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SYSTEMATIC REVIEW

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The efficacy of arthroscopy-assisted versus stand-alone open reduction and internal fixation for treating tibial plateau fracture: a systematic review and meta-analysis

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Abstract

Background The optimal surgical technique for treating tibial plateau fractures remains controversial. This study aimed to compare the outcomes of arthroscopy-assisted reduction and internal fixation (ARIF) to those of open reduction and internal fixation (ORIF) in treating tibial plateau fractures.

Methods This systematic review and meta-analysis were conducted to compare surgical outcomes between ARIF versus ORIF for patients with tibial plateau fractures. Relevant studies, comprising randomized controlled trials (RCTs) and non-RCTs, were identified through searches in Cochrane CENTRAL, PubMed, and Embase databases. Risk of bias assessments were conducted using the revised Cochrane risk-of-bias tool for RCTs (RoB 2.0), Newcastle Ottawa scales for non-RCTs, and Joanna Briggs Institute Critical Appraisal Checklist for case series studies. Data synthesis utilized a random-effects model meta-analysis. The primary outcome assessed was functional outcomes, with complications considered as secondary outcomes.

Results There were fifteen studies (one RCT and fourteen non-RCTs) included in this study, comprising a total of 969 participants (548 in the ARIF group and 421 in the ORIF group). Although patients in the ARIF group showed a trend towards better functional outcomes compared to the ORIF group, the difference was not statistically significant (Hospital for special surgery score, mean difference (MD) = 5.13, 95% confidence interval (CI)=-1.67 to 11.92, I^2=83%; Knee society score, MD = 5.84, 95% CI=-1.18 to 12.86, I^2=74%). No significant differences were noted in infection, stiffness, DVT, and overall complications between two groups. The ARIF group included ten case series studies with a total of 302 patients. The pooled mean Rasmussen Radiological Score was 16.59 (95% CI, 15.72 to 17.50), and the pooled mean Rasmussen Clinical Score was 27.38 (95% CI, 26.45 to 28.33).

Conclusion The findings of this study reveal no significant difference in clinical outcomes and complication rates between ARIF and ORIF. Additionally, this study found that the complication rate for patients undergoing ARIF falls within previously reported ranges. This suggests that ARIF is a reliable and effective surgical option for treating tibial plateau fractures, even in cases involving high-energy trauma.

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Keywords Arthroscopy-assisted reduction and internal fixation (ARIF), Open reduction and internal fixation (ORIF), Tibial plateau fractures, Arthroscopy systematic review, Meta-analysis

Introduction

Tibial plateau fractures represent a relatively infrequent occurrence within the weight-bearing joint, comprising approximately 1% of all fractures [1]. The distribution of these fractures follows a bimodal pattern and correlates with gender, predominantly affecting young males following high-energy trauma or elderly females with osteoporosis [2, 3]. Due to the complex nature of the injury mechanism, tibial plateau fractures often entail a broad spectrum of intra-articular injuries, encompassing cartilage, ligament, and meniscal damage, alongside various extra-articular injuries involving soft tissues, nerves, and vasculature [4]. Additionally, there exists a risk of developing compartment syndrome. Achieving optimal functional outcomes necessitates addressing several critical components: achieving anatomical reduction to restore alignment and joint congruity, ensuring stable fixation, performing comprehensive ligamentous repair, and reconstructing neurovascular structures [5].

Traditionally, the treatment of displaced tibial plateau fractures has predominantly involved open reduction and internal fixation (ORIF) [5]. The anterolateral approach was mainly used in lateral site injuries (Schatzker type 1–3 fractures), whereas the posteromedial approach was used in the medial site injuries (Schatzker type 4 fractures). Combined approaches were necessary for more complex fracture patterns or those involving posterior fragments [5]. These approaches offer the advantage of excellent visualization of the joint surface, facilitating precise reduction of the fracture fragments and optimal placement of fixation hardware. However, this technique entails significant soft tissue dissection to gain adequate access to the fracture site and perform the necessary procedures which raises the risk of surgical site infections, delayed healing, or implant failure [6]. As an alternative surgical technique, arthroscopic-assisted reduction and internal fixation (ARIF), was first introduced by Caspari et al. [7] and Jennings et al. [8] in 1980s. The use of ARIF remains a subject of debate. ARIF enhances the accuracy of intra-articular reduction and concurrently addresses associated intra-articular injuries, such as meniscal tears. Although ARIF is thought to carry a lower risk of complications and lower morbidity, there are also potential drawbacks, including iatrogenic infections, wound complications, or non-union [9]. Additionally, it has been reported that ARIF may be more effective for Schatzker type 1–3 fractures but not recommended for Schatzker type 4–6 fractures due to higher risks of extravasation leaks of irrigation fluid and hence compartment syndrome [10].

However, other study has reported the safety and efficacy of arthroscopic surgery for all Schatzker-type tibial plateau fractures, based on a follow-up period ranging from 2 to 10 years [11]. Nonetheless, there remains controversy surrounding the effectiveness and potential complications associated with these approaches. In order to address this ongoing debate, this systematic review was conducted to compare the efficacy of ARIF with traditional ORIF in the management of tibial plateau fractures. Moreover, a separate systematic review was performed to specifically focus on studies employing ARIF techniques only, aiming to offer novel insights into the outcomes of ARIF.

Methods

This systematic review is performed under the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline [12]. The PRISMA 2020 checklist was available as supplementary materials (Table S1).

Search Strategy

A systematic search was conducted from the following databases: Medline, PubMed, the Cochrane Library, and Embase were utilized to conduct a search with the combination of medical subject heading and free-text terms including "tibial plateau fracture" OR "tibial platform fracture" AND "arthroscopy" OR "arthroscopic-assisted" OR "ARIF" OR "arthroscopic" AND "open reduction" OR "ORIF" OR "operation" OR "surgery" OR "surgical intervention". The final search was performed on August 05, 2023. Two independent reviewers have carefully screened all the titles and abstracts. Authors were contacted via email to obtain any missing data. Relevant studies underwent a detailed full-text review after this initial search. The study was registered in PROSPERO (CRD42024561001).

Selection criteria

In the current study, comparative studies presenting data on knee joint function and clinical scores following open reduction and internal fixation (ORIF) versus arthroscopic-assisted reduction and internal fixation (ARIF) or ARIF alone for treating tibial plateau fracture were included. Case reports or series with fewer than five subjects were excluded, as well as animal or cadaveric studies and studies without reported outcomes.

Data extraction and quality assessment

Two authors, independently collected the necessary data using a predefined spreadsheet. This spreadsheet included the study's name (first author, publication year), country, study design, patient characteristics (number, age, gender, Schatzker fracture type), duration of follow-up, and various outcomes like the Rasmussen Clinical Score (RCS), Rasmussen Radiological Score (RRS), Knee Society Score (KSS), and Hospital for Special Surgery Knee Rating Scale (HSS), among others. Subsequently, a third author, conducted a data review process, making corrections and justifications where needed.

The primary outcomes encompassed RCS, RRS, KSS, and HSS scores, while complications, including infection, stiffness, deep vein thrombosis, revision surgery, and total complications, were also assessed as secondary outcome.

To evaluate the quality of the included studies, the Newcastle-Ottawa Scale (NOS), the revised Cochrane risk-of-bias tool for randomized trials (RoB 2.0) and Joanna Briggs Institute (JBI) Critical Appraisal Tools were used (Table S2, Table S3). Two review authors, independently assessed the risk of bias among the included studies, with any discrepancies resolved through discussion with the third review author.

Statistical analysis

For the statistical analysis, the Review Manager software (RevMan 5.4, Nordic Cochrane Centre) was used for meta-analysis. Primary outcomes, such as RCS, RRS, KSS, and HSS, were pooled using mean differences with a random effect model, while complications were pooled using risk differences with a random effect model. All pooled mean values were presented with 95% confidence intervals (CIs). A p-value less than 0.05 was considered statistically significant, and an I^2 value of less than 30% indicated low statistical heterogeneity between studies for each outcome.

Results

Study selection

Electronic database searches initially yielded fifty-eight records. After removing the duplicates, 31 records remained. After the initial screening of the title and abstract, seven studies were excluded, leaving twenty-four articles for full-text review. Upon a comprehensive examination of these articles and further exclusion of citations with study populations involving fewer than five patients, a total of seventeen studies are included in the systematic review. Figure 1 provides a summary of the study selection process. It's important to note that each study involved a distinct patient population, resulting in a

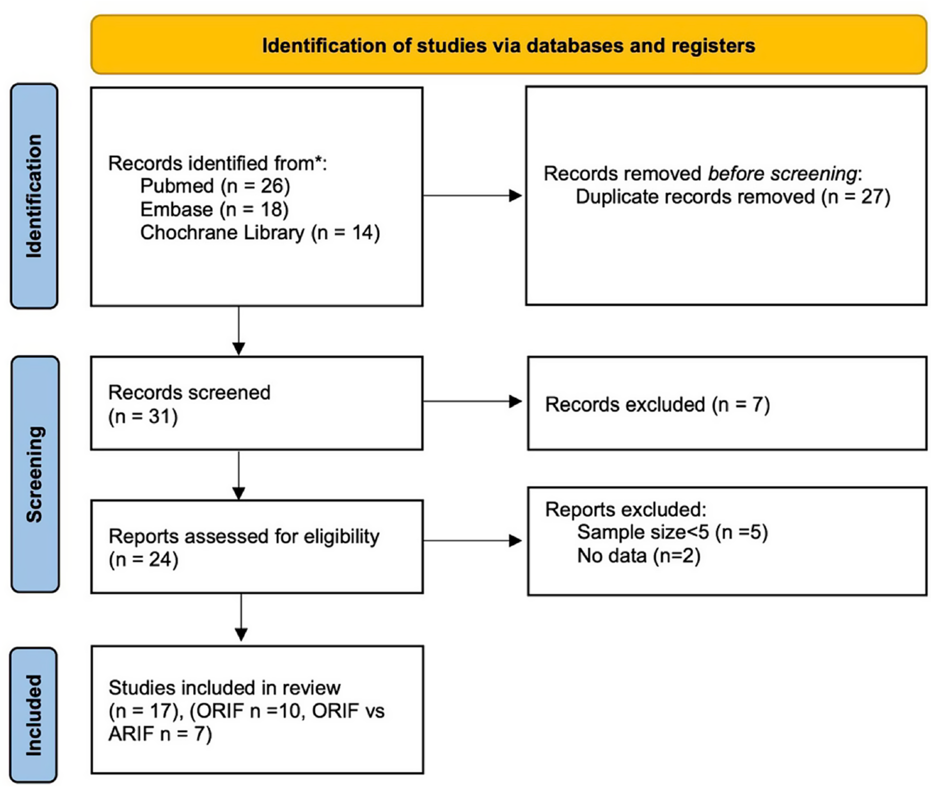

Fig. 1 Preferred Reported Items for Systematic Review and Meta-Analyses flow diagram summarizing the selection of studies for systematic review and meta-analysis

combined sample size of only 987 patients. These patients were categorized into two groups: the case-control or randomized controlled trial (RCT) group, comparing ARIF to ORIF, consisting of seven studies with a total of 685 patients and the case series group [10, 13–18], ARIF only, comprising ten studies involving 302 patients [11, 19–27].

Study characteristics and quality

As assessed by the Newcastle-Ottawa scale, the seven case-control studies demonstrated a high level of quality (Supplementary Table S2). Additionally, the risk of bias in the one included randomized controlled trial (RCT) was deemed to be low based on the revised Cochrane risk-of-bias tool for randomized trials (RoB 2.0). Furthermore, according to the JBI Critical Appraisal Checklist for Case Series 2017, the ten case series studies were of high quality in terms of their level of evidence (Supplementary Table S3).

Detailed information regarding the characteristics of these studies can be found in Table 1. In Group ARIF versus ORIF, a total of 685 patients underwent either ARIF or ORIF. Group ARIF only included 302 patients who were exclusively treated with ARIF.

Patient demographics

Table 2 provides a comprehensive overview of the patients' demographics, surgical techniques, types of implants used, and the inclusion of bone grafts. In Group ARIF vs. ORIF, there were a total of 410 male and 275 female patients, with an average age of 46.54 years (with a mean age range between 46.0 and 51.0 years). Following the Schatzker classification of tibial plateau fractures, the distribution by Schatzker type was as follows: 123 in type 1, 315 in type 2, 209 in type 3, 16 in type 4, 12 in type 5, and 10 in type 6. Within this group, 264 patients underwent ARIF, while 421 patients underwent ORIF.

In Group ARIF, there were 177 male and 125 female patients, with an average age of 43.74 years (with a mean age range between 34.2 and 52.2 years). The distribution of Schatzker types in this group included 28 in type 1, 82 in type 2, 64 in type 3, 33 in type 4, 19 in type 5, 45 in type 6, and the fracture types of 21 patients from Siegler et al. was not recorded [26].

Treatment

Regarding treatment, in the ARIF group, most researchers employed standard anterolateral and anteromedial ports, sometimes with the application of a tourniquet and irrigation pump. In the ORIF group, the surgical approach utilized was either anterolateral, medial, or a combination of these approaches. Detailed information on implant selection and bone graft types for each study can be found in Table 2.

Radiological outcome

Group ARIF vs. ORIF

Among the included studies, two of them assessed the image results using the Rasmussen Radiological Score (RRS) [13, 18]. Two other studies utilized the modified radiological Rasmussen score (MRRS) [14, 17], and one study employed the Hip-Knee-Ankle (HKA) score measurement [16]. The analysis of RRS data did not reveal a significant difference between patients treated with ARIF and ORIF (MD = -0.02; 95% CI= -1.46 to 1.43; I^2=70%; p=0.98) (Fig. 2A) [13, 18]. When examining the mRRS, a statistical difference was not observed either between the ARIF and ORIF groups (MD=0.41; 95% CI = -0.61 to 1.43; I^2=53%; p=0.43) [14, 17].

Group ARIF

In radiologic outcomes, six included studies utilized the Rasmussen Radiological Score (RRS) [11, 20, 22, 24, 25, 27], while one study employed the modified Rasmussen score (mRRS) [26], and another used the Resnick and Niwoyama criteria [19]. The mean pooled RRS was 16.59 (95% CI, 15.72 to 17.50) (Fig. 3A) [11, 20, 22, 25].

Functional outcome and patient-reported outcome measurements

Group ARIF vs. ORIF

In Group ARIF vs. ORIF, clinical outcomes were assessed using various measures. Three studies evaluated the RCS [13, 14, 18] while another three evaluated HSS score [13, 15, 16]. Two studies utilized the KSS [17, 18], two other studies utilized IKDC score, and ROM of the knee [15, 16]. Additionally, one study applied the Hohl & Delamarter scoring system. Regarding RCS, the analysis of three studies [13, 14, 18] showed no significant difference between patients who underwent ARIF and ORIF (MD=0.18; 95% CI = -0.39 to 0.76; I^2=29%; p=0.53) (Fig. 2B). For KSS, evaluated in two studies [17, 18], no significant difference was found (MD=5.84; 95% CI = -1.18 to 12.86; I^2=74%; p=0.05) (Fig. 2C). Two studies that assessed HSS outcomes showed a result of (MD=5.13; 95% CI = -1.67 to 11.92; I^2=83%; p=0.003) in our analysis (Fig. 2D). The IKDC score also revealed no significant difference between the ORIF and ARIF groups (MD=0.76; 95% CI = -1.67 to 3.19; I^2=0%; p=0.38) (Fig. 2E) [15, 16].

Group ARIF

In Group ARIF, eight studies employed the RCS to assess functional outcomes [11, 20–22, 24–27]. Three studies measured the range of motion [23, 24, 26], while two studies reported the Lysholm score [23, 26]. Additionally, one study utilized the International Knee Society functional scoring system (IKS) [26]. According to our

Table 1 Characteristics of the included studies

Study (Author, Year)	Study Design	LOE	Metadata: Sample Size (n=): Sex (Male)	Operation		Schatzker type: I	II	III	IV	V	VI	Age[a] (Year)	Follow-up[b] (Month)	Measures and Outcomes
Dall'Oca 2012 [13]	Retrospective	IV	54	**ARIF**	50	4	7	26	5	4	4	51.0 (13–77)	73.27 ± 14.55 (12–116)	RCS, RRS, HSS score.
				ORIF	50	10	5	18	3	8	16			
Elabjer 2017 [14]	RCT	II	58	**ARIF**	40	9	18	13	-	-	-	47.0 (20–54)	13.5 (12–15)	RCS, Modified RRS.
				ORIF	35	10	15	10	-	-	-			
Baron 2019 [16]	Retrospective	IV	186	**ARIF**	77	20	32	25	-	-	-	48.0 ± 14 (18–82)	38.0 ± 23 (24–90)	Lysholm score, IKDC score, HSS score, HKA angle, ROM.
				ORIF	240	56	141	43	-	-	-			
Ohdera 2003 [10]	Retrospective	IV	9	**ARIF**	19	-	10	9	-	-	-	47.5 (16–75)	22 (12-53.5)	ROM, Hohl & Delamarter score.
				ORIF	9	-	5	2	1	1	-	51.5 (31–66)	51.7 (32-72.7)	
Verona 2019 [17]	Retrospective	IV	21	**ARIF**	19	4	8	7	-	-	-	48.0 ± 15.67	41.95 ± 28.85 (12–52)	RCS, Modified RRS, KSS score.
				ORIF	21	1	8	12	-	-	-			
Wang 2017 [18]	Retrospective	IV	36	**ARIF**	26	4	13	5	4	-	-	46.0 (24–65)	44.4 ± 11.8 (24–64)	RCS, RRS, KSS score.
				ORIF	31	5	15	7	4	-	-			
Huang 2023 [15]	Retrospective	IV	46	**ARIF**	33	-	18	15	-	-	-	48.73 ± 7.99	36 (26–40)	HSS score, IKDC score, ROM.
				ORIF	35	-	20	15	-	-	-	50.69 ± 8.81		
Liang 2018 [25]	Retrospective	IV	10	**ARIF**	26	-	5	21	-	-	-	47.3 ± 2.7 (35–64)	24	RCS, RRS.
Zawam 2019 [27]	Retrospective	IV	16	**ARIF**	25	5	11	9	-	-	-	38.8 (19–55)	14 (11–18)	RCS, RRS.
Chiu 2013 [20]	Retrospective	IV	15	**ARIF**	25	-	-	-	5	2	18	46.0 (21–79)	86 (60–108)	RCS, RRS.
Chan 2018 [11]	Prospective	III	25	**ARIF**	54	1	21	4	10	8	10	48.0 (22–68)	2–10 Years	RCS, RRS, ROM.
Asik 2002 [19]	Retrospective	IV	34	**ARIF**	46	5	8	12	6	3	2	39 (15–68)	36 (14–72)	RCS, RRS, Resnick and Niwoyama criteria.
Dhillon 2021 [21]	Prospective	III	12	**ARIF**	15	5	8	2	-	-	-	34.2 (18–54)	> 6	RCS.
Huang 2015 [22]	Retrospective	IV	21	**ARIF**	41	-	12	-	8	6	15	42.9 (21–58)	72.8 (60–102)	RCS, RRS.
Siegler 2010 [26]	Retrospective	IV	17	**ARIF**	21	(Between I-III)						45.0 (18–79)	59.5 (24–138)	RCS, Modified RRS, IKS knee score, IKS function score, Lysholm score, ROM.

Table 1 (continued)

Study (Author, Year)	Study Design	LOE	Metadata												
			Sample Size (*n*=)									Age[a] (Year)	Follow-up[b] (Month)	Measures and Outcomes
			Sex (Male)	Operation		Schatzker type								
						I	II	III	IV	V	VI			
Kiefer 2001 [23]	Retrospective	IV	17	ARIF	31	12	10	7	2	-	-	47.4 (19–82)	25.1 (15–32)	Lysholm score, Patient's satisfaction, ROM.
Leigheb 2020 [24]	Retrospective	IV	10	ARIF	18	-	7	9	2	-	-	52.2 ± 13.4	84 ± 22.5	RCS, RRS.

[a]Age is expressed as mean, ± standard deviation or (range), [b]Follow-up is expressed as mean, ± standard deviation or (range)

ARIF, arthroscopic-assisted reduction and internal fixation; HKA, hip-knee-ankle; HSS, hospital for special surgery; IKDC, international knee documentation committee; KSS, knee society score; LOE, level of evidence; N/A, not available; n, number; ORIF, open reduction and internal fixation; RCS, Rasmussen clinical score; RCT, randomized controlled trial; RMS, Rasmussen radiological score; ROM, range of motion

meta-analysis, the mean RCS was 27.38 (95% CI, 26.45 to 28.33) (Fig. 3B) [11, 20–22, 24–27].

Complications

Group ARIF vs. ORIF

In Group ARIF vs. ORIF, all seven studies provided data on complications, which are summarized in Fig. 4A [10, 13–18]. Complications are categorized into five groups: infection, stiffness, deep vein thrombosis (DVT), revision, and all complications. The infection rate in patients who underwent ARIF compared with ORIF did not show a statistically significant difference (risk difference (RD)= -0.02; 95% CI= -0.04 to 0.01; I^2=0%; p=0.26). The rate of joint stiffness was 0.7% in the ARIF group and 1.4% in the ORIF group, with no significant difference between the two groups (RD = -0.00; 95% CI = -0.03 to 0.02; I^2=0%; p=0.73). Deep vein thrombosis (DVT) occurred in 1.8% of ARIF patients and 0.7% of ORIF patients, and the ARIF group did not have a significantly higher risk (RD=0.01; 95% CI = -0.02 to 0.03; I^2=0%; p=0.61). Revision surgery was required for 1.5% of patients after ARIF and had a 2.6% revision rate in patients after ORIF, with no significant difference (RD = -0.00; 95% CI = -0.03 to 0.02; I^2=0%; p=0.82). The overall complication rate was lower in the ARIF group (4.9%) compared to the ORIF group (14.9%) but did not reach statistical significance (RD = -0.13; 95% CI = -0.28 to 0.01; I^2=90%; p=0.08). The details of complications were shown in supplementary Table S4.

Group ARIF

In Group ARIF, all ten studies reported complications and the findings are summarized in Fig. 4B and Supplementary Table S4 [11, 19–27]. Two patients (0.6%) experienced infection episodes after the operation. One patient had DVT post operatively (0.3%). Joint stiffness was observed in four patients (1.3%), and three patients required revision surgery due to prosthesis loosening and joint stiffness (0.9%). The overall complication category included screw prominence, extensor lag, complex regional disease, wound dehiscence, superficial or deep infection, nerve palsy, vascular injury, DVT, compartment syndrome, joint stiffness, bone non-union, reduction loss, and revision. The pooled overall complication rate was 0.16 (95% CI, 0.10 to 0.25), indicating one complication may happen in every seven cases of tibial plateau fracture treated with ARIF.

All findings in both group ARIF vs. ORIF and group ARIF were summarized in Table 3, 4.

Discussion

This systematic review showed that ARIF showed a comparable reduction quality and a similar rate of reduction loss compared to ORIF. Although ARIF did not show

Table 2 Surgical Details of the included studies

Study (Author, year)	Operative method	Implants	Bone graft type
Dall'Oca 2012 [13]	Double plates, 2 incisions; Circular fixator; External fixator.	Schatzker type I: cannulated screws; II: plates and screws; III: cannulated screws or plates and screws; V, V and VI: plates and screws with cannulated screws.	Autologous: Iliac crest.
Elabjer 2017 [14]	ARIF: Standard anterolateral and anteromedial port. ORIF: Sub-meniscal arthrotomy, incision, anterolateral approach.	ARIF: 6.5-mm screws. ORIF: Conventional buttress or locking plate.	Autologous: Cancellous bone.
Baron 2019 [16]	ARIF: Tourniquet, irrigation. ORIF: Anterolateral or medial approach	ARIF: 6.5 mm percutaneous screws ORIF: Standard, locking or 6.5 mm percutaneous.	Autogenous bone graft or bone substitutes in 1/4 of patients. Synthetic bone graft substitutes in 3/4 of patients.
Ohdera 2003 [10]	ARIF: Electric shaver, bone impactor ORIF: Open reduction and internal fixation	Cannulated screws.	N/A
Verona 2019 [17]	ARIF: Standard anterolateral and anteromedial ports; without irrigation pump. ORIF: Anterolateral sub-meniscal approach; meniscus lesion procedure afterwards; ACL postponed.	ARIF: Cannulated screws. ORIF: Cannulated screws, plate.	ARIF: Synthetic bone graft substitutes. ORIF: Auto or allograft augmentation.
Wang 2017 [18]	ARIF: Tourniquet, no irrigation pump; ACL/MCL/LCL/meniscus repair done. ORIF: Medial or lateral sub-meniscal approach.	Screw, plate, screw, and plate.	Autogenous bone graft or bone substitutes.
Huang 2023 [15]	Anterolateral and anteromedial arthroscopic port.	Screw, plate, screw, and plate.	Autologous: Iliac bone.
Liang 2018 [25]	Anterolateral and anteromedial arthroscopic port. Compression fracture: bone void filler. Split fracture: supra-fibular-head approach.	Lateral tibial locking compression plate, locking screws.	Synthetic: Calcium sulfate bone void filler.
Zawam 2019 [27]	Anterolateral portal for viewing, anteromedial portal for manipulation.	Cannulated screws.	Autologous: Iliac crest.
Chiu 2013 [20]	Anteromedial and anterolateral portal; incisions were placed directly medial to the fractured side.	Buttress plate and > 2 4.5 mm cannulated screw and washer.	Synthetic: Calcium composite biomaterial.
Chan 2018 [11]	Anterolateral and anteromedial portals.	Inter-fragmental screws, dual buttress plates.	Autologous: Iliac bone graft. Allogeneic bone graft.
Asik 2002 [19]	Anterolateral parapatellar portal; extended anterolateral incision in type V and VI.	Type I&II: Screw. Type II: Plates. Type IV&V&VI: Plates and screw.	Autologous: Anterior superior iliac spine.
Dhillon 2021 [21]	Anteromedial and anterolateral portals; tourniquet, no pump.	Cannulated partially threaded cancellous screws and buttress plate.	Autologous: Cancellous bone from anterior superior iliac spine.
Huang 2015 [22]	Anterolateral and anteromedial portals; tourniquet and pump used.	Buttress plate and screw.	Allogeneic bone graft. Artificial bone substitute.
Siegler 2010 [26]	Autograft material / bone substitute	6.5-mm screw fixation.	N/A
Kiefer 2001 [23]	Anterolateral approach, Medial Port for viewing; tourniquet and pump used.	lag screw, buttress plate.	Autogenous bone graft.
Leigheb 2020 [24]	ARIF, wire cerclage, suture, meniscal tears, selective meniscectomy when needed	Plate and screws.	Allogenic cancellous bone graft

ACL, anterior cruciate ligament; ARIF, arthroscopic-assisted reduction and internal fixation; LCL, lateral collateral ligament; MCL, Medial collateral ligament; N/A, not available; n, number; ORIF, open reduction and internal fixation

better clinical outcomes than ORIF in terms of various patient-reported outcome measures (PROMs). Furthermore, the ARIF group also had a similar complication rate as the ORIF group. The difference in complication rate between the two groups was still not significant in subgroup analysis, even in high-energy tibial plateau fractures. Therefore, ARIF seems to be reasonable alternative to ORIF in treating tibial plateau fracture without increasing complications.

ORIF is generally regarded as the standard treatment for complex tibial plateau fractures, with studies like that by Timmers et al. documenting a range of fair to excellent clinical outcomes after a mean 6-year follow-up [28]. Despite these findings, patients with high-energy trauma may suffer increased knee pain and a greater need for medication, likely due to the extensive soft tissue dissection and resulting inflammation associated with traditional ORIF procedures. Khatri et al. found a 93.7% rate

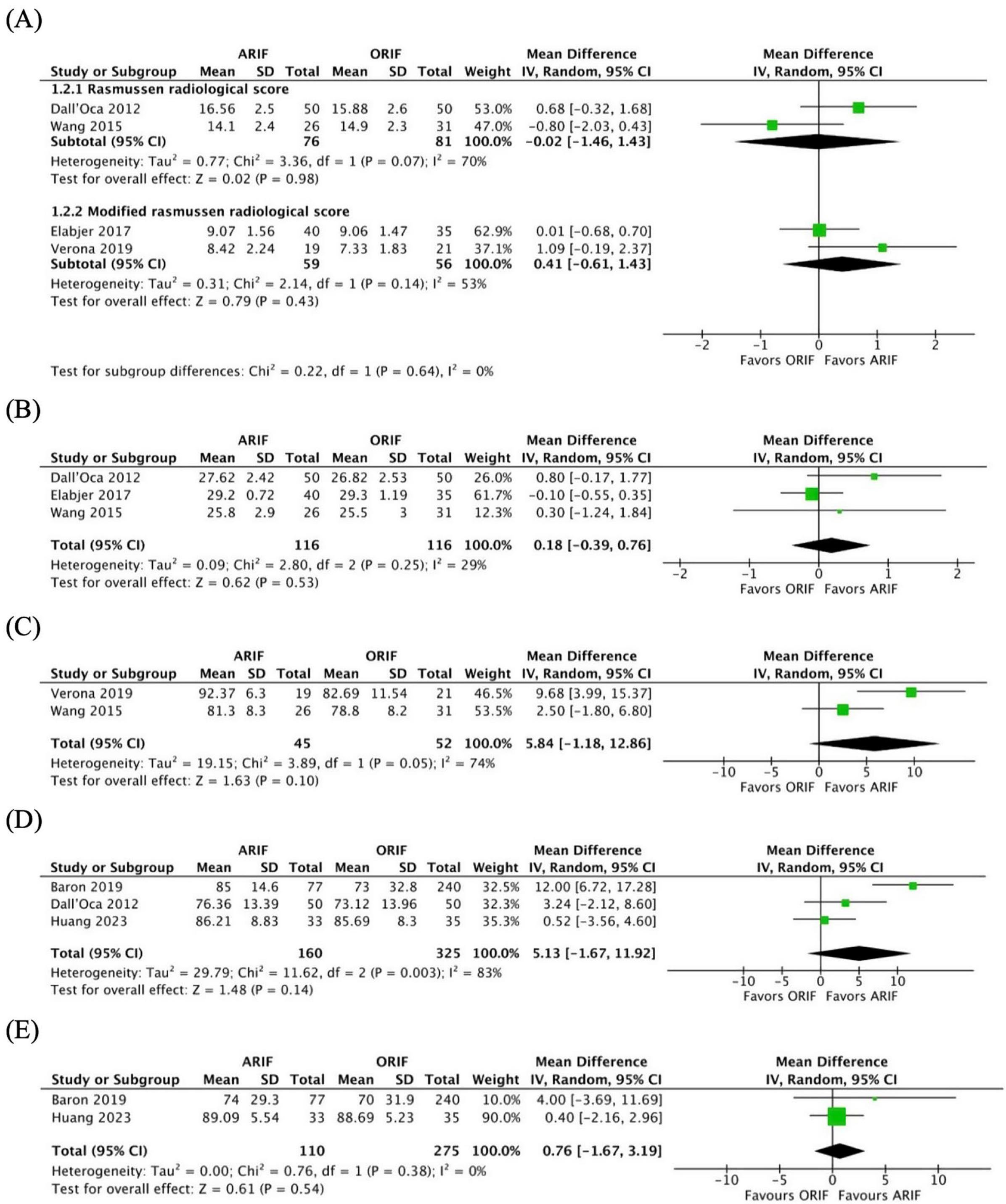

Fig. 2 Forest plot of the functional outcomes of group ARIF vs. ORIF in (**A**) Rasmussen Radiological Score; (**B**) Rasmussen Clinical Score; (**C**) Knee Society Score; (**D**) Hospital for Special Surgery Knee Rating-Scale score; (**E**) International Knee Documentation Committee score, no significant difference was found in all subgroup analysis

of good to excellent clinical outcomes at 32 months post-ORIF in patients with high-energy tibial plateau fractures [29].

Patients with tibial plateau fracture from high-energy trauma do not experience worse outcomes when undergoing either ARIF or ORIF procedures, according to the findings of this study. Conventionally, ARIF is favored for Schatzker type 1–3 fractures, except in comminute fractures or open fractures with significant contamination. However, the preferred treatment for

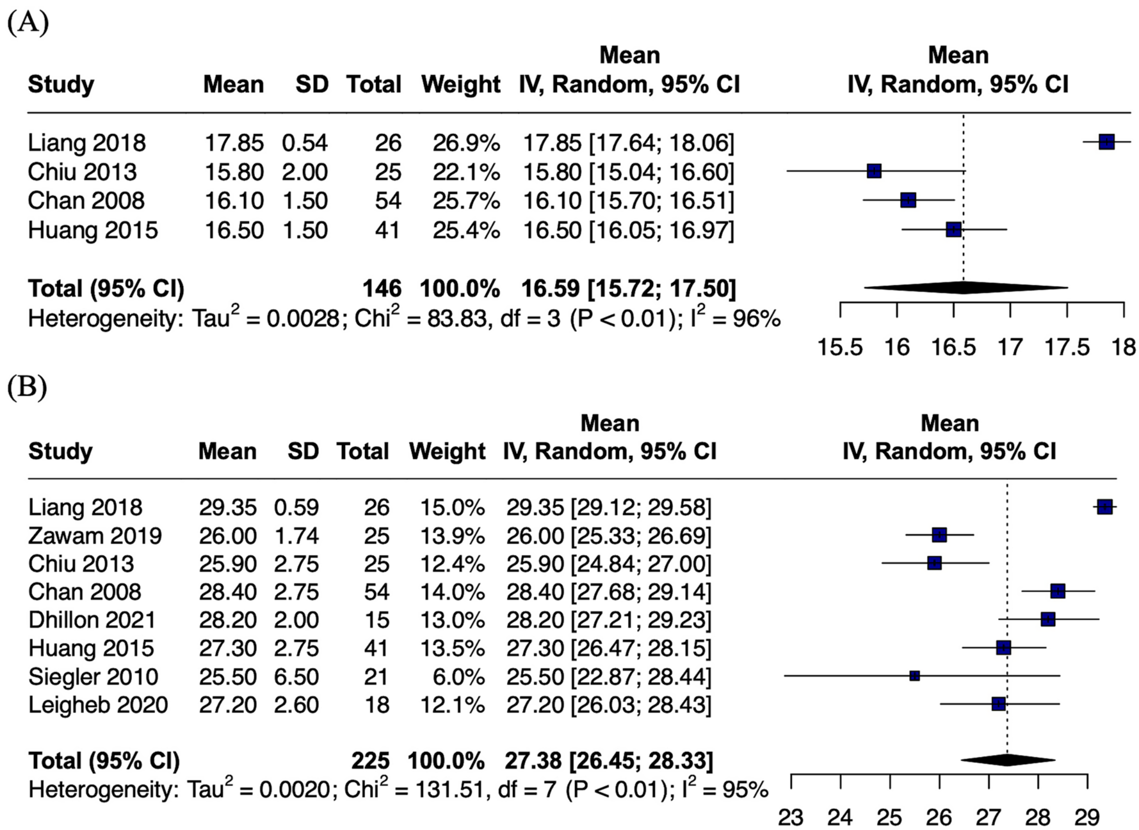

Fig. 3 Forest plot of the pooled radiological outcomes in (**A**) Rasmussen Radiological Score; and functional outcomes (**B**) Rasmussen Clinical Score of group ARIF

Schatzker type 4–6 fractures remains controversial. In these fractures, surgeons often express caution due to several potential drawbacks of ARIF. These fractures typically involve significant articular surface disruption, making them challenging to manage, and ARIF can be associated with risks such as deep infections, neurovascular damage, and complications arising from the compromised soft tissue envelope, leading some surgeons to favor ORIF [30]. These injuries resulting from high-energy trauma often carry a higher risk of compartment syndrome and an increased likelihood of deep infection [31, 32]. The heightened risk of complications prompts surgeons to opt for a more conventional treatment approach. Our meta-analysis findings regarding group ARIF indicated satisfactory knee functional and radiological outcomes with low complication rates, which were consistent with a recent study by Cheng et al. demonstrating that the majority of patients with complex tibial plateau fractures achieved excellent outcomes after ARIF [33].

ORIF for tibial plateau fractures may worsen soft tissue conditions because of the extensive dissection it involves, which is compounded by the edema and inflammation caused by the injury [34]. Additionally, the stripping of periosteum raises concerns about the risk of non-union. These factors could adversely affect clinical outcomes [35]. To address these challenges, minimally invasive surgery using ARIF has been introduced. ARIF offers several advantages, including reduced soft tissue dissection and the elimination of the need for arthrotomy. Furthermore, ARIF can address ligamentous or meniscal injuries simultaneously. Arthroscopy provides real-time, direct visualization of anatomical reduction, which helps prevent mal-reduction resulting from the inaccuracies associated with real-time radiography [36, 37].

However, as previously reported, there was a reported complication rate of around 6.5% with ARIF according to recent study [33]. These complications included issues such as fluid extravasation, compartment syndrome, and synovial pouch rupture, which are linked to high intra-articular pressure exceeding the range of 120 to 150 mm-Hg. It's worth noting that modern irrigation devices used in arthroscopic surgery often deliver much higher-pressure levels. The results of this study showed only one case experienced compartment syndrome, representing a low occurrence rate of 0.4% [11, 20]. Notably, other studies by Chan et al. and Chiu et al., which included a significant number of high-energy tibial plateau fractures, reported no instances of compartment syndrome during follow-up periods of 2 to 10 years [11,

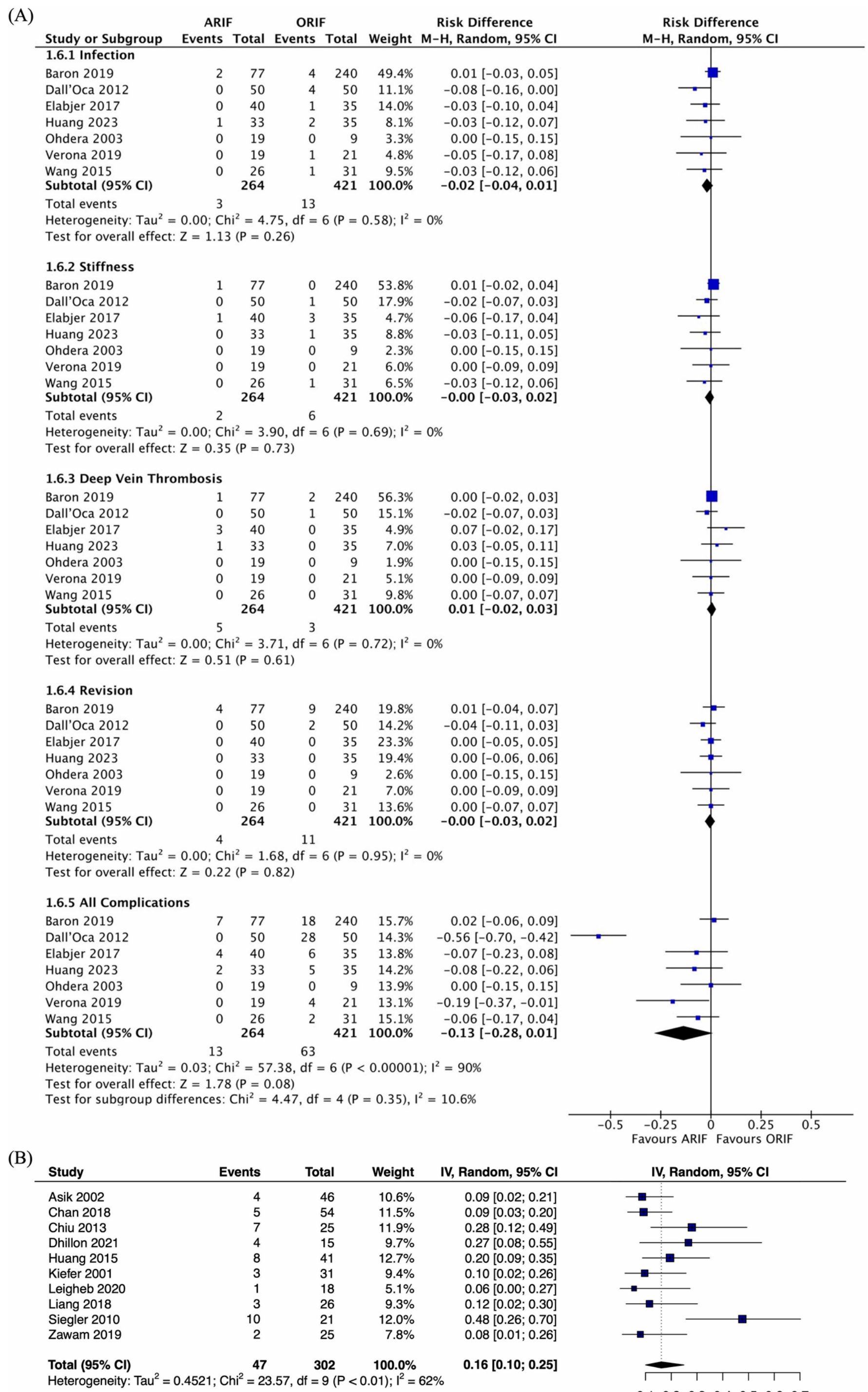

Fig. 4 Forest plot of the complications of (**A**) Group ARIF vs. ORIF, showing no significance difference between groups; (**B**) Group ORIF, the pooled result for all complications

20, 38]. This suggests that the occurrence of this severe complication could be avoided with early evaluation of soft tissue, when the soft tissues are compromised due to swelling, bruising, or other trauma-related factors that indicate the risk of increased intra-compartmental pressure [39]. By delaying surgery until the soft tissues have stabilized, surgeons can minimize the risk of severe complications. The low rate of compartment syndrome observed in these studies highlight that, with appropriate timing and management of the soft tissue envelope, ARIF can be performed safely even in high-energy fractures.

Table 3 Summary of findings

Outcome	Study (*n*)	Patients (ARIF/ORIF)	Overall Effect		Heterogenicity	
			MD [95%CI]	*P*	I^2	*p*
3.1 Group ARIF vs. ORIF						
Rasmussen radiological score						
Conventional	2	76/81	-0.02 [-1.46, 1.43]	0.98	70%	0.07
Modified	2	59/56	0.41 [-0.61, 1.43]	0.43	53%	0.14
Rasmussen clinical score	3	116/116	0.18 [-0.39, 0.76]	0.53	29%	0.25
Knee society score	2	45/52	5.84 [-1.18, 12.86]	0.10	74%	0.05
Hospital for special surgery score	3	160/325	5.13 [-1.67, 11.92]	0.14	83%	0.003
International knee documentation committee score	2	110/275	0.76 [-1.67, 3.19]	0.54	0%	0.38
			RD [95%CI]	***P***	I^2	***p***
Complications						
Infection	7	264/421	-0.02 [-0.04, 0.01]	0.26	0%	0.58
Stiffness	7	264/421	-0.00 [-0.03, 0.02]	0.73	0%	0.69
Deep Vein Thrombosis	7	264/421	0.01 [-0.02, 0.03]	0.61	0%	0.72
Revision	7	264/421	-0.00 [-0.03, 0.02]	0.82	0%	0.95
All Complications	7	264/421	-0.13 [-0.28, 0.01]	0.08	90%	< 0.00001

ARIF, arthroscopic assisted reduction and internal fixation; CI, confidence interval; MD, mean difference; N/A, not available; n, number; ORIF, open reduction and internal fixation; RD, risk difference

Table 4 .

Outcome	Study (*n*)	ARIF Patients (*n*)	Overall Effect
			Mean [95%CI]
3.2 Group ARIF			
Rasmussen radiological score			
Conventional	4	146	16.59 [15.72, 17.50]
Rasmussen clinical score	8	225	27.38 [26.45, 28.33]
Complications			**Occurrence [95%CI]**
All Complications	10	302	0.16 [0.10, 0.25]
			Incidence rate
Infection	10	302	0.6%
Stiffness	10	302	1.3%
Deep Vein Thrombosis	10	302	0.3%
Revision	10	302	0.9%

ARIF, arthroscopic assisted reduction and internal fixation; CI, confidence interval; n, number

However, based on the findings of current study, these complications appear to be less frequent than previously reported. Previous study also reported that with advances in surgical technique, modern implants, and careful perioperative management, ARIF can be a safe and effective surgical option for treating Schatzker type 4–6 fractures [40]. The relatively lower complication rate observed in this study indicates that concerns over postoperative risks may be overstated, reinforcing ARIF as a viable, reliable alternative in treating complex tibial plateau fractures.

In the realm of tibial plateau fracture treatment, there is a notable scarcity of meta-analyses and systematic reviews. Jiang et al. and Nguyen et al. published the meta-analysis about the arthroscopic-assisted procedure and traditional open surgery in treating tibial plateau fractures [38, 41]. Their findings indicated several advantages of arthroscopic-assisted procedures, including shorter hospital stays, increased detection of intra-articular injuries during surgery, and improved standardized functional outcomes. As a minimally invasive surgical technique, ARIF offers various benefits. It eliminates the need for sub-meniscal arthrotomy and significantly reduces soft tissue dissection and periosteal stripping [11]. With direct visualization, ARIF allows for precise reduction of tibial plateau fracture fragments and facilitates the identification and simultaneous repair of ligamentous or meniscal injuries [37]. While these findings are promising, the overall outcome of the meta-analysis did not reveal any significant differences between ARIF and ORIF in terms of treatment effectiveness.

Nonetheless, it's important to acknowledge that previous studies still require further direct comparisons and more in-depth sub analyses focused on complications and functional outcomes. In our meta-analysis results, a higher mean functional outcome score is observed in the ARIF group. Furthermore, there was a trend towards lower overall complication and infection rates in the ARIF group, although these differences did not reach statistical significance. Despite initial concerns about ARIF in the context of high-energy tibial plateau fractures, prior studies have reported overall complication rates ranging from 10.0 to 18.6% after ARIF [11, 37]. This study found that the complication rate in group ARIF fell within the range reported in previous research [31, 32]. Even among patients with high-energy tibial plateau fractures, minimally invasive ARIF appeared to provide superior clinical outcomes, and its complication rate was not inferior to that of ORIF. Consequently, ARIF emerges as a compelling and potentially optimal treatment option for tibial plateau fractures.

There are still some limitations. Firstly, although we included most of the current studies investigating this issue were included in this study, there was still a limited number of patients enrolled in this study. It could result in an unexplainable wide confidence interval and imprecision of the analysis. Secondly, only one randomized controlled trial was included and most included studies were retrospective. Bicondylar fracture patients were excluded in most included studies. These characteristics of the included studies might cause selection bias and reduce the representability, which may limit the applicability of study's findings, especially for more complex fracture pattern. Thirdly, the included studies in this study did not present individual outcomes for the different Schatzker types, preventing further analysis of the impact of fracture severity on the outcomes. Further studies comparing the outcomes between different severities of fractures may be needed to solve this dilemma. Lastly, varied functional and radiological scoring scales were adopted in different papers. Although the Rasmussen clinical and radiological scores were the majority evaluation system in our meta-analysis, these only account for less than half of our included studies. The lack of a generally acknowledged scoring system might lead to high heterogeneity and poor comparability. A larger patient cohort with reporting both Rasmussen clinical and radiological scores is recommended in the future investigation.

Conclusion

The findings of this study reveal no significant difference in clinical outcomes and complication rates between ARIF and ORIF. Additionally, this study found that the complication rate for patients undergoing ARIF falls within previously reported ranges. This suggests that ARIF is a reliable and effective surgical option for treating tibial plateau fractures, even in cases involving high-energy trauma.

Abbreviations

ARIF	Arthroscopic-assisted reduction and internal fixation
Cis	Confidence intervals
DVT	Deep vein thrombosis
HKA	Hip-Knee-Ankle score
HSS	Hospital for Special Surgery Knee Rating-Scale score
IKS	International Knee Society functional scoring system
JBI	Joanna Briggs Institute
KSS	Knee society score
MD	Mean difference
MRRS	Modified radiological Rasmussen score
NOS	Newcastle-Ottawa scale
ORIF	Open reduction and internal fixation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROMs	Patient-reported outcome measures
RCS	Rasmussen Clinical Score
RD	Risk difference
RMS	Rasmussen Radiological Score
RRS	Rasmussen Radiological Score
ROM	Range of motion
RoB	Risk of bias
Vs.	Versus

Supplementary Information

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Supplementary Material 1: Table S1. Preferred Reported Items for Systematic Review and Meta-Analyses (PRISMA) 2020 checklist.

Supplementary Material 2: Table S2. Newcastle-Ottawa Scale (NOS).

Supplementary Material 3: Table S3. Joanna Briggs Institute (JBI) critical appraisal tool.

Supplementary Material 4: Table S4. Details of Complications of Group ARIF.

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Author contributions
LTK proposed the topic and design the overall structure of the study. STT and MZC contributed to article search and manuscript drafting. STT performed statistical analyses and presented the data. LTK and YSC oversaw the whole research and provided critical comments. Authorship was assignment according to the ICMJE recommendations.

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The authors declare no competing interests.

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