A Meta-analysis Comparing External Fixation against Open Reduction and Internal Fixation for the Management of Tibial Plateau Fractures

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Abstract

Aim: This article aims to compare the outcomes between open reduction and internal fixation (ORIF) and external fixation (ExFix) in tibial plateau fractures.

Background: Open reduction and internal fixation and external fixation are common methods for managing tibial plateau fractures without a consensus of choice.

Materials and methods: PubMed, Cochrane Library, Ovid, CINAHL®, Scopus, and Embase were searched. Clinical studies in humans comparing ExFix and ORIF for tibial plateau fractures were included. Case reports, pathological, and biomechanical studies were excluded. Two investigators reviewed the studies independently, and any discrepancies were resolved. The quality and heterogeneity of each study were assessed in addition to calculating the odds ratio (OR) of the surgical outcomes and complications at a 95% confidence interval, with $p < 0.05$ as statistical significance.

Results: Of the 14 included studies, one was a randomised trial, one was a prospective study, and 12 were retrospective studies. The 865 fractures identified across the studies constituted 458 (52.9%) in the ExFix group and 407 (47.1%) in the ORIF group. Most studies indicated a better outcome for ORIF as compared to ExFix. Open reduction and internal fixation had a lower incidence of superficial infection and postoperative osteoarthritis, while ExFix revealed a lower proportion with heterotopic ossification (HTO).

Conclusion: ExFix has a higher rate of superficial infections and osteoarthritis, whereas ORIF has a higher incidence of HTO. Larger studies are needed to compare outcomes and investigate the findings of this study further.

Clinical significance: This up-to-date meta-analysis on tibial plateau management will help surgeons make evidence-based decisions regarding the use of ORIF versus ExFix.

Keywords: External fixator, Fracture, Internal fracture fixation, Tibia.

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Introduction

Tibial plateau fractures affect major weight-bearing joints[1] and account for 1–2% of all fractures.[2–4] They result from high-energy trauma in young adults and occur as fragility fractures in older populations. Despite its rarity, the sequelae might be devastating. The high-energy and complex articular tibial plateau fractures (Schatzker types IV, V, and VI; or Orthopaedic Trauma Association or AO types 41 C1, C2, and C3) have soft tissue damage and fracture elements that affect articular congruity and cartilage quality.[5–9] Fractures may lead to compartment syndrome, secondary osteoarthritis (OA), and produce knee instability complications.[10]

The re-establishment of joint congruity and stability determines the success of the treatment.[11] Successful treatment of tibial plateau fractures comprises a reconstruction of the articular surface, usually with open reduction of the tibial plateau. However, ORIF has been associated with complications attributed to soft tissue compromise[12] despite the evolution of minimally invasive techniques.[13] Alternatively, management by external fixation (ExFix; using indirect reduction through closed manipulation or minor open reduction by limited access incisions) has been a satisfactory alternative when the soft tissue integrity is affected severely.[14,15] The better management choice is still not clear.

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Metcalfe et al. in 2015 compared ExFix and ORIF for the management of bicondylar tibial plateau fractures and found no significant difference in the postoperative complications, radiological evaluations, and functional outcomes.[16] However, the study samples and measured complications were not

comprehensive. This study aims a more inclusive and up-to-date meta-analysis for high-energy complex tibial plateau fractures.

Our study samples for this meta-analysis included Schatzker type IV fractures. There are two reasons for this inclusion. First, the three column-classification elaborated by Kfuri et al.[17] stresses the importance of the posterior column, present in the coronal section of the articular surface of a tibial plateau posteromedial fracture (a subtype of Schatzker type IV), which may require ExFix as definitive treatment. This is recommended because of the inaccessibility and difficulty of stabilising the posteromedial part of the medial fragment. Second, the medial part of the tibial plateau is denser than the lateral; therefore, a higher force is needed to produce the fracture which supports classifying type IV fractures as high-energy types.[17]

There are five new observational comparative studies included to this meta-analysis and with eight previous studies makes this the largest meta-analysis presently.[16,18] Included is a discussion on the incidence of several complications not previously described in the literature, including the rate of HTO.

The aim of this meta-analysis was to identify the better option for the management of high-energy complex tibial plateau fractures (Schatzker IV, V, and VI) through a comparison of the postoperative outcomes and complications of ORIF and ExFix.

MATERIALS AND METHODS

Searches

A meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[19] The literature search strategy used PubMed, Cochrane Library, Ovid MEDLINE, CINAHL® (cumulative index to nursing and allied health literature), Scopus, and Embase. There were no limits in terms of language, study design, or publication status. The following medical subject headings (MeSH) and terms were used:

- 'Internal fixation'
- 'External fixation'
- 'Tibial plateau fracture' or 'tibial plateau'
- 'Bicondylar tibial plateau fracture' or 'condylar tibial plateau fracture' or 'complex tibial plateau fracture' or 'high energy tibia', 'high energy tibial plateau fracture'
- Articular fractures 41 C1 C2 C3 OR AO/OTA type C (C1, C2, C3)
- 'Schatzker 4' or 'Schatzker IV' or 'Schatzker type IV' or 'Schatzker type IV'
- 'Schatzker 5', 'Schatzker V' or 'Schatzker type V' or 'Schatzker type V'
- 'Schatzker 6' or 'Schatzker VI' or 'Schatzker type VI' or 'Schatzker type VI'
- Long-term complications AND tibial plateau
- 3 AND 7–9

For further information regarding current trials, the WHO International Clinical Trials Registry Platform[20] was searched using the following three MeSH terms: 'internal fixation', 'external fixation', and 'tibial plateau fracture'.

To complete information on some included articles, we contacted corresponding authors. The translation of the Chinese article presented was performed by the China Asia On Demand (CAOD) professional human translation service.

Study Inclusion and Exclusion Criteria

Inclusion criteria were as follows:

- Studies done on humans
- Studies on condylar or bicondylar, open or closed Schatzker types IV, V, and VI tibial plateau fractures
- Studies directly comparing ExFix and ORIF
- Studies reporting data of efficacy outcomes (radiological, clinical, and others) and postoperative complications

Exclusion criteria were as follows:

- Reviews or isolated case reports
- Studied fractures were pathological (e.g., osteoporotic fractures)
- Biomechanical analyses
- Articles highlighting ORIF or ExFix as the sole method

Study Selection and Data Extraction

Two investigators screened the retrieved database independently; based on the title and abstract initially and full-text thereafter following an exclusivity protocol. Any discrepancies were discussed and reviewed. A single author extracted and summarised data in a uniform format.

Study Quality Assessment

The risks of bias were assessed independently by two of the authors. For non-randomised controlled trials (non-RCTs), the methodological index for non-randomised studies (MINORs) scale was used. Methodological index for non-randomised studies is a valid instrument designed to assess the methodological quality of non-randomised surgical studies, whether comparative or non-comparative, scoring from 0 to 24 (Table 1).[21] A revised tool to assess the risk of bias in randomised trials, known as the risk of bias 2 [(RoB 2), Version of October 9, 2018)], was used for [randomised control trials (RCT), Table 2]. The updated version of the tool is structured into five domains including signalling questions. The five domains constitute bias related to the randomisation process, deviations from intended interventions, missing outcome data, measurement of the outcome, or a selection of the reported result. Each item was recorded as 'high risk', 'low risk', 'some concern risk'.[21]

Statistical Analysis

The meta-analysis and forest plots were performed using the meta-analysis package 'meta' and statistical software R (version 5.3, R Foundation, Vienna, Austria). Review manager version 5.3 was used for statistical analysis. Two models were applied for meta-analysis based on heterogeneity testing using I^2 and Chi-square tests. The random-effect model was applied when the heterogeneity test was found to be significant with I^2 greater than 50% and a *p*-value less than 0.1, while the fixed-effect model was applied in the remaining instances. The combined OR and its 95% confidence interval was based on a random-effects model, taking into account the between- and within-variation from different studies. Each variable included in the study was presented as an OR with their 95% confidence interval, and then plotted on one graph in addition to the summarised finding.

Excluding assessment of heterogeneity, *p*-values <0.05 were considered statistically significant. Heterogeneity was examined based on τ^2 statistic and I^2 statistic from either random-effects model (if significant) or fixed-effects model (if not significant).

Table 1: Quality assessment for non-randomised trials (MINORs)

Assessment criteria	Ahearn et al.[22]	Bertrand et al.[24]	Berven et al.[31]	Boston: Covall et al.,[29] Mallik et al.[41]	Bove et al.[35]	Chan et al.[34]	Chertsey: Guryel et al.,[36] Nawaz et al.[47]	Conserva et al.[28]	Jansen et al.[7]	Krupp et al.[26]	Malakasi et al.[32]	Pun et al.[40]	Zhuo et al.[33]
A clearly stated aim	2	2	2	2	2	2	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	2	2	2	2	2	2	2	2	2	2
Prospective data collection	0	2	0	0	0	0	0	0	0	0	2	0	0
Endpoints appropriate to the aim of the study	2	2	2	2	2	2	2	2	2	2	2	2	2
Unbiased assessment of the study endpoint	2	2	2	2	2	2	2	2	2	2	2	2	2
Follow-up period appropriate to study aims	2	2	2	2	2	2	2	2	2	2	2	2	2
Less than 5% loss to follow-up	1	2	0	2	0	2	2	2	2	1	2	0	2
Prospective sample size calculation	0	0	0	0	0	0	0	0	0	0	0	0	0
An adequate control group	2	2	2	2	2	2	2	2	2	2	2	2	2
Contemporary groups	2	2	2	2	2	2	2	2	2	2	2	2	2
Baseline equivalence of groups	2	2	2	1	2	2	2	2	2	2	2	1	2
Adequate statistical analyses	2	2	2	2	2	2	2	2	2	2	2	2	2
Total score	19	22	18	19	20	20	20	20	20	19	22	20	20

Results

Study Quality Assessment

The risk of bias for the Canadian Orthopaedic Trauma Society (COTS) studies[22,23] was evaluated using the ROB 2 tool.[5,24] This was the only RCT presented in this meta-analysis, and it demonstrated a low risk of bias in almost all elements except for the measurement of the outcome. This was because the evaluators in the COTS were not blinded, and the study protocol was not published before recruitment of the participants (Table 2). Therefore, there were some risk concerns regarding the selection of the reported results.

As for the prospective and retrospective studies, the risk of bias was evaluated using MINORS.[18] The majority were appraised as high quality except for two studies as greater than 5% of their participants were lost to follow-up.[22,25] Likewise, four studies showed a high risk of attrition bias[26–30] (Table 1).

Study Characteristics

Initially, 986 articles were identified from the search, and 640 were excluded as duplicates. Three hundred forty-six articles were screened for title and abstract where 242 were excluded. Of the 17 identified articles, one was an RCT, one was a prospective study, 12 were retrospective studies,[7,22,26–29,31–36] and three published conference abstracts.[22,37,38] The search process followed the PRISMA flow chart (Flowchart 1) and reported through a checklist (Supplement 1).

The characteristics of the included studies are presented in Table 3. The meta-analysis included 865 fractures across the studies divided as 458 (52.9%) in the ExFix group and 407 (47.1%) in the ORIF group. The COTS study[22,30] was the only multicentre randomised clinical trial, and it accounted for 9.2% of the published knee cases available for analysis. In the only prospective non-RCT, Malakasi[33] presented 60 knees (6.7%) where hybrid external fixators were used for 50% of the knees and antiglide plates or cannulated screws were used as ORIF for the others.

The remaining 12 retrospective studies had 753 knees (84%) of the issued cases presented for analysis. Considerable variability of methods was used for treatment in the latter studies. Each retrospective study highlighted more than one device in the techniques of ExFix and ORIF.

The effect and heterogeneity I^2 results are shown in Table 4 for each postoperative outcome or complication.

Results of Meta-analysis

The primary aim of this meta-analysis is to compare the outcomes between ORIF and ExFix in tibial plateau fractures while assessing the postoperative complications of both surgical strategies through forest plots of the analysed studies. Although the measured outcomes varied throughout the studies (Tables 1 and 2), we aligned the complications recorded in the studies through this

Table 2: Risk of Bias 2 (RoB 2) for randomised controlled trials

Assessment criteria	Pirani and McKee[27]
Bias arising from the randomisation process	Low risk
Bias due to deviations from intended interventions	Low risk
Bias due to missing outcome data	Low risk
Bias is measurement of the outcome	High risk
Bias in selection of the reported result	Some concerns risk

Flowchart 1: PRISMA flow diagram showing the study selection process
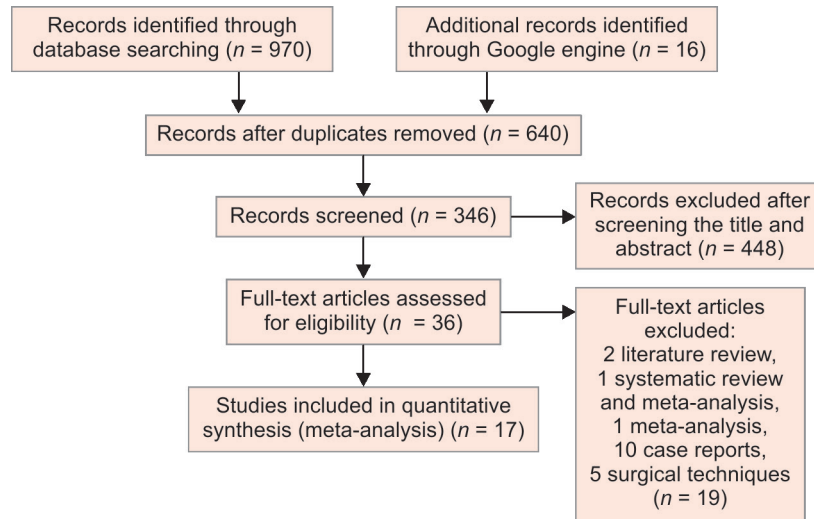
meta-analysis and compared them. The complications were malunion (two studies), non-union (three studies), postoperative OA (seven studies), re-operation (six studies), total knee replacement (TKR) (five studies), superficial infection (13 studies), deep infections (eight studies), DVT (four studies), compartment syndrome (two studies), HTO (two studies), knee stiffness (four studies), degrees of extension (two studies) and degrees of flexion (two studies). Although some forest plots were based on only two studies, we were able to study the heterogeneity and retrieve any statistical significance, if present, to enable a conclusion.

Radiographic Outcomes

Two knee scores were used to assess the radiographs. Rasmussen's radiological score was used in three papers to assess radiographic outcomes. This is based on joint depression, condylar widening, and varus or valgus angulation.[39] The reliability and validity remain debatable even though it assesses the radiologic outcome of the knee specifically.[40] Malakasi et al., Chan et al., and Conserva et al. showed that the difference was not significant between the ExFix group and the ORIF group with non-significant *p* values.[28,29,33] Conversely, the Kellgren–Lawrence score radiographic interpretation tool was used by Jansen et al. and Berven et al., and no differences were highlighted between the groups.[7,32]

Healing time was assessed as an outcome parameter. Three studies highlighted the time of healing in terms of radiographic union. Berven et al. reported a non-significant larger number of patients in the ORIF group who were healed after 3 months, and this was more than in the ExFix group (*p* = 0.057); however, when smoking behaviour and injury severity score (ISS) were included in a logistic regression analysis, the *p*-value became significant (0.041).[32] Krupp et al. reported an average of 7.4 months in the ExFix group and 5.9 months in the ORIF group. Conserva et al. reported 15.9 months in the ExFix group and 17.2 months in the ORIF group.[29] Zhuo et al. showed an average healing time of 7.3 months in the internal fixation group compared to 5.1 months in the ExFix group.[26] According to Bertrand et al., the average time needed for consolidation to occur was 19.28 weeks in the ORIF group (95% CI: 16.32–22.28) and 22.83 weeks in the ExFix group (95% CI: 13.50–32.17), with a non-significant *p*-value (*p* = 0.393).[31]

Based on evidence from radiography, malunion, non-union, and OA were assessed. Malunion was assessed in two papers accounting for 87 fractures (10.05% of total fractures). Krupp et al. reported 13 (5%) in ExFix and 4 (1%) in ORIF and Malakasi et al. showed two (13%) in ExFix and six (43%) in ORIF group.[16,27,41] These results are shown in Figure 2 (OR 1.54, 95% CI 0.62–3.78, *p* = 0.35). There is some heterogeneity between the two studies (*p*-value of 0.006) that might be related to different follow-up periods and patient characteristics. Non-union was highlighted in three papers. Berven et al. reported three (4.83%) in the ExFix group against nine (13.2%) in the ORIF group. Bove et al. reported one (7.1%) in the ExFix group and one (7.1%) in the ORIF group. Krupp et al. reported four (13.3%) in the ExFix group and three (10.7%) in the ORIF group.[27,32,36] These results are shown in Figure 2 (OR 0.60, 95% CI 0.24–1.52, *p* = 0.28). Nevertheless, in these studies, the homogeneity is mainly related to the 'relative' similarity in the short-term follow-up (6 months to 1.5 years), and these were high-energy fractures. Osteoarthritis was assessed in 582 fractures (67% of all fractures). These results are shown in Figure 3 (OR 1.67, 95% CI 1.08–2.58, *p* = 0.02). Bove et al. used the ASAMI radiological outcome score based on bone healing and alignment. It was rated as excellent in 10 patients (71%), good in four patients (29%) in the ExFix group, as opposed to excellent in eight patients (57%), good in five patients (36%), and poor in one patient (7%) in the ORIF group.[36] *I*² showed homogeneity in this list of studies that can be attributed to the design, similarities in type of management, follow-up, and fracture classification.

Length of Hospital Stay

The overall length of hospital stay was highlighted in three studies. Bertrand et al. showed no significant differences between ExFix and ORIF (*p* = 0.536).[31] Conversely, COTS and Conserva et al. presented statistically significant *p* values in favour of the ExFix group, which had shorter hospital stays than did the ORIF group (9.9 ± 1.6 days against 23.4 ± 3.8 days, *p* = 0.024; 7.8 against 14.2 days, *p* = 0.002).[22,30] In the study by Malakasi et al., postoperative hospitalisation for ORIF was 4.8 days against 3.8 days for ExFix for Schatzker 4, ORIF 6.5 days against 5.5 for ExFix in Schatzker V, and 3.8 days for ORIF against 3.6 days for ExFix in Schatzker VI group with a non-significant *p*-value.[33]

Table 3: Characteristics of included studies

Study	Design	Mean ages (years)	Fracture types (knees)	Interventions (knees and methods)		Follow-up (months)
				ExFix	ORIF	
Ahearn et al.[22]	Retrospective, Non-RCT	44 years	[b]C3 (30), Others were unknown	TSF (21)	Lateral locking plate ± medical plate fixation (34)	ExFix: 31 months, ORIF: 41 months
Bertrand et al.[24]	Retrospective, Non-RCT	46.71 years	[c]V (31) and VI (62)	Hybrid external fixator (67)	Two buttressing plates (26)	24 months
Berven et al.[31]	Retrospective, Non-RCT	ExFix: 55.74 years, ORIF: 50.44 years	[b]AO 41 A2 (12), A3 (5), or C1 (14), C2 (25), C3 (74)	Ilizarov wire frame (62)	Locking plates (68)	6 months
Boston Covall et al.[29] Mallik et al.[41]	Retrospective, Non-RCT	45 years	NM	Monticelli-Spinelli circular fixator (10)	Bilateral buttress, semi-tubular plates, or cannulated screws (7)	ExFix: 10 months, ORIF: 33 months
Bove et al.[35]	Retrospective, Non-RCT	ExFix: 51 years, ORIF: 43 years	[c]VI/ [b]41C2 (10) or 41C3 (18)	Ilizarov frame (1/14 7.14%), TrueLok (2/14 14.2%), Ring Rod (2/14 14.2%), TSF (9/14 64.2%) (14)	LISS (14)	12 months
Chan et al.[34]	Retrospective, Non-RCT	ExFix: 52.03 years, ORIF: 45.04 years	[b]C1 (18), C2 (2), C3 (39)	Ilizarov circular frame (23/35, 65.7%), Hoffman II with limited internal fixation (13/35, 37.1%) (35)	Buttress plate (21/24, 84%), LISS (4/24, 16%) (24)	3, 6, 12, and 24 months
Chertsey Guryel et al.[36] Nawaz et al.[37]	Retrospective, Non-RCT	NM	[d]Vagus (62), varus (14), axial (48)	Ilizarov circular frame (79)	NM (45)	NM
Conserva et al.[28]	Retrospective, Non-RCT	54.1 years	[c]IV (23), V (29), VI (27)	Percutaneous lag screw + hybrid external fixator (41)	LCP ± bone graft substitute (38)	EF: 39.4 months, ORIF: 35.1 months
COTS[a] Pirani and McKee[27]	RCT	ExFix: 46.2 years, ORIF: 43.3 years	[c]V (18), VI (65) bC1 (20), C2 (39), C3 (24)	Percutaneous lag screw, and Ilizarov circular frame (43)	Medial and lateral non-locking buttress plates ± bone grafting (40)	6,12, 24 months
Jansen et al.[7]	Retrospective, Non-RCT	46 years	[b]C1 (7), C2 (7), C3 (9)	Ilizarov circular frame (2)	LISS (19/20, 95.0%) ± additional plates (7/20, 30.4%) ± artificial bone substitute (7/20, 30.4%) (21)	67 months
Krupp et al.[26]	Retrospective, Non-RCT	ExFix: 48.8 years, ORIF: 46.64 years	[c]V (37), VI (21)	Hoffman II Hybrid (16/28, 57.1%) or circular frames (14/28, 50.0%) (30)	Dual platting (8/28, 28.6%), Lateral locking plate + medial screws or buttress plate (20/28, 71.4%) (28)	EF: 16.4 months, ORIF: 10.2 months
Malakasi et al.[32]	Prospective, Non-RCT	40.5 years	[c]IV (10), V (10), VI (9)	Hybrid external fixator (30)	Antiglide plates or cannulated screws (30)	12 months
Pun et al.[40]	Retrospective, Non-RCT	43.85 years	[c]V (11), VI (10)	Circular frame + medial percutaneous screws (12)	Dual plate (9)	30 months
Zhuo et al.[33]	Retrospective, Non-RCT	ExFix: 44.2 years, ORIF: 45.4 years	[c]IV (31), V (13), VI (22)	Hybrid external fixator (27)	Screws, steel plates (39)	1–5 years

COTS, Canadian Orthopaedic Trauma Society; ExFix, external fixation; LCP, locking compression plate; LISS, less invasive stabilisation system; NM, not mentioned; Non-RCT, non-randomised control trial; ORIF, open reduction and internal fixation; RCT, randomised control trial; TSF, Taylor spatial frame; [a]multicentre randomised controlled trial; [b]orthopaedic trauma association classification; [c]Schatzker classification; [d]the chertsey classification of tibial plateau fractures

Table 4: Overall effect and heterogeneity of postoperative outcomes and complications

| Outcomes	Number of studies	Effect estimate (95% CI)	p-value	Heterogeneity I^2 (%)	p-value
Malunion	2	1.54 (0.62–3.78)	<0.01	87%	0.35
Non-union	3	0.60 (0.24–1.52)	0.42	0%	0.28
Postoperative osteoarthritis (PTOA)	7	1.67 (1.08–2.58)	0.65	0%	0.02
Reoperation	6	1.03 (0.65–1.65)	0.37	7%	0.89
Total knee replacement	5	0.51 (0.20–1.34)	0.99	0%	0.17
Superficial infections	13	3.40 (2.03–5.68)	0.04	45%	<0.01
Deep infections	8	1.14 (0.60–2.17)	0.20	29%	0.70
Deep vein thrombosis	4	1.67 (0.59–4.74)	0.26	25%	0.33
Compartment syndrome	2	0.61 (0.12–3.20)	0.37	0%	0.56
Heterotopic ossification	2	0.17 (0.04–0.80)	0.38	0%	0.03
Knee stiffness	4	1.38 (0.62–3.03)	0.36	6%	0.43
Flexion <90°	2	3.71 (0.78–17.59)	0.90	0%	0.10
Extension deficit ≥10°	2	1.17 (0.56–2.42)	0.39	0%	0.68
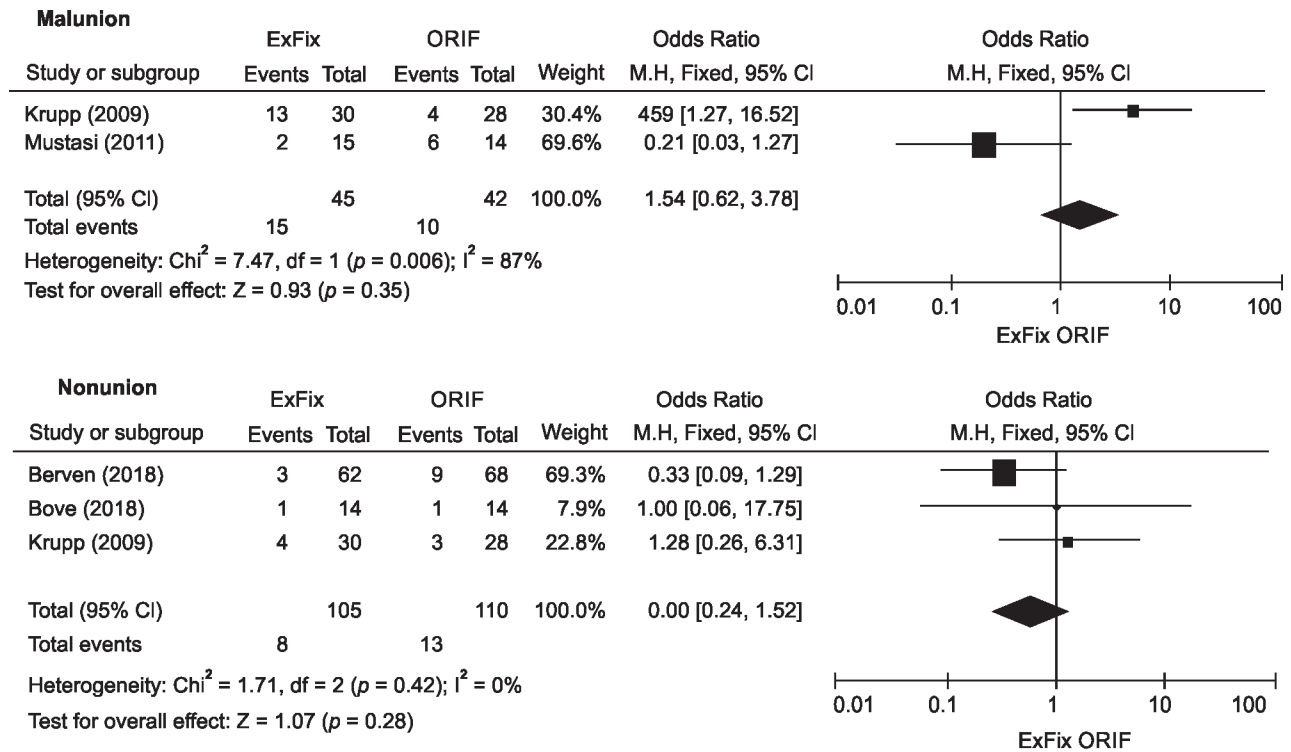
Fig. 2: Malunion and non-union odds ratios

Reoperation

Six studies reported the reoperation rate after surgery with a total of 498 fractures (57% of total fractures) (Fig. 4). In the ExFix group, 58 fractures (21.96%) needed reoperation against 45 fractures (19.23%) in the ORIF group. The difference in reoperation rate was not statistically significant (OR 1.03, 95% CI 0.65–1.65, $p = 0.89$). Most of the reoperations mentioned in the literature included pin-track debridement, screw removal, and knee manipulation in the ExFix group against above-the-knee amputation, rotational or free flaps or both, incision and drainage with plate removal, and osteotomy in the ORIF group.[22,30] There was no heterogeneity in the studies

with p-value 0.37 mainly related to the similarities in the design and short-term follow-up.

Total Knee Replacement after Surgery

Five papers mentioned late surgery for total knee arthroplasty (TKA). Figure 4 shows the same numbers reported previously with 7 (3%) TKA in the ExFix group against 12 (4.2%) in the ORIF group (OR 0.51, 95% CI 0.20–1.34, $p = 0.17$). There was ambiguity concerning the accuracy of follow-up shown in some of the papers and the unclear timing of the TKA, leading to possible length of time bias imputed to uncertainty as to whether TKA was a postoperative outcome and what was the exact number of the surgeries. We also
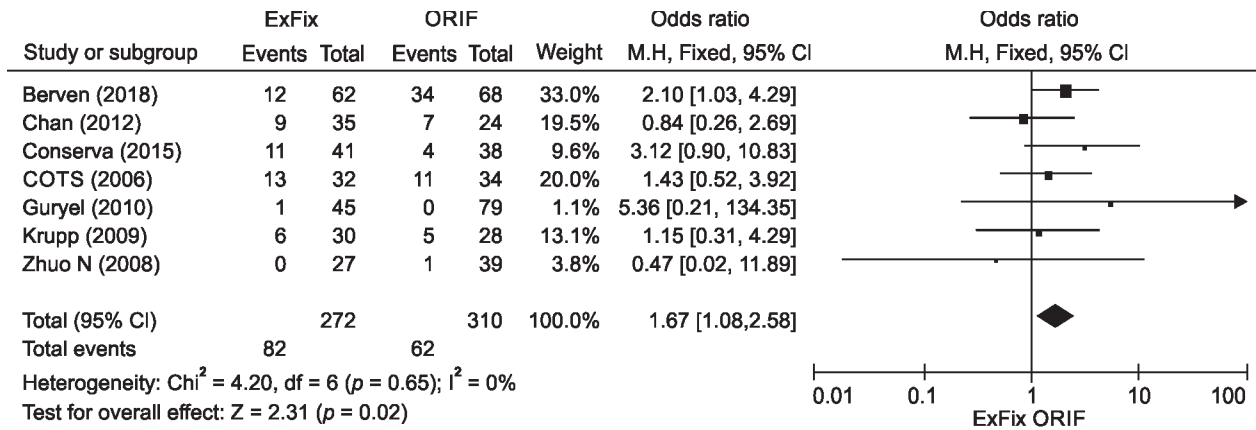
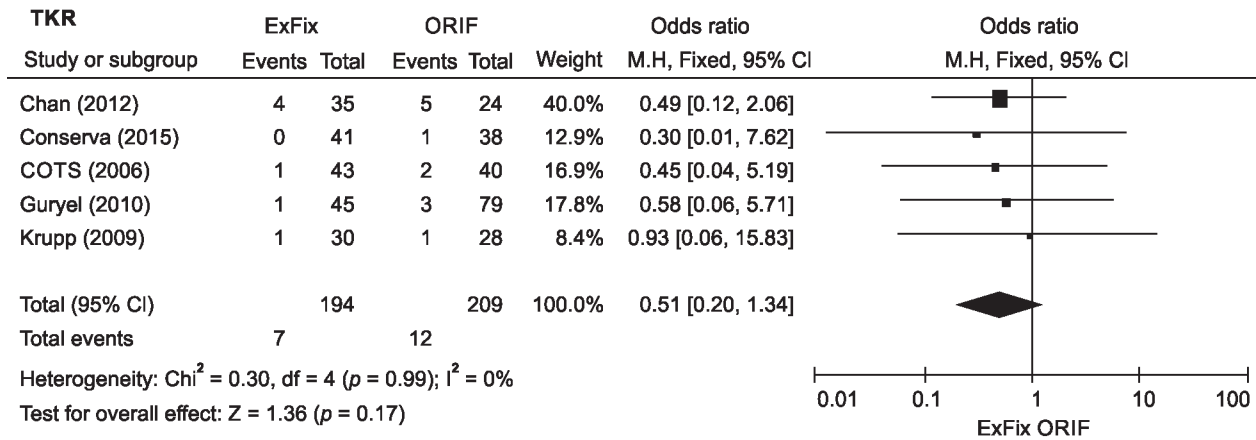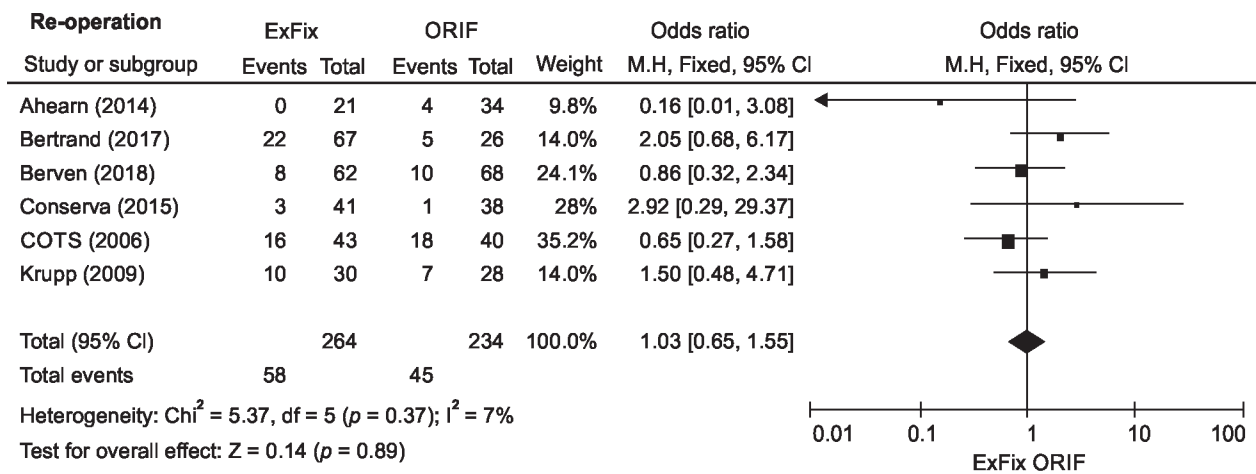**Fig. 3:** Postop osteoarthritis (PTOA) odds ratios

Fig. 4: The odds ratios of reoperation and total knee replacements (TKR)

note the homogeneity in this list of studies as mentioned earlier with a *p*-value of 0.99.

Postoperative Complications

Superficial Infections

All 13 non-RCTs reported superficial infection rates in a total of 781 fractures (90%). Figure 5 shows a higher number of superficial infections in the ExFix group than in the ORIF group (OR 3.40, 95% CI 2.03–5.68, *p* <0.001). Superficial infections involved only the skin and subcutaneous tissues. Nevertheless, there was heterogeneity between the studies (*p*-value 0.04) which might be explained by the different study design (in this forest plot there has been both retrospective studies and an RCT). Also, there are different types of tibial plateau fractures (different Schatzker and AO classification). Patient characteristics might have been a factor, but this cannot be confirmed due to the lack of demonstration of the detailed patient demographics within each study.
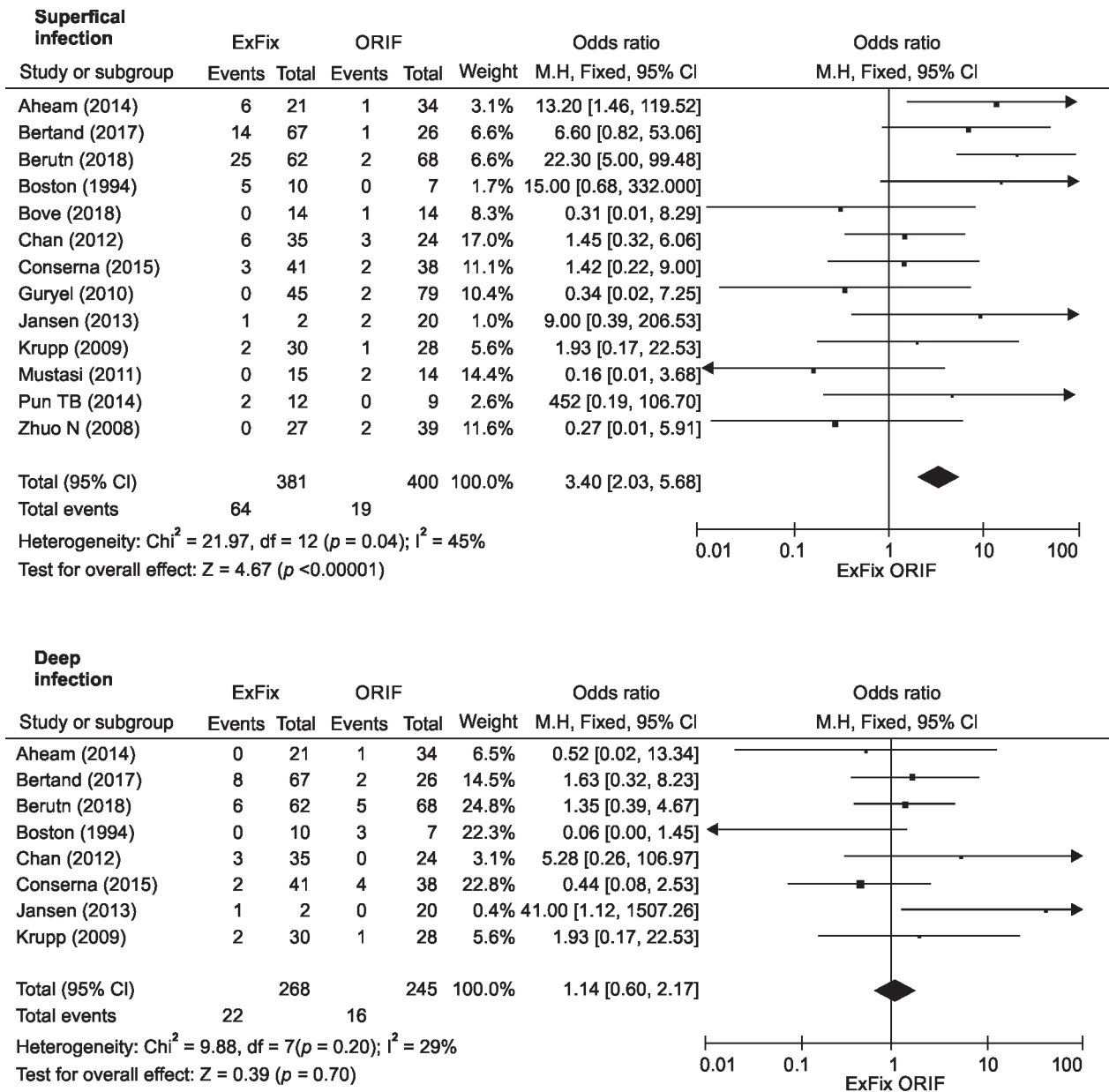
Fig. 5: Superficial and deep infection odds ratios

Deep Infections

Eight non-RCTs[8,13,16,17,25,36,42–44] reported deep infections with a total of 513 fractures (59%). Figure 5 shows a higher number of deep infections in the ExFix group than in the ORIF group (OR 1.14, 95% CI 0.60–2.17, $p = 0.70$). The presence of deep infection was assumed when septic arthritis or osteomyelitis or both were documented requiring IV antibiotics and operative irrigation with revision or removal of the fixating implants.[32] As far as heterogeneity, there has been a homogenous effect between the lists of the studies included in the list of deep infection with a p-value of 0.20. It might be explained because the prospective study of the Malakazi et al. was extracted from this forest plot.

Deep Venous Thromboembolism (DVT)

Four studies reported the rate of venous thromboembolism (VTE), with no statistically significant differences between the ORIF group and the ExFix group as shown in Figure 6 (OR 1.67, 95% CI 0.59–4.74, $p = 0.33$). None of the studies mentioned the type of DVT screening tool used; therefore, cases were considered symptomatic.[28,32,34,37]

Compartment Syndrome

The forest plot shown in Figure 6 shows postoperative compartment syndrome in two studies. It was highlighted in two (3.9%) of ExFix cases and four (8.62%) in the ORIF group (OR 0.61, 95% CI 0.12–3.20, $p = 0.56$).[7,28,36]

Studies that included both DVT and compartment syndrome showed homogeneity with a p-value of 026 and 0.37, respectively.

Heterotopic Ossification

Krupp et al. and Berven et al. reported two cases (2.17%) of HTO in the ExFix group and 11 (11.46%) in the ORIF group with
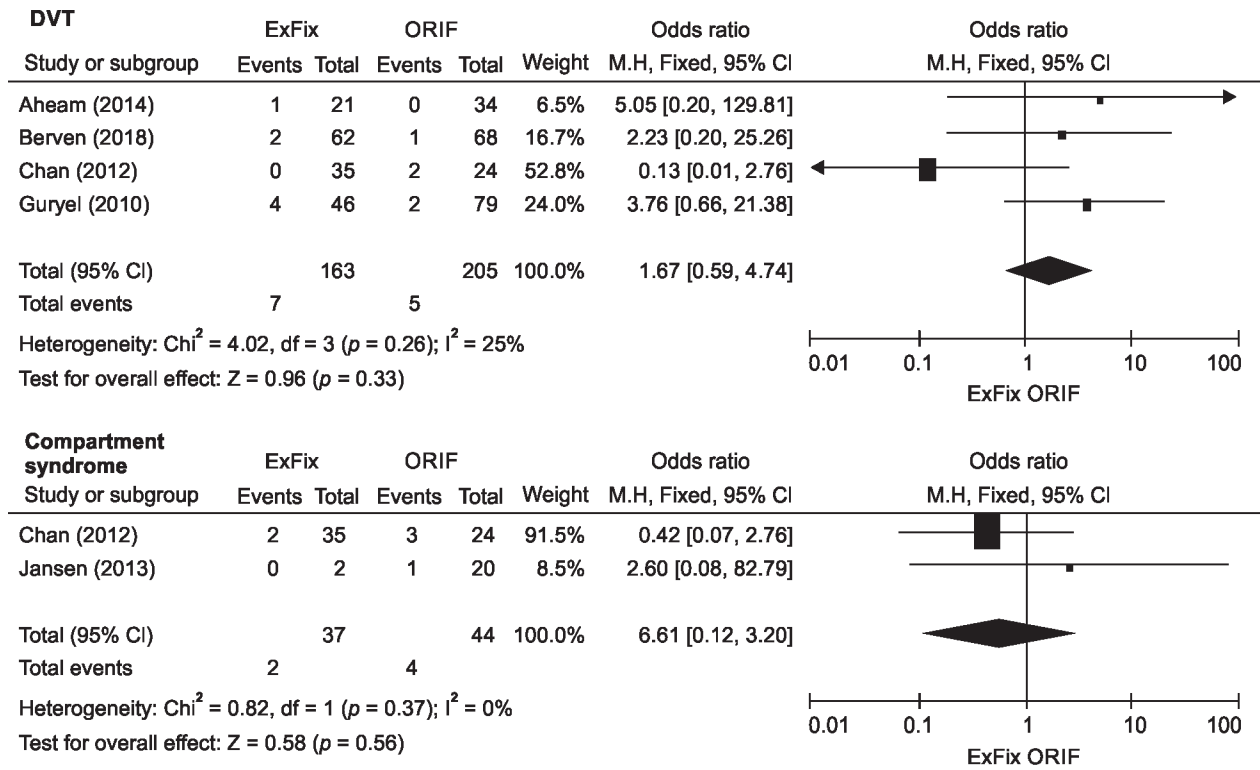
Fig. 6: The odds ratios of postoperative deep vein thromboembolism and compartment syndrome
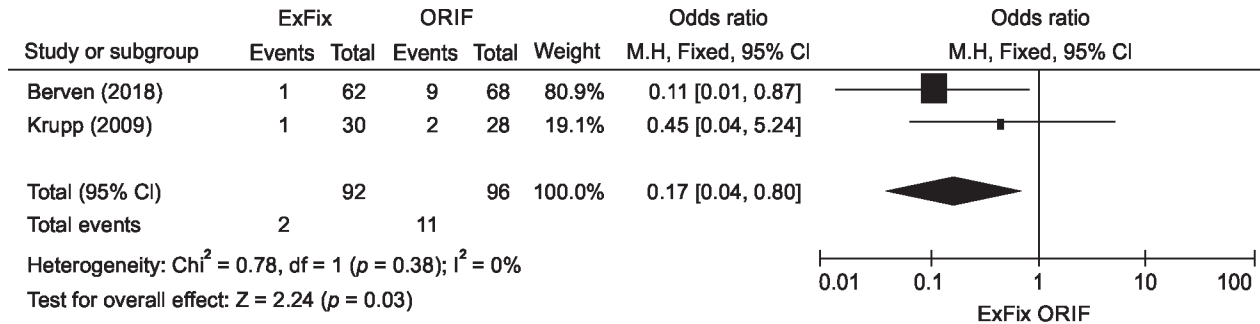

Fig. 7: Heterotopic ossifications odds ratio

statistically significant differences between the groups, as shown in Figure 7 (OR 0.17, 95% CI 0.0–0.80, $p = 0.03$).[32,27] There was homogeneity between these two studies with a p-value more than 0.05.

Knee Stiffness

The forest plot in Figure 8 reported the postoperative knee stiffness in four studies. Knee stiffness was defined with a range of motion less than 90°.[27] It was highlighted in 15 (8.72%) of ExFix cases and 12 (7.45%) of the ORIF group with no significant differences between the groups (OR 1.38, 95% CI 0.62–3.03, $p = 0.43$).[26,27,29,32]

Discussion

Our study revealed significant differences between ORIF and ExFix in terms of OA, superficial infection, and HTO outcomes but non-significant differences in other outcomes and postoperative complications. Although not the first in the literature, this meta-analysis is the most current and comprehensive. Metcalfe

et al.[16] have found no superiority of either technique for the management of bicondylar tibial plateau fractures as assessed through postoperative complications, radiological evaluations, and functional outcomes. Zhao et al.[45] indicated ExFix as superior over ORIF with regard to speed of return to preinjury state but no difference between the two in the long-term outcomes.

In this meta-analysis, ORIF was found to be superior to ExFix in radiological and functional outcomes without reaching statistical significance. This may arise from allowing for better visualisation of fracture configuration and achieving an anatomical reduction, but there are compromises made over soft tissue integrity and to the disruption of biological osteosynthesis. External fixators with different specific frame types ranging from circular hexapod, hybrid, to classic Ilizarov have gained popularity and allow for adequate closed reduction, permit early weight-bearing while respecting the soft tissue envelope. Various types of complications arise from the method of treatment itself, ranging from pin-site infections, prolonged time of healing, and the inconvenience of the device location outside the body leading to poorer patient
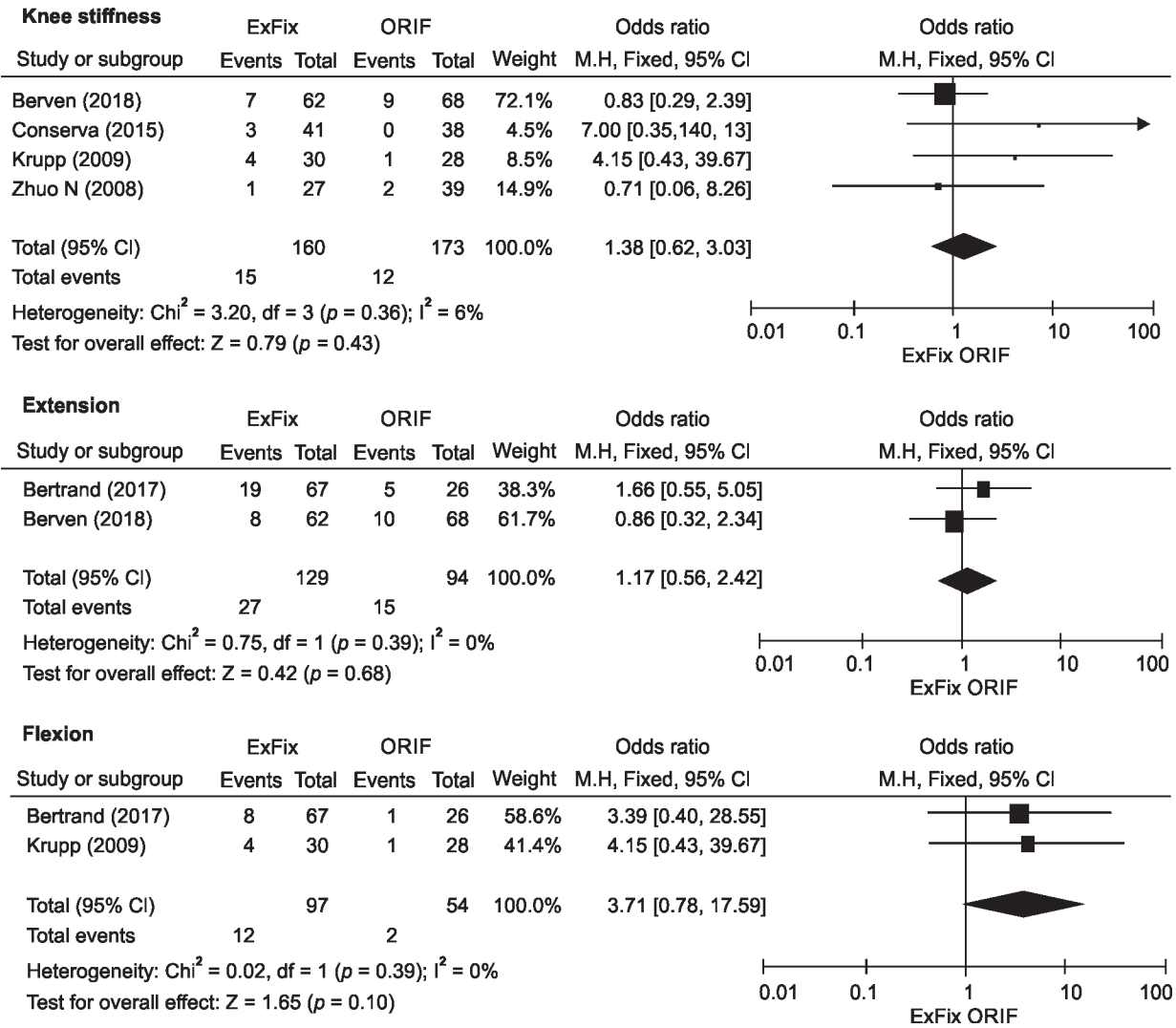
Fig. 8: The odds ratios of function parameters: Knee stiffness, extension deficit of ≥10°, and flexion <90°

tolerance or compliance. Furthermore, ExFix might jeopardise the absolute quality of reduction as most is done percutaneously or by closed methods; however, it remains unclear as to whether this affects functional outcomes ultimately because of the lack of long-term follow-up in the literature.[25,39,46,47]

Our analysis showed a higher rate of malunion in the ExFix group than in the ORIF group with no statistical significance. The reason may be related to indirect reduction mostly done in the ExFix group leading to varus or valgus malalignment. In contrast, use of an anatomical locking plate, increased use of bone grafting, and anatomical reduction may have decreased the risk of malunion in ORIF.[27]

Secondary OA remains an issue after intra-articular fractures of the knee. A pooled analysis of seven studies showed a significantly higher rate of secondary OA in the ExFix group than in the ORIF group with statistical significance. In addition to the cartilage injury, malalignment after treatment is considered an important factor of poor outcome after tibial plateau fracture with a higher risk of OA.[9,46] Although less invasive, ExFix does not allow for an anatomic realignment of the joint surface, which may influence the integrity of the reduction. The loss of anatomical reduction at the

articular surface may lead to increased joint reactive forces linked to development of OA.

In addition to postoperative malalignment, functional outcomes during follow-up have shown to be predictive of postoperative OA.[9] The lack of long-term follow-up and the few short-term functional outcomes published in the ORIF and ExFix groups leaves the long-term impact on knee OA unknown.[16]

It is worth mentioning that post-traumatic OA does not appear to be influential on short-term patient-reported outcome measures and may be more important when long-term results are compared.[7] Therefore, our findings may underestimate the problem, and this warrants comparative trials with longer follow-up periods.

The pooled analysis of 13 studies showed that ORIF was superior to ExFix in terms of superficial infections attributed mainly to the pins as a source of infection, a finding that is consistent with those reported previously.[16,33,47] In clinical practice, ORIF requires a relatively big incision with dissection of the soft tissue to reach the fracture to reduce it. Previously, the literature has reported a higher risk of deep infection in ORIF as compared to ExFix. Nevertheless, in our meta-analysis, the rates of deep infections were higher in ExFix compared to ORIF but with no statistical significance. This

finding might be attributable to the advancement of minimally invasive techniques and minimisation of the amount of metal used in ORIF. Also, patients with compromised soft tissue integrity are more likely to be treated with ExFix leading to a higher rate of deep infection. This is due to the loss of integrity of the skin as a barrier to deep infections confounding as a potential selection bias. This anomaly should be considered and raises this as a potential subject in future research while excluding the baseline soft tissue injury as a selection bias. Bertrand et al.[31] reported that deep infections were more common when a hybrid external fixator was used after open reduction than when the closed reduction was performed although this was not statistically significant. The authors stated that this combination of opening up the fracture together with the use of permanent pins appears to encourage contamination and hence subsequent infection.

Heterotopic ossification is rare in tibial plateau fractures. A pooled analysis of two studies done in 2009 and 2018 showed a significantly higher rate of HTO in ORIF. This is attributed possibly to either the post-reduction use of bone graft or bone graft substitutes[27,32,44] or to the mechanical stimuli from plate placement within a leg compartment that has been subject to soft tissue compromise which alters the pH, oxygen tension, and availability of micronutrients.[48]

Although there are statistically significant findings of differences in complications between ORIF and ExFix, this conclusion omits to consider the possible influence of soft tissue conditions. This is a major factor that cannot be excluded when dealing with patients with tibial plateau fractures and represents a major influence in clinical decision-making. A patient with severely compromised soft tissue is likely to be managed with an external fixator, whether temporarily or definitively. The soft tissue compromise places the patient at higher risk of negative sequelae that is independent of the fixation device. Conversely, a patient with a good soft tissue status is likely to be fixed by ORIF in an attempt to secure anatomical reduction. This will put the patient on a different spectrum of complications like HTO as shown in this analysis. Thus, the initial conclusions of this meta-analysis, where the included studies have not enabled this major confounder to be balanced across the comparative groups, have to be reconciled accordingly. This study however does highlight the type and risk of potential complications that can be encountered in either ORIF or ExFix in order to guide clinicians in the decision making, especially when dealing with tibial plateau fractures with 'grey zone' characteristics and deciding which form of definitive fixation should be implemented.

Limitations

In spite of the high level of evidence meta-analyses deliver, the robustness of evidence does depend on the quality and the number of the studies included. The limitations of this meta-analysis were that most included studies were observational, hence minimising the external validity of the findings. Consequently, there were heterogeneities involved in implants used, surgeon expertise, technique, and patient characteristics such as age, sex, functional status, comorbidities, smoking habits, and work-related injuries. Selection bias attributed to the low evidence study designs included in this paper is present. A definitive conclusion of superiority of one technique in terms of complications when treating tibial plateau fractures is not possible with current evidence. Higher evidence is needed to establish a conclusive

answer. This is reflected in the literature where there is a lack of clinical trials except for one study which was included in our analysis.

Most of the papers had a relatively short follow-up of less than 3 years. The longest follow-up was 5 years, which is long enough to determine short-, mid-, and long-term complications post-treatment of tibial plateau fractures (e.g., development of OA).

Conclusions

Larger randomised trials are needed to compare the complication profile of ORIF versus ExFix. ExFix has a higher tendency for superficial infection and OA. Open reduction and internal fixation has a higher tendency for HTO compared to ORIF. Nevertheless, patient characteristics, post-fracture soft tissue integrity, mechanism of injury, and surgical expertise are all contributing factors that must be considered when approaching complex tibial plateau fractures. Further studies need to be conducted to assess the potential determining factors in addition to mode of fixation that can affect postoperative reduction, soft tissue integrity, and functional outcomes.

Clinical Significance

This meta-analysis is the largest and most comprehensive on tibial plateau management currently. These initial conclusions will help surgeons be aware of the potential outcomes and complications that may influence their decisions between the use of ORIF or ExFix for tibial plateau fractures.

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Supplementary Material

All the supplementary material are available online on the website of www.stlrjournal.com.

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