	23	ES + DS: 13/10	ES + DS: 6.1	ES + DS: 14.5	N/A	ES: < 6 h from injury, DS: > 6 h from injury[b]
Suganuma et al. (2020)[a] [22]	RC	66	ES + DS: 52/14	ES + DS: 6.5	N/A	ES: 30, DS: 47.5	ES: < 12 h from injury, DS: > 12 h from injury
Okkaoglu et al. (2021) [23]	RC	150	ES: 46/44, DS: 36/24	ES: 5.8, DS: 6.1	ES: 6, DS:16.6	ES: 58.8, DS: 66.7	ES: < 12 h from admission, DS: > 12 h from admission

N number of patients, *ES* early surgery, *DS* delayed surgery, *N/A* not available, *RC* retrospective cohort, *PC* prospective cohort

[a]These studies included Gartland type II and III fractures. N/A applied if Gartland type III fracture data cannot be extracted separately for the mentioned characteristic

[b]These studies had more than two groups based on the time to surgery. For our systematic review and meta-analysis, the earliest group was considered the ES group and the later groups were considered as one forming the DS group. Iyengar et al. [10]; Gupta et al. [11]; Carmichael et al. [12]; Sibinski et al. [13]; Walmsley et al. [14]; Yildirim et al. [15]; Bales et al. [16]; Murnaghan et al. [17]; Han et al. [18]; Schmid et al. [19]; Khabiri et al. [20]; Kwiatkowska et al. [21]; Suganuma et al. [22]; Okkaoglu et al. [23]

Primary Outcome (Risk of Conversion to Open Reduction)

All 14 studies included assessed the risk of conversion to open reduction upon failed closed reduction attempts. Meta-analysis conducted on these studies showed no significant difference in the risk of conversion to open reduction between ES and DS (RD − 0.10; 95% CI − 0.25–0.04; $p = 0.17$; $n = 1263$; Fig. 2). The funnel plot for the primary outcome showed significant heterogeneity in the results for 1 of the 14 studies, Yildirim et al. [15], in comparison to the other studies [15] (Fig. 3). A replicated meta-analysis
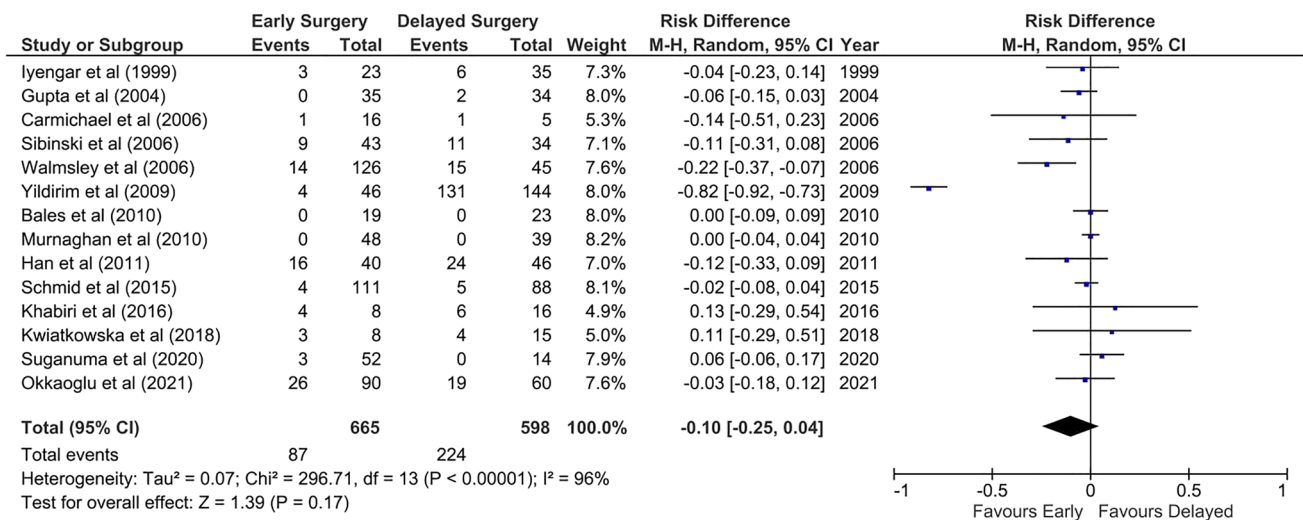
Fig. 2 Forest plot of ES versus DS for the primary outcome: risk of conversion to open reduction. Yildirim et al.'s [15] study included in meta-analysis. *CI* Confidence Interval, *Random* random-effects model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Heterogeneity. Iyengar et al. [10]; Gupta et al. [11]; Carmichael et al. [12];

Sibinski et al. [13]; Walmsley et al. [14]; Yildirim et al. [15]; Bales et al. [16]; Murnaghan et al. [17]; Han et al. [18]; Schmid et al. [19]; Khabiri et al. [20]; Kwiatkowska et al. [21]; Suganuma et al. [22]; Okkaoglu et al. [23]

Fig. 3 Funnel plot on the 14 studies for the primary outcome: risk of conversion to open reduction. The Yildirim et al.'s [15] study shows significant heterogeneity to the left. The dotted line represents the RD for the meta-analysis including the above study, while the continuous line represents the RD for the meta-analysis excluding the study. *RD* Risk Difference. Yildirim et al. [15]
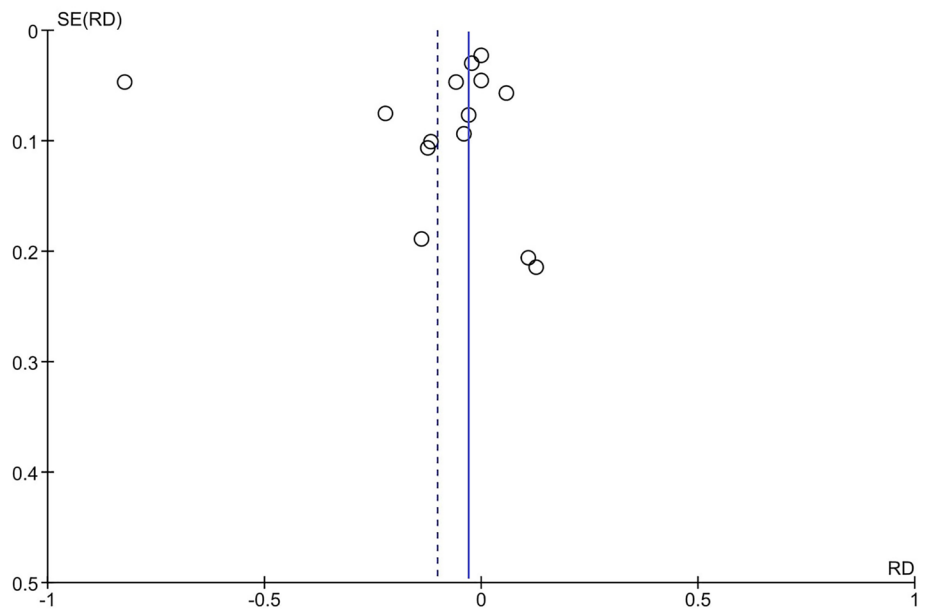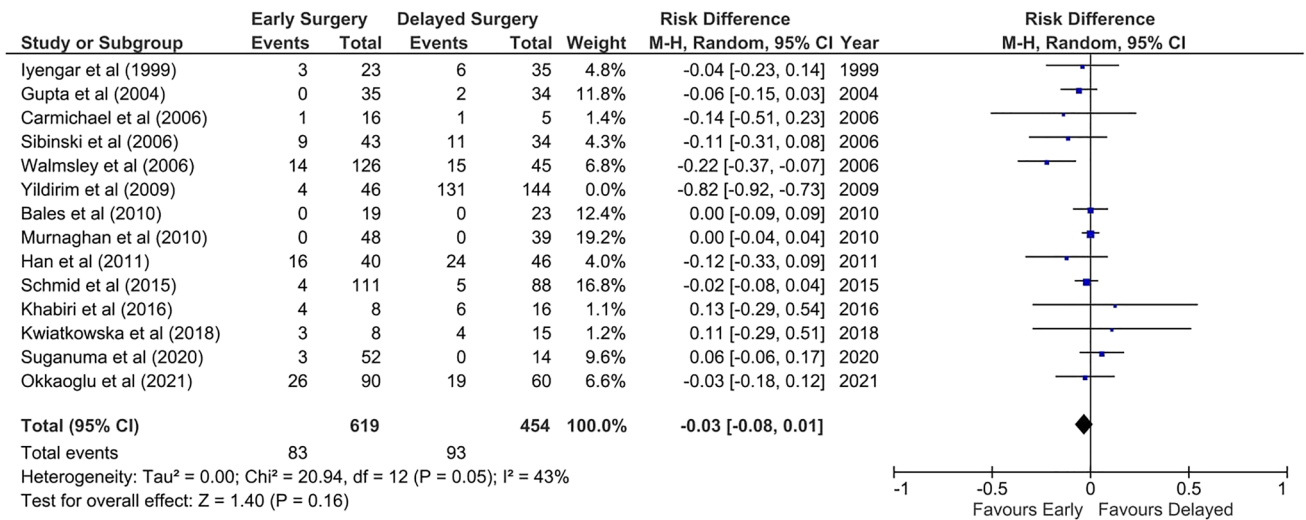
excluding this study, however, did not yield a statistical significance either (RD − 0.03; 95% CI − 0.08–0.01; $p = 0.16$; $n = 1073$; Fig. 4).

Secondary Outcome (Compartment Syndrome)

The risk of developing compartment syndrome was assessed in four studies, in which no cases were reported in either the ES or the DS group (RD 0.00; 95% CI − 0.03–0.03; $p = 1.00$; $n = 330$; Fig. 5).
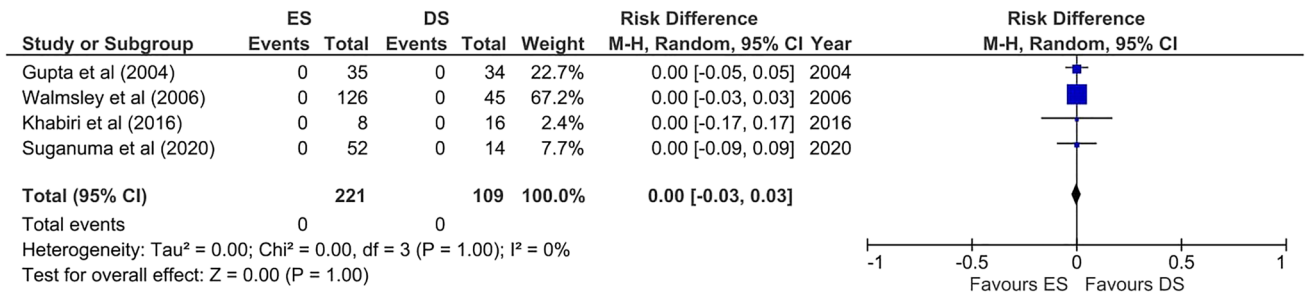
Secondary Outcome (Iatrogenic Nerve Injury)

Iatrogenic nerve injury was assessed in six of the studies. Meta-analysis showed that there was no significant difference for ES compared with DS regarding the risk of nerve injury (RD 0.00; 95% CI − 0.04–0.04; $p = 0.90$; $n = 439$; Fig. 6).

Study or Subgroup	Early Surgery Events	Early Surgery Total	Delayed Surgery Events	Delayed Surgery Total	Weight	Risk Difference M-H, Random, 95% CI	Year	Risk Difference M-H, Random, 95% CI
Iyengar et al (1999)	3	23	6	35	4.8%	-0.04 [-0.23, 0.14]	1999	
Gupta et al (2004)	0	35	2	34	11.8%	-0.06 [-0.15, 0.03]	2004	
Carmichael et al (2006)	1	16	1	5	1.4%	-0.14 [-0.51, 0.23]	2006	
Sibinski et al (2006)	9	43	11	34	4.3%	-0.11 [-0.31, 0.08]	2006	
Walmsley et al (2006)	14	126	15	45	6.8%	-0.22 [-0.37, -0.07]	2006	
Yildirim et al (2009)	4	46	131	144	0.0%	-0.82 [-0.92, -0.73]	2009	
Bales et al (2010)	0	19	0	23	12.4%	0.00 [-0.09, 0.09]	2010	
Murnaghan et al (2010)	0	48	0	39	19.2%	0.00 [-0.04, 0.04]	2010	
Han et al (2011)	16	40	24	46	4.0%	-0.12 [-0.33, 0.09]	2011	
Schmid et al (2015)	4	111	5	88	16.8%	-0.02 [-0.08, 0.04]	2015	
Khabiri et al (2016)	4	8	6	16	1.1%	0.13 [-0.29, 0.54]	2016	
Kwiatkowska et al (2018)	3	8	4	15	1.2%	0.11 [-0.29, 0.51]	2018	
Suganuma et al (2020)	3	52	0	14	9.6%	0.06 [-0.06, 0.17]	2020	
Okkaoglu et al (2021)	26	90	19	60	6.6%	-0.03 [-0.18, 0.12]	2021	
Total (95% CI)		619		454	100.0%	-0.03 [-0.08, 0.01]		
Total events	83		93					

Heterogeneity: Tau² = 0.00; Chi² = 20.94, df = 12 (P = 0.05); I² = 43%
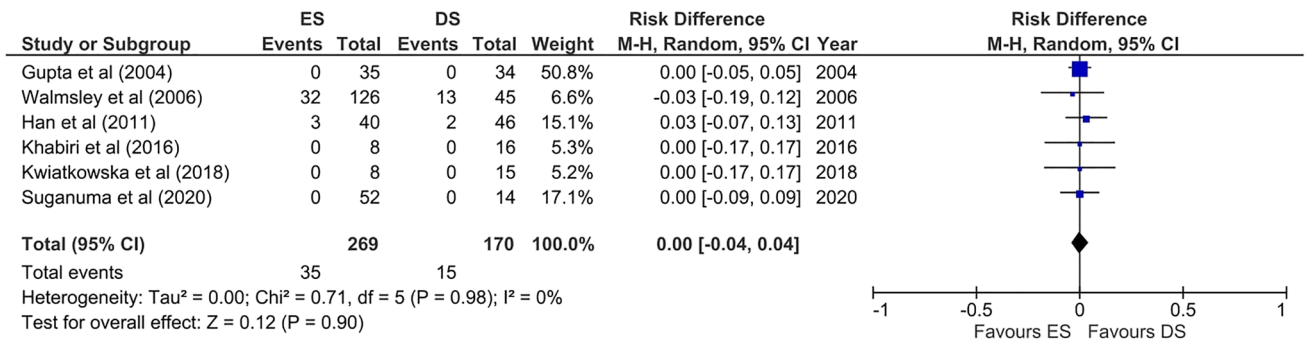Test for overall effect: Z = 1.40 (P = 0.16)

Fig. 4 Forest plot (replicated) of ES versus DS for the primary outcome: risk of conversion to open reduction. Yildirim et al.'s [15] study excluded from meta-analysis. *CI* Confidence Interval, *Random* Random-Effects Model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Heterogeneity. Iyengar et al. [10]; Gupta et al. [11]; Carmichael et al. [12]; Sibinski et al. [13]; Walmsley et al. [14]; Yildirim et al. [15]; Bales et al. [16]; Murnaghan et al. [17]; Han et al. [18]; Schmid et al. [19]; Khabiri et al. [20]; Kwiatkowska et al. [21]; Suganuma et al. [22]; Okkaoglu et al. [23]

Study or Subgroup	ES Events	ES Total	DS Events	DS Total	Weight	Risk Difference M-H, Random, 95% CI	Year	Risk Difference M-H, Random, 95% CI
Gupta et al (2004)	0	35	0	34	22.7%	0.00 [-0.05, 0.05]	2004	
Walmsley et al (2006)	0	126	0	45	67.2%	0.00 [-0.03, 0.03]	2006	
Khabiri et al (2016)	0	8	0	16	2.4%	0.00 [-0.17, 0.17]	2016	
Suganuma et al (2020)	0	52	0	14	7.7%	0.00 [-0.09, 0.09]	2020	
Total (95% CI)		221		109	100.0%	0.00 [-0.03, 0.03]		
Total events	0		0					

Heterogeneity: Tau² = 0.00; Chi² = 0.00, df = 3 (P = 1.00); I² = 0%
Test for overall effect: Z = 0.00 (P = 1.00)

Fig. 5 Forest plot of ES versus DS for the secondary outcome: risk of compartment syndrome. *CI* confidence interval, *Random* random-effects model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Heterogeneity. Gupta et al. [11]; Walmsley et al. [14]; Khabiri et al. [20]; Suganuma et al. [22]

Study or Subgroup	ES Events	ES Total	DS Events	DS Total	Weight	Risk Difference M-H, Random, 95% CI	Year	Risk Difference M-H, Random, 95% CI
Gupta et al (2004)	0	35	0	34	50.8%	0.00 [-0.05, 0.05]	2004	
Walmsley et al (2006)	32	126	13	45	6.6%	-0.03 [-0.19, 0.12]	2006	
Han et al (2011)	3	40	2	46	15.1%	0.03 [-0.07, 0.13]	2011	
Khabiri et al (2016)	0	8	0	16	5.3%	0.00 [-0.17, 0.17]	2016	
Kwiatkowska et al (2018)	0	8	0	15	5.2%	0.00 [-0.17, 0.17]	2018	
Suganuma et al (2020)	0	52	0	14	17.1%	0.00 [-0.09, 0.09]	2020	
Total (95% CI)		269		170	100.0%	0.00 [-0.04, 0.04]		
Total events	35		15					

Heterogeneity: Tau² = 0.00; Chi² = 0.71, df = 5 (P = 0.98); I² = 0%
Test for overall effect: Z = 0.12 (P = 0.90)

Fig. 6 Forest plot of ES versus DS for the secondary outcome: risk of iatrogenic nerve injury. *CI* confidence interval, *Random* random-effects model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Heterogeneity. Gupta et al. [11]; Walmsley et al. [14]; Han et al. [18]; Khabiri et al. [20]; Kwiatkowska et al. [21]; Suganuma et al. [22]

Secondary Outcome (Vascular Injury)

The rate of vascular deficit postoperatively was mentioned in four studies. No significant difference was noted in the risk of vascular injury for ES versus DS (RD 0.00; 95% CI − 0.02–0.03; $p = 0.79$; $n = 330$; Fig. 7).

Secondary Outcome (Infection)

Post-operative infection was reported in five studies. There was no significant difference between ES and DS for the risk of post-operative infection (RD 0.02; 95% CI − 0.06–0.01; $p = 0.21$; $n = 373$; Fig. 8).

ROBINS-I Assessment

The Risk of Bias in Non-Randomised Studies-Interventions (ROBINS-I) tool was utilized to assess the risk of bias in the studies included in the systematic review and meta-analysis. The overall risk of bias was noted to be serious across all 14 studies, mainly attributed to concerns of bias due to confounding factors pre-intervention and bias in the classification of interventions.

GRADE Assessment

The Grading of Recommendations, Assessment, Development and Evaluations (GRADE) assessment was utilized to analyse the quality of evidence across the studies for each outcome. The quality of evidence was found to be very low for the primary outcome (risk of open reduction requirement) and the secondary outcome (risk of post-operative infection), whereas it was felt to be low for the remaining secondary outcomes (Table 2).

Discussion

The most significant finding from this systematic review and meta-analysis was that delayed surgery for Gartland type III supracondylar humeral fractures in children did not increase the risk of conversion to open reduction. Furthermore, there were no significantly increased risks of perioperative complications in terms of vascular injury, compartment syndrome, iatrogenic nerve injury, and infection with delayed surgery.

A systematic review of Gartland type III fractures, Loizou et al. [5], which defined delayed surgery as greater than
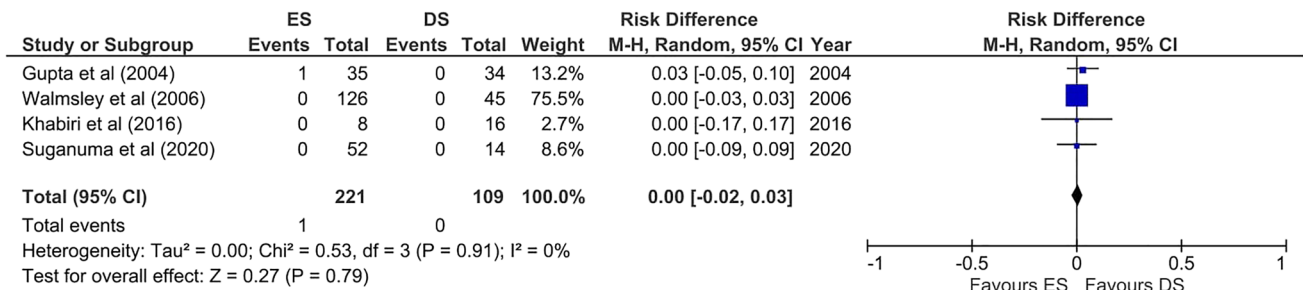
Fig. 7 Forest plot of ES versus DS for the secondary outcome: risk of vascular injury. *CI* Confidence Interval, *Random* Random-Effects Model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Hetero-geneity. Gupta et al. [11]; Walmsley et al. [14]; Khabiri et al. [20]; Suganuma et al. [22]
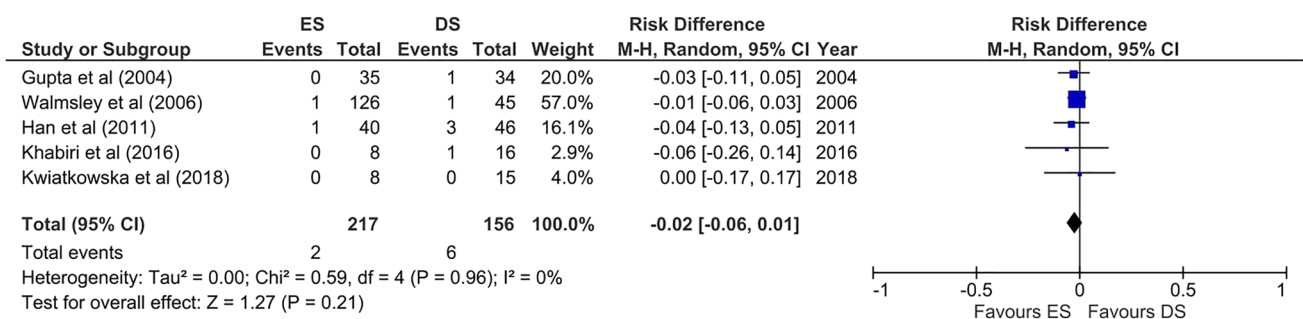
Fig. 8 Forest plot of ES versus DS for the secondary outcome: risk of infection. *CI* confidence interval, *Random* random-effects model, *M–H* Mantel–Haenszel, *df* Degrees of Freedom, *I2* Heterogeneity. Gupta et al. [11]; Walmsley et al. [14]; Han et al. [18]; Khabiri et al. [20]; Kwiatkowska et al. [21]

Table 2 GRADE assessment summary of findings

Outcomes	Early surgery	Delayed surgery,	Risk difference, [95% CI]	Total number of patients	Number of studies	Quality of evidence	Comments
Open reduction risk	87/665	224/598	RD − 0.10 [− 0.25, 0.04]	1263	14	Very low	Serious inconsistency and imprecision
Compartment syndrome	0/221	0/109	RD 0.00 [− 0.03, 0.03]	330	4	Low	
Nerve injury	35/269	15/170	RD 0.00 [− 0.04, 0.04]	439	6	Low	
Vascular injury	1/221	0/109	RD 0.00 [− 0.02, 0.03]	330	4	Low	
Infection	2/217	6/156	RD -0.02 [− 0.06, 0.01]	373	5	Very low	Serious imprecision

GRADE grading of recommendations assessment, development and evaluation, *CI* confidence interval, *RD* risk difference

8–12 h from injury found that there was an increased risk of converting to open reduction when surgical intervention was delayed. It stated that 11% of the children who were treated early and 22.9% of the children who had a delayed treatment required an open technique for reduction (odds ratio 0.37, *p* value 0.0007) [5]. The findings from our systematic review challenge this observation. Historically, surgeons have considered moderate-to-severe supracondylar humeral fractures as an orthopaedic emergency and would advocate for emergency surgery outside of normal working hours. However, more recent literature echoes similar conclusions for treatment of Gartland type III fractures to our findings. A retrospective study, Abbott et al. [24], of 297 children who were treated for Gartland type III fractures showed that delayed surgery did not increase the chance of conversion to open reduction. It was noted that 28 of their patients required open reduction with a mean time of 15.5 h ± 5.6 from injury to the operating room, while 269 of their patients who did not require open reduction had a mean time of 13.1 h ± 6.3 from injury to the operating room with a *p* value of 0.06 [24]. Furthermore, a systematic review and meta-analysis of 12 studies, Farrow et al. [6], found that delaying operative management for Gartland type II and III fractures by a mean time of 91 h had no clinically significant impact on the need to convert to open reduction [6]. There was significant heterogeneity noted on the funnel plot in the results of 1 of the 14 studies included in our meta-analysis, Yildirim et al. [15], in comparison to the other studies when assessing the primary outcome. Upon reviewing the full-text article, the reasons behind the deviation in the results of this study are not entirely clear. It was noticeable that the time to surgery scale in this study was longer than that of the other studies, with 46 (24.2%) out of a total 190 patients undergoing treatment over 58 h from time of injury, and all 94 (49.5%) patients that underwent surgery after 32 h from injury required open reduction. Nevertheless, the population,

intervention, and design of the study were congruent with the other studies, and thus, it was included in the systematic review and meta-analysis. It is important to note, however, that the meta-analysis with and without the Yildirim et al.'s [15] study found no statistical significance for the primary outcome. The secondary outcomes were not assessed in this study, and thus, it was not included in any further meta-analysis [15].

When a delay in intervention is considered, one of the biggest concerns is the development of compartment syndrome as extensive soft-tissue swelling and deformity of the elbow is often present [25]. From our analysis, four studies assessed the risk of compartment syndrome in which no cases were identified within either the early or delayed surgery group. Recent evidence supports this finding; a systematic review of 11 studies, Baghdadi et al. [26] found that the rate of compartment syndrome in patients with supracondylar fractures was low, ranging from 0 to 12% in incidence with a frequency-adjusted incidence of 2% [26]. A retrospective analysis in Yaokreh et al. [27] study of 89 children with delayed surgery of 4.5 days for severe supracondylar fractures found that none of the children had developed compartment syndrome as a complication [27]. Although the evidence suggests that the risks of developing compartment syndrome in patients with Gartland type III fractures are very unlikely, clinicians must remain vigilant as the consequences of those that are missed are significant.

Iatrogenic nerve injury was assessed in six of the studies included in our systematic review, consisting of 439 patients, of which there were 35 patients identified to have iatrogenic nerve injury in the early surgery cohort and 15 patients in the delayed surgery cohort. There was no statistical difference in the risk between the two cohorts of patients. Current literature mirrors what has been inferred to from our study. Kronner et al. [28], performed a retrospective study of 134 patients comparing early and delayed treatment of

Gartland type III fractures, with the delayed group defined as receiving surgical treatment 12 h or more from the time of presentation and the early group receiving surgical treatment within 12 h. It concluded that delayed surgical intervention did not increase the perioperative complications, including iatrogenic nerve injury [28].

There were four studies within our systematic review which assessed post-operative vascular complications in delayed Gartland type III fractures, with one patient being identified in the early group amongst the 330 patients to have vascular injury. There was no statistical significance in the risk of vascular injury between the early and delayed surgery groups. From this, we can deduce that vascular complications are rare as a perioperative complication of supracondylar fractures whether treated early or delayed. Current concepts in the treatment of Gartland type III supracondylar humeral fractures dictate that it is usually treated surgically with a closed reduction and percutaneous pinning from the medial and lateral epicondyles. There are no vascular structures in the epicondylar regions, and most reductions are successfully managed closed. Open reduction is through an anterior approach to the forearm which can potentially disrupt the neurovascular structures, but these are directly visualised, and thus, injury is less likely [29]. The systematic review by Farrow et al. [6] showed that a delay in surgical treatment did not increase the risk of vascular complications [6].

Kirschner wire site infections are known complications for supracondylar fractures managed with percutaneous pinning. Post-operative infection rates were reported in five of the studies included in our systematic review, in which eight cases were identified from a total of 373 patients. We found that there was no statistical difference in the risk of post-operative infection in DS compared to ES groups. Our findings are supported by Mayne et al. [30] who conducted a retrospective study of 115 patients with Gartland type II and III fractures, which concluded that there was an overall infection rate of 3.5% and no significant difference between those treated early and late [30]. A further retrospective comparative study of 1296 patients [31] which assessed the rate of complications for Gartland type II and III fractures in relation to time of surgery echo similar findings. Overall infection rates were 2%, half of which were superficial pin site infections, with no significant change in the infection rates with increasing time to surgery [31].

The expertise of the operating surgeon is an important influencing element on the outcome of the procedure. Carmichael et al. [12] noticed that most of the ES patients were operated on by non-paediatric specialists, while the DS patients were mostly operated on by paediatric specialists [12]. The seniority or level of experience of the operating team was mentioned in five of the studies included in our systematic review [14–16, 21, 23]. However, none of the studies included have assessed or identified the impact of the surgeon factor on the perioperative outcomes between the early and delayed treatment groups.

Limitations

A significant limitation of our systematic review is the variability in the parameter for the time to surgery defining the early and delayed surgery groups in the studies included, with the set time ranging from 6 to 24 h between the studies. Inconsistency in the timings means that comparatively the findings from one study may not strictly be applicable to another.

Although, no significant difference in perioperative outcome was found in our study between ES and DS groups, the long-term outcomes and complications for each group were not assessed. Furthermore, the quality of the surgeon operating in both ES and DS groups can influence the outcome of the surgery in favour of one group over the other, which has not been evaluated in the studies included in this systematic review.

The overall risk of bias was noted to be serious for all studies and the overall quality of evidence for the outcomes identified within the systematic review were low to very low. This likely reflects the difficulty in organising high-quality randomised controlled trials for this condition, mainly due to the clinical settings, ethical implications, and the psychological impact on both child and parents that can result from delaying treatment for the purposes of research.

Conclusion

Despite the limitations in the literature, evidence exists to support the notion that a delayed approach to the treatment of Gartland type III supracondylar humeral fractures in children does not result in an increased risk of converting to open reduction and perioperative complications. However, clinicians should remain vigilant and treat the patient on an individual basis and utilize their clinical acumen to assess whether early operative intervention is required over delayed.

It has been over 10 years since the last systematic review on this subject in Gartland type III supracondylar fractures, and multiple studies have been conducted since then on the topic. However, they do not provide the high level of quality evidence needed to achieve a definitive conclusion. We recommend future studies to aim on providing higher quality of evidence on this topic through clinical trials and randomised controlled studies, while taking the clinical settings and ethical standards into consideration.

Declarations

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