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REVIEW ARTICLE

Meta-analysis shows that highly comminuted bicondylar tibial plateau fractures treated by single lateral locking plate give similar outcomes as dual plate fixation

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Abstract
Objectives This meta-analysis was conducted to compare the clinical outcomes of single lateral locking plate (SP) versus dual plate fixation (DP) for the repair of bicondylar tibial plateau fractures (AO/OTA type C or Schatzker type V and VI).
Methods PubMed, Embase, Medline, CNKI, Wanfang database and Chinese VIP information were searched to identify the randomized and prospective comparative clinical studies which concern the treatment of bicondylar tibial plateau fractures (AO/OTA type C or Schatzker type V and VI) both with SP and DP fixation before October 1, 2015. STATA version 11.0 (Stata Corporation, College Station, TX, USA) was used for data-analysis after the critical assessment of the methodological quality of the trials.
Results Finally, nine trials comprising 559 patients were included for this meta-analysis after the filtration. There were no significant differences between SP fixation and DP fixation with regards to outcomes for bone graft, post-operative malalignment and post-operative malreduciton in surgical details; infection, venous thrombosis, implant irritation and loss of reduction in complications; knee motion range in final outcomes. Lower surgical time, hospital stay, union time and incision necrosis were found in SP fixation compared with DP fixation. High rate of loss of alignment and more satisfaction with 12-month HSS score were associated with SP fixation than with DP fixation.
Conclusions Both SP fixation and DP fixation are acceptable strategies for managing this type of fracture. However, more high quality RCTs with large number of patients and long-term clinical evaluations are required to determine the optimal strategy for bicondylar tibial plateau fractures.

Keywords Bicondylar tibial plateau · Dual plate · Fixation · Fracture · Locking plate · Meta-analysis · Single

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Introduction

Bicondylar tibial plateau fracture, which consists of AO/OTA type C or Schatzker type V and VI, accounts for 35.8 % of all tibial plateau fractures [1]. With the increase of high energy traffic accidents, the number of complex tibial plateau fracture has gradually increased [2]. Because of the significant articular comminution, severe soft-tissue injury as well as intra- and post-operative complications, surgical fixation of bicondylar

fractures of tibial plateau still remains problematic and challenging, even to the experienced surgeons [3–6]. The objectives of surgical treatment include restoration of articular surface, preservation of soft tissues and correction of anatomic alignment in the lower extremities and stable fixation that allows for early mobilization [4, 7].

To date, the commonly used treatment strategies include external fixation with Ilizarov circular frame or other kind of circular frame, open reduction and internal fixation (ORIF), a combination of external and limited internal fixation (hybrid technique). Open reduction with dual buttress plate fixation is the classic treatment modality which is favoured by AO/ASIF [8, 9] and biomechanically proven as the ideal fixation for stability requirement of fragments both from lateral and medial side [10–13]. However, extensive soft tissue dissection of the fracture zone will compromise the biological conditions for fracture healing and increase the risks of wound complications [4, 10]. With the improvement of modern locking plating system and the minimally invasive percutaneous osteosynthesis (MIPO) techniques, unilateral locking plate fixation becomes a good alternative for the treatment of complex tibial plateau fractures. Several studies have compared the biomechanical strength of unilateral locked screw plate and double plating for the treatment of bicondylar tibial plateau fractures and showed no statistically significant difference between these two fixation methods [12, 14, 15]. However, the problem of secondary loss of reduction especially happening in the medial component or posteromedial fragment has been found in some clinical articles [16–18].

This meta-analysis from original comparative studies was conducted to evaluate whether the isolated lateral locking plate fixation (SP) is preferable over the dual plate fixation (DP) in terms of surgical details, clinical outcomes and postoperative complications for the treatment of bicondylar tibial plateau fractures.

Materials and methods

Search strategy

A systematic search of PubMed, Embase, Medline database, CNKI, Wanfang database and Chinese VIP database were performed independently by two investigators (Chang and Zhu) for eligible trials before October 1, 2015 regardless of language limitation. The following key words and combinations were used: "tibial plateau" AND "complex" or "complicated" or "bicondylar" or "high energy" or "comminuted" or "AO/OTA type C" or "type C" or "AO/OTA C" or "schatzker 6" or "schatzker VI" or "schatzker type 6" or "schatzker type VI" or "schatzker 5" or "schatzker V" or "schatzker type 5" or "schatzker type V" AND "dual plat*" or "double plat*". Additional literature works were manually searched from the reference lists of identified articles and Google Scholar resources.

Inclusion and exclusion criteria

We included studies if the following criteria were met: (1) published research literature which were RCTs with high level of evidence or prospectively comparative studies; (2) patients with tibial plateau fractures of AO/OTA type C or Schatzker type V and VI were allocated into two treatment groups: (a) single lateral locking plate (SP) fixation group and (b) dual plate (DP) fixation group; (3) studies presented with any parameter on surgical details, complications and final outcomes were included; and (4) studies in which a follow-up of a

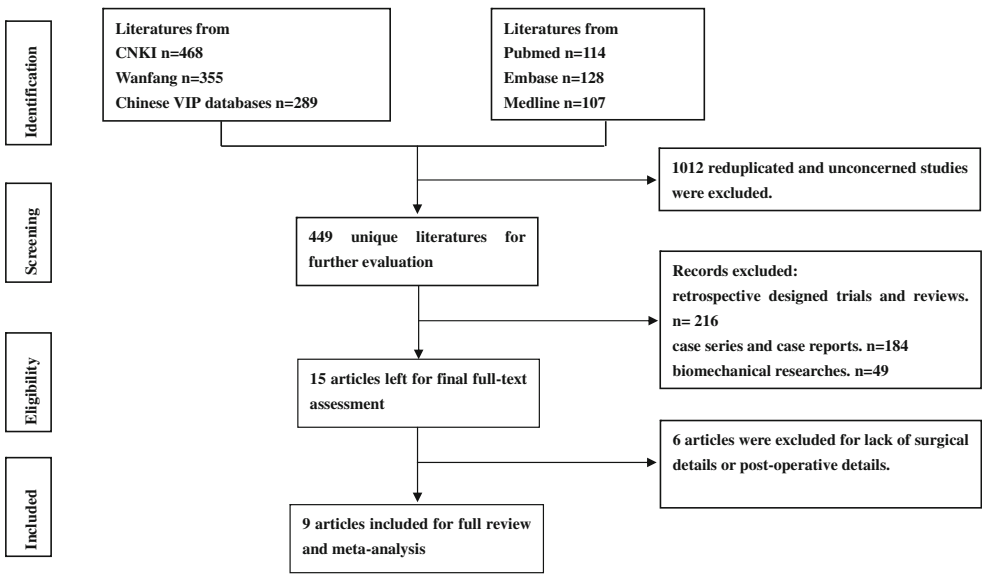


Fig. 1 The procedure of literature selection

Table 1 The characteristics of included studies

Name	Year	Intervention		Patients (SP V. DP)	Percentage male (%) (SP V. DP)	Mean age (year) (SP V.DP)	Follow-up (month)	Study type	Jadad score
		SP	DP						
Jiang et al [16]	2008	LISS fixation	L: T or L-shaped buttress plate M: LC-DCP	41 V. 43	70.7 V. 67.4	41.4(8.3) V. 43.0(9.1)	24	Prospective	4
Yao et al [2]	2015	LCP	Dual buttress plate	41 V. 44	63.4 V. 63.6	43.2(8.9)V. 45.5(7.2)	12-36	RCT	4
Neogi et al [20]	2015	LCP	L: LCP M: reconstruction plate/3.5mmDCP/distal end radius plate	29 V. 32	69.0 V. 65.6	41 V. 37	24	Prospective	2
Zhang et al [21]	2010	LCP	L: Golt-shaped LCP M: reconstruction plate	20 V. 20	87.5	32(21-56)	18	Prospective	2
Yang et al [22]	2013	LCP	Dual buttress plate	21 V. 21	66.7	30.1(3.8)	10-12	Prospective	2
Ding et al [23]	2014	LCP	Dual buttress plate	34 V. 34	52.9	43.7(11.6)	6	Prospective	2
Jia et al [24]	2013	LCP	Dual LCP	25 V. 25	52.0 V. 60.0	39.52(11.52) V. 38.54(11.28)	12	Prospective	2
Luo et al [25]	2015	LISS fixation	L: Golf-shaped LCP M: T or L-shaped buttress plate	23 V. 23	65.2	23-59	12	Prospective	2
Wang et al [26]	2015	LISS fixation	L: Golf-shaped LCP M: T or L-shaped buttress plate	42 V. 41	59.5 V. 63.4	37.8(4.5)V. 37.5(4.6)	12	Prospective	3

Abbreviation: SP, single lateral locking plate; DP, dual plate; L, lateral side; M, medial side; V, versus; LISS, the less invasive stabilization system; LCP, locking compression plate; DCP, dynamic compression plate; LC-DCP, limited-contact dynamic compression plate; RCT, randomized controlled trial

minimum of 12 months was involved. Exclusion criteria were: (1) retrospective designed trials, case series, case reports, reviews and unconcerned studies like isolate abstracts, meeting proceedings and letters; (2) biomechanical research; and (3) any pathological or metabolic fractures.

Data extraction and quality assessment

Two investigators (Chang and Zhu) identified the appropriate research works according to the pre-stated inclusion criteria and extracted the data independently. A third author would give objective advice if there were any different opinions between them. Necessary information was extracted including article's characteristics (the first name of author, year of publication, the type of studies, gender composition, mean age, fracture type, time to follow-up); surgical details; post-operative complications and outcomes.

The quality of included articles was graded using a modified Jadad score system in terms of eight-item scales—randomization, blinding, withdrawals and dropouts, inclusion and exclusion criteria, adverse effects and statistical analysis. Low-quality or level B studies were defined with three points or below and high quality or level A studies were defined with four points or above.

Definitions of parameters

Post-operative malalignment was defined as a tibial plateau angle (TPA) ≥ 90 degrees or ≤ 80 degrees or a posterior slope angle (PSA) ≥ 15 degrees or ≤ −5 degrees and post-operative malruduction was defined as an intra-articular step-off of 2 mm or greater revealed in the instant radiographs after the operation [2, 16, 19]. Loss of alignment and loss of reduction were defined respectively as a change of 5° or greater in alignment and 2 mm or greater in depression compared with the first post-operative radiological outcomes [2, 16, 19, 20]. Surgical time was defined as the time interval from the beginning of incision to wound closure [21–23].

Statistical analyses

Two authors conducted all calculations independently by using STATA software, version 11.0 (Stata Corporation, College Station, TX, USA). A P value <0.05 was considered statistically significant. The dichotomous variables were summarized with the odds radios (ORs) and their corresponding 95 % CI. Also, the continuous variables were summarized with the weighted mean difference (WMD) and their corresponding 95 % CI. A visual inspection of forest plot as well as the I^2 test were used for heterogeneity evaluation among the studies [18]. The random-effects model was used when significant heterogeneity substantially existed ($P < 0.05$,

Table 2 Summary of the interest outcomes in this meta-analysis

Outcomes	Number of studies	Participants	Overall effect			Heterogeneity	
			Statistical method	Effect estimate	P-value	I^2%	P-value
Surgical details							
Bone grafting	3	230	OR (fixed, 95 % CI)	0.68 [0.39, 1.17]	0.165	22.2 %	0.276
Post-op malalignment	3	230	OR (fixed, 95 % CI)	2.06 [0.74, 5.73]	0.168	24 %	0.268
Post-op malreduction	3	230	OR (fixed, 95 % CI)	1.0 [0.39, 2.57]	0.996	0.0 %	0.884
Surgical time(minutes)	4	251	WMD (random, 95 % CI)	−22.79 [-28.19, -17.38]	<0.001	55.1 %	0.083
Complications							
Infection	6	421	OR (fixed, 95 % CI)	0.72 [0.36, 1.44]	0.355	15.4 %	0.315
Venous thrombosis	3	237	OR (fixed, 95 % CI)	0.80 [0.19, 3.32]	0.757	0.0 %	0.620
Implant irritation	3	185	OR (fixed, 95 % CI)	2.12 [0.74, 6.08]	0.162	34.9 %	0.215
Incision necrosis	4	174	OR (fixed, 95 % CI)	0.16 [0.04, 0.76]	0.021	0 %	0.973
Loss of alignment	4	276	OR (fixed, 95 % CI)	5.23 [1.32, 20.73]	0.019	0.0 %	0.788
Loss of reduction	3	230	OR (fixed, 95 % CI)	0.86 [0.22, 3.26]	0.819	0.0 %	0.624
Final outcomes							
Hospital stay (weeks)	3	171	WMD (random, 95 % CI)	−5.202[-7.694, -2.710]	<0.001	81.7 %	0.004
Union time (weeks)	5	296	WMD (random, 95 % CI)	−2.62 [-3.39, -1.85]	<0.001	48.5 %	0.100
HSS score (12 months)	4	298	WMD (random, 95 % CI)	3.09 [0.20, 5.99]	0.036	52.9 %	0.095
Knee motion (degree)	4	247	WMD (random, 95 % CI)	0.43 [-6.08, 6.94]	0.897	77.8 %	0.004

Abbreviations: MD, weighted mean difference; OR, odds radio; NA, not applicable; CI, confidence interval; Post-op, post-operative

$I^2 > 50$ %); otherwise, the fixed-effects model was used ($P \geq 0.05$, $I^2 \leq 50$ %) [24].

Result

Data

A total of 1461 potentially eligible studies were initially identified. After carefully screening, 1012 reduplicated and unconcerned studies were excluded. When title and abstract browsing were accomplished, 434 literature were identified according to the key words restriction and exclusion criteria (retrospective designed trials and reviews. n = 216; case series and case reports. n = 184; biomechanical researches. n = 49). Finally, nine studies [2, 16, 19–23, 25, 26] comprising 559 patients (276 in the single plate group and 283 in the dual plate group) were eligible for this meta-analysis after the full-text assessment, including three English and six Chinese literature. One RCT and eight prospective comparative studies included were included. Figure 1 represents the flowchart which indicates the progress of literature selection and Table 1 represents the characteristics of included studies.

Meta-analysis

This meta-analysis was carried out focusing on three aspects, surgical details (surgical time, bone grafing, post-operative malalignment and post-operative reduction), complications (infection, venous thrombosis, incision necrosis, implant irritation, loss of reduction and loss of alignment) and final outcomes (hospital stay, union time, knee motion range and HSS score).

Table 2 shows all outcomes of this meta-analysis. There were no significant differences identified between the SP group and the DP group for the surgical details in bone grafting (OR, 0.68, 95%CI, 0.39 to 1.17; $P = 0.165$), post-operative malalignment (OR, 2.06, 95%CI, 0.74 to 5.73; $P = 0.168$) and post-operative malreduction (OR, 1.0, 95%CI, 0.39 to 2.57; $P = 0.996$). A fixed effects model was applied for them because no significant heterogeneity ($P > 0.05$, $I^2 < 50$ %) existed. The WMD of surgical time in SP group was significantly lower compared to the DP group (WMD, -22.79, 95%CI, -28.19 to -17.38; $P < 0.001$). Figure 2 shows all forest plots of the interest in surgical details.

For the complications, there was no difference between these two groups in infection (OR, 0.72, 95%CI, 0.36 to 1.44; $P = 0.355$), venous thrombosis (OR, 0.80, 95%CI, 0.19 to 3.32; $P = 0.757$), implant irritation (OR, 2.12, 95% CI, 0.74 to 6.08; $P = 0.162$), loss of reduction (OR, 0.86, 95% CI, 0.22 to 3.26; $P = 0.819$). The OR of incision necrosis in SP group was significantly lower compared with the DP group (OR, 0.16, 95%CI, 0.04 to 0.76; $P = 0.021$). The OR of loss of alignment in single lateral locking plate group was significantly higher compared to the dual plate group (OR, 5.225, 95%CI, 1.317 to 20.734; $P = 0.019$). A fixed effects model

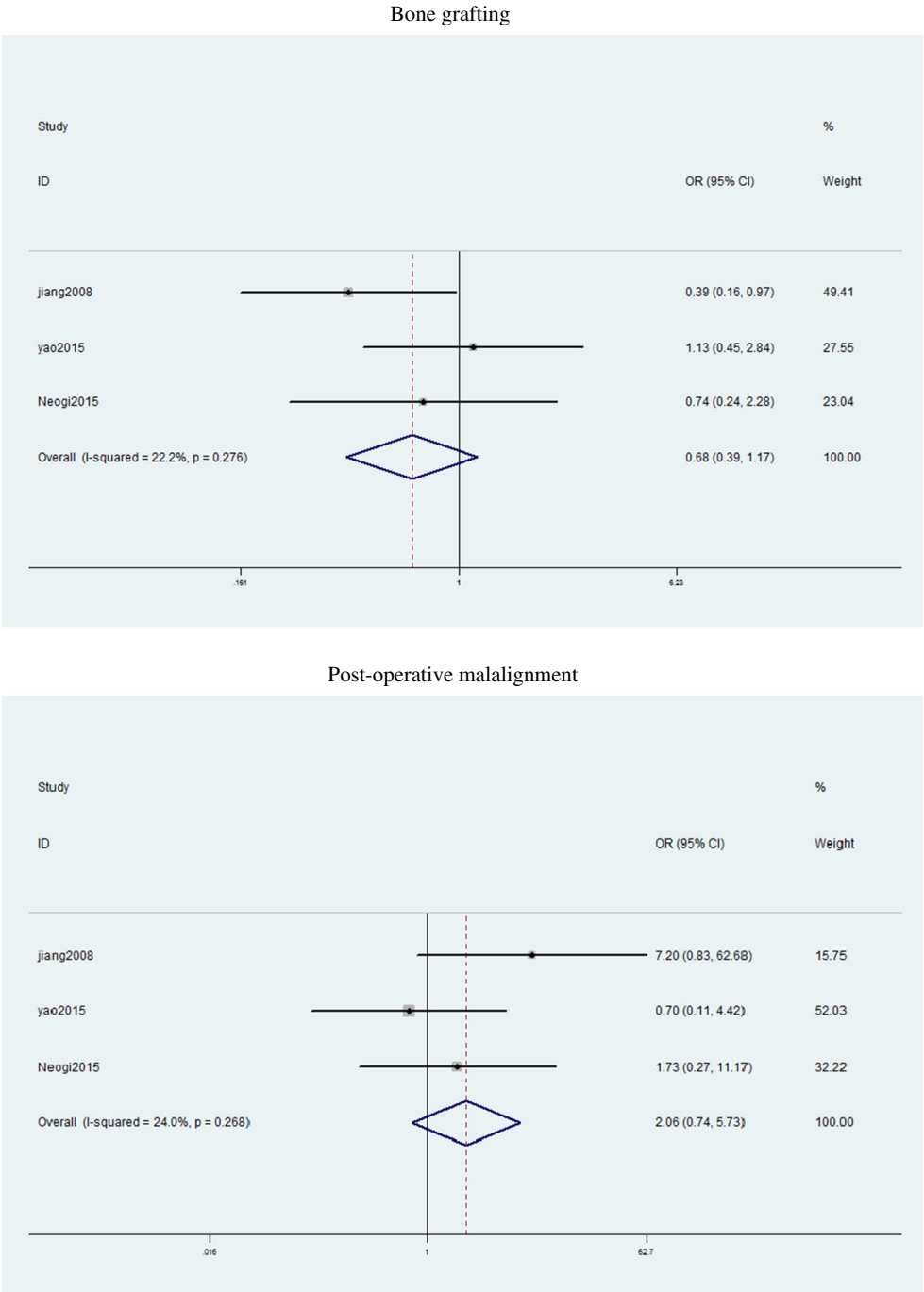
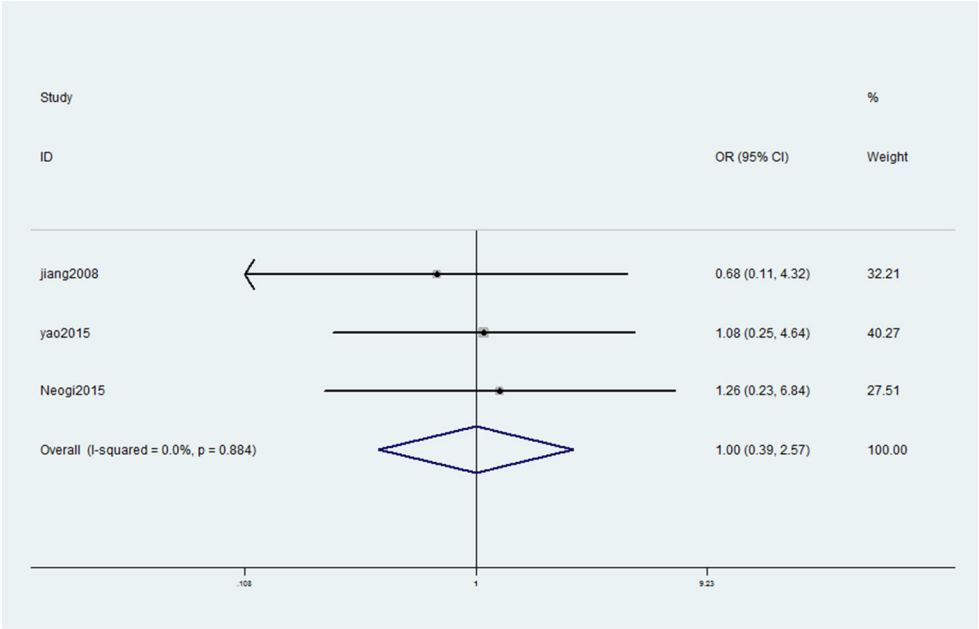


Fig. 2 Forest plots of comparison of bone grafting, post-operative malalignment, post-operative malreduction and surgical time between SP fixation and DP fixation for bicondylar tibial plateau fractures. The horizontal line represents the 95% CI and each square represents the proportional weight of the study

was applied for all of them because no significant heterogeneity ($P > 0.05$, $I^2 < 50$ %) existed. Figure 3 shows all forest plots of the interest in complications.

As for final outcomes, no significant difference between these two groups in knee motion range (WMD, 0.43, 95%CI, -6.08 to 6.94; $P = 0.897$). The WMD of hospital stay (WMD, -5.202, 95%CI, -7.694 to -2.710; $P < 0.001$) and union time (WMD, -2.62, 95%CI, -3.39 to -1.85; $P < 0.001$) in SP group were both significantly lower compared to the DP group. The WMD of HSS score (12 months) in SP group was significantly higher compared with the DP group (WMD, 3.09, 95%CI, 0.20 to 5.99; $P = 0.036$). Taking the substantial heterogeneity into account, the random effects model was applied for continuous-variable assessment. Figure 4 shows all forest plots of the interest in clinical outcomes.

Post-operative malreduction



Surgical time

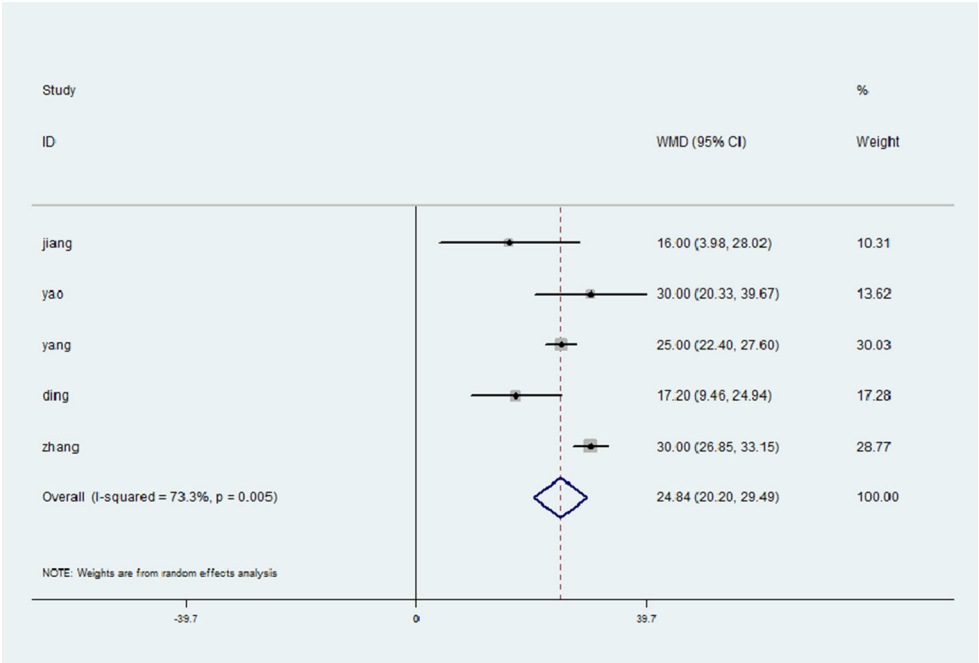


Fig. 2 continued.

Discussion

Although the technique of open reduction and internal fixation (ORIF) with DP or SP fixation has been commonly reported for bicondylar tibial plateau fractures, the preferable method still remains controversial. Focusing on the same topic, Wen et al conducted a meta-analysis comparing the effectiveness between both fixations, but only four Chinese studies were included [27]. The results showed functional outcomes were comparable between two fixations; however, complication problems were not mentioned at all. According to our meta-analysis, patients treated with DP fixation underwent a greater risk of incision necrosis but lower risk of loss of alignment. However, neither of these two fixations appeared to be superior regarding the other complications. When further

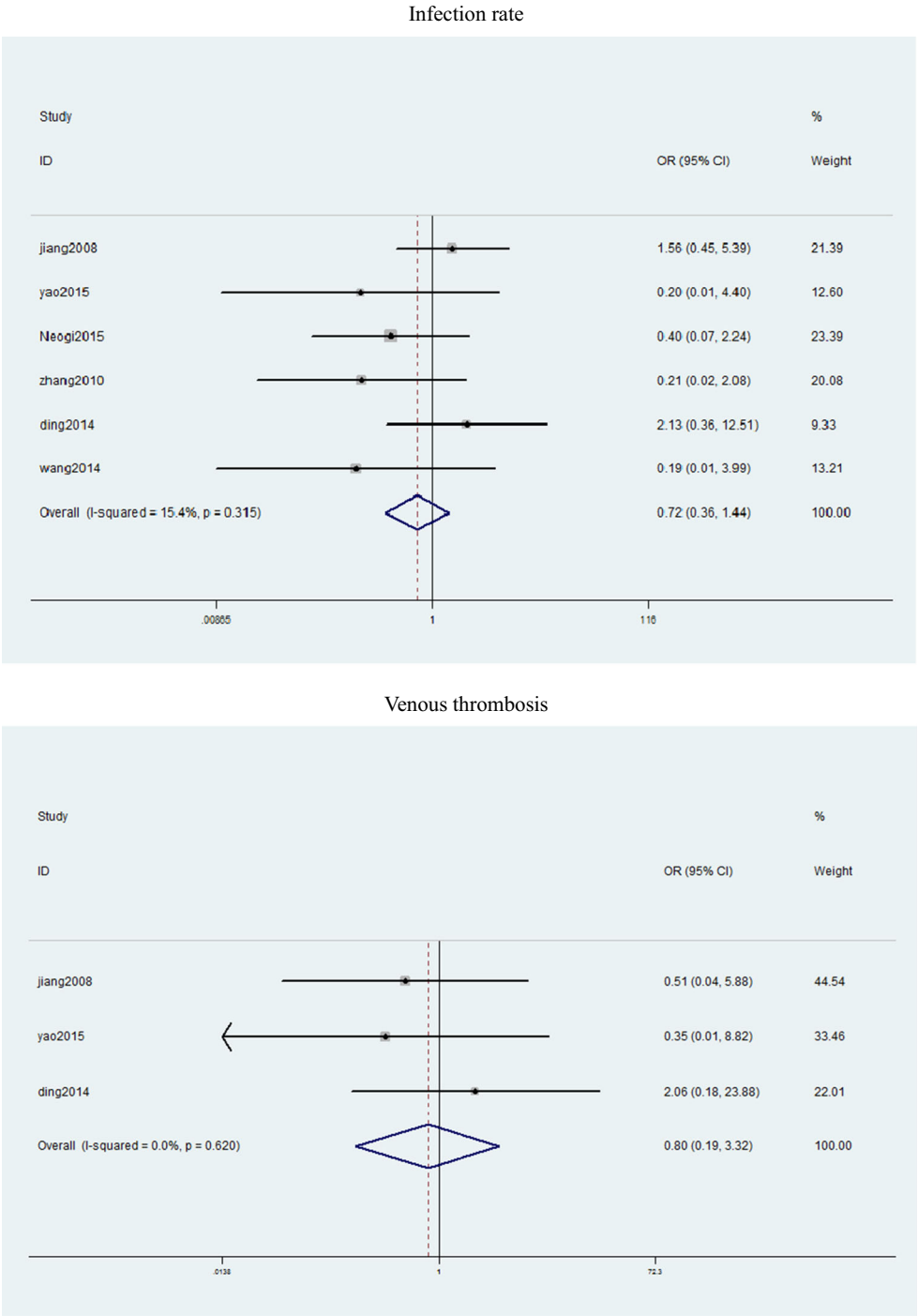
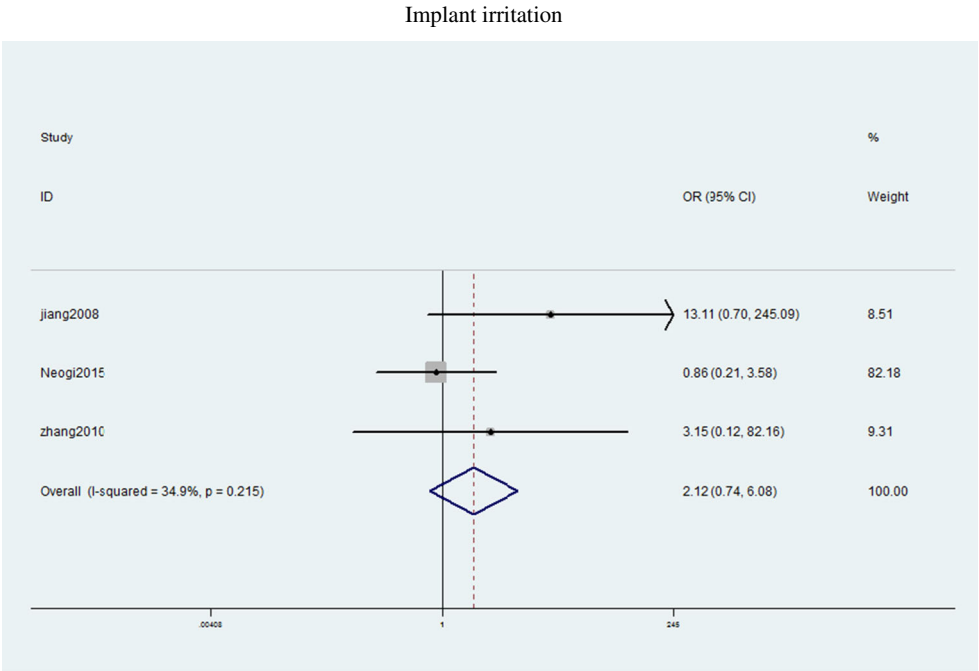


Fig. 3 Forest plot of comparison of infection rate, venous thrombosis, implant irritation, incision necrosis, loss of alignment and loss of reduction between SP fixation and DP fixation for bicondylar tibial plateau fractures. The horizontal line represents the 95%CI and each square represents the proportional weight of the study

compared to the clinical outcomes, SP fixation had advantages over DP fixation with reduced surgical time, shorter hospital stay, rapid union and greater HSS score (12 months). For other outcomes, no significant difference was found in terms of bone grafting, post-operative malalignment, post-operative malreducition and knee motion range between these two groups.

For treatment of bicondylar tibial plateau fractures, soft-tissue complications such as infection and incision necrosis are the major concerns due to the high-energy injury and extensive tissue exposure during the operation. With the improved methods of double-plate fixation via two incisions, the infection rate has significantly reduced to 0-17 % [4, 7, 28–31]. Moreover, locking plate systems and minimally invasive



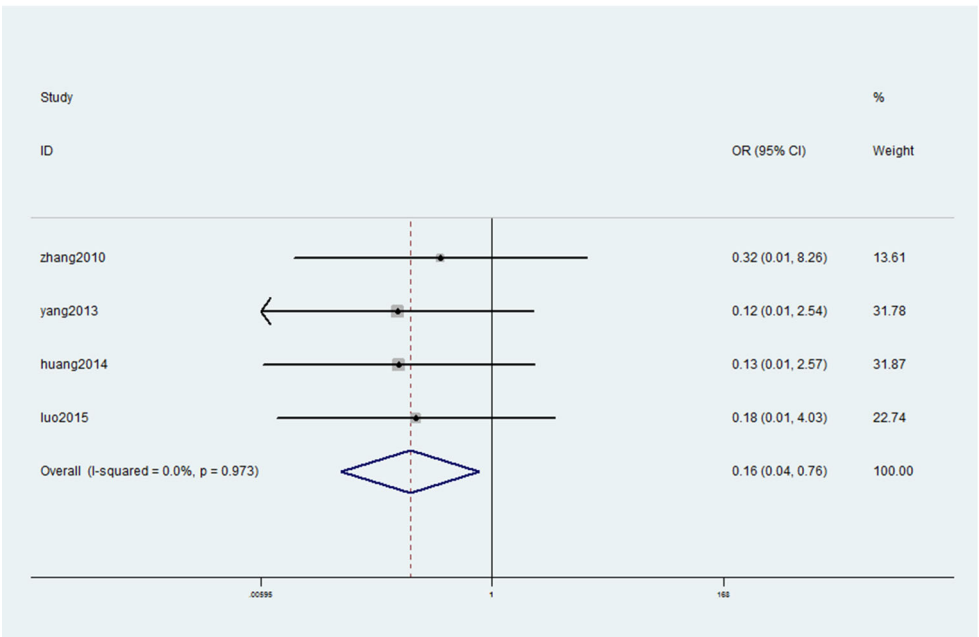


Fig. 3 continued.

percutaneous osteosynthesis (MIPO) technique has changed the treatment mode for these fractures over the past ten years [32]. Both Egol et al and Stannard et al showed LISS plate fixation from lateral side is a feasible method for the treatment of bicondylar tibial plateau fractures with a low infection rate of 0 % and 5.9 % [12, 33]. The result from this meta-analysis shows no significant difference between SP and DP fixation in the risk of infection, plate irritation and venous thrombosis but a lower incidence of incision necrosis was found in SP fixation compared to DP fixation. It seems that SP fixation had no significant advantages in reducing the soft-tissue complications over DP fixation except for incision necrosis. Similar to our conclusion, the retrospective study of Lee at al which compared the clinical outcomes of bicondylar tibial plateau fractures showed the cellulitis (13.3 % vs. 10 %) and deep infection (6.7 % vs. 10 %) rates were comparable between SP and DP fixation groups [10].

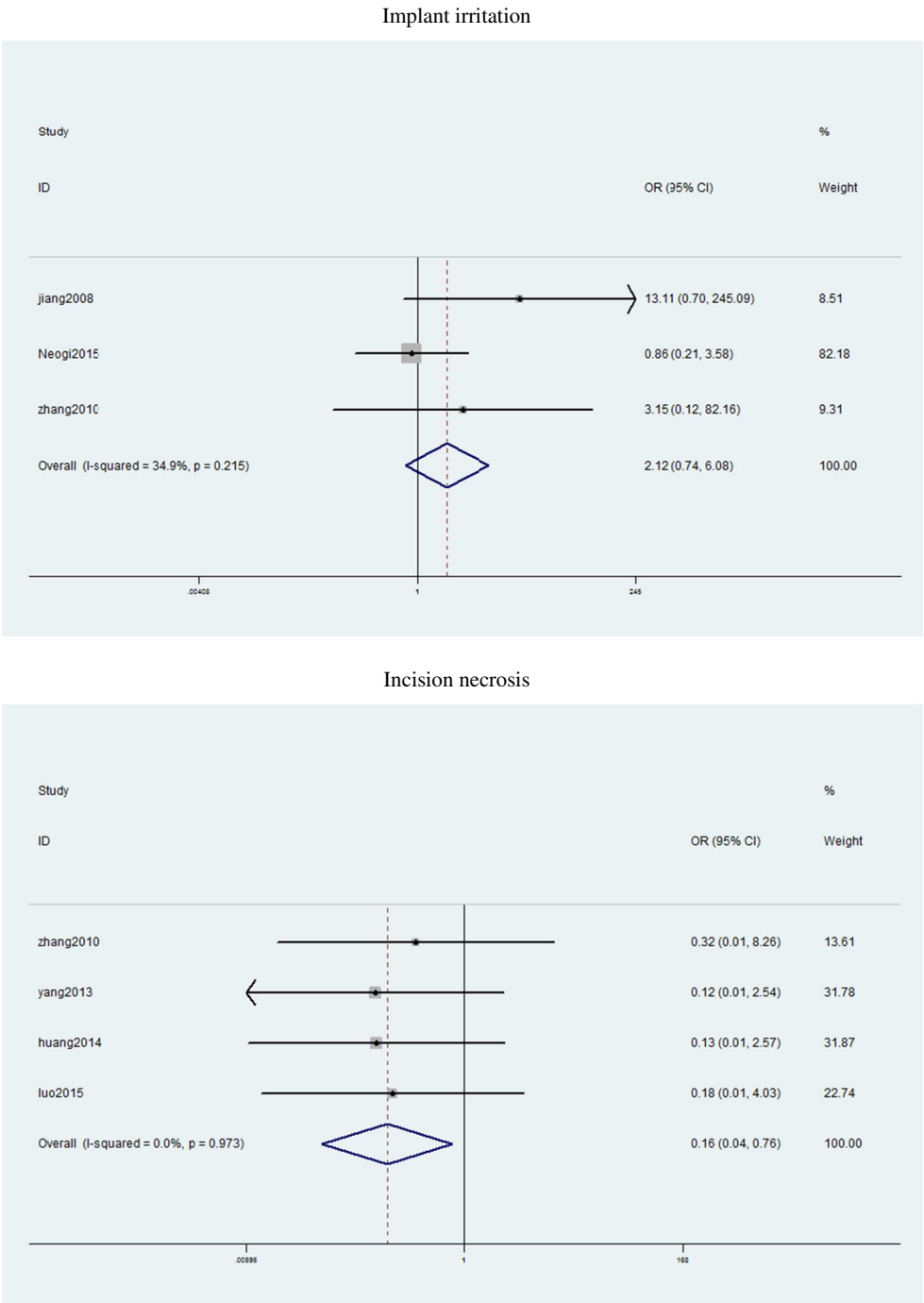


Fig. 3 continued.

Anatomic restoration of articular surface and lower extremity's alignment was the critical factor for early mobilization and functional recovery of knee joint. The mechanical stability of these two fixations has been investigated in several biomechanical analyses with fresh-frozen cadaver or synthetic tibiae models. Studies from Gösling et al and Mueller et al gave the analogous results that the overall construct stiffness between SP and DP fixation had no statistical difference under the axial loading conditions [14, 15]. However, both Egol et al and Higgins et al showed DP construction allowed less subsidence especially on the medial plateau compared to the SP fixation after the cycling loading tests [11, 12]. Although the locking plate could provide angle stability, it is not surprising that the fragment from medial plateau was prone to be displaced due to unreliable penetration by lateral locking screws, especially when the posteromedial fragments existed.

As for clinical studies, malalignment and malreduction were commonly identified on the instantly post-operative

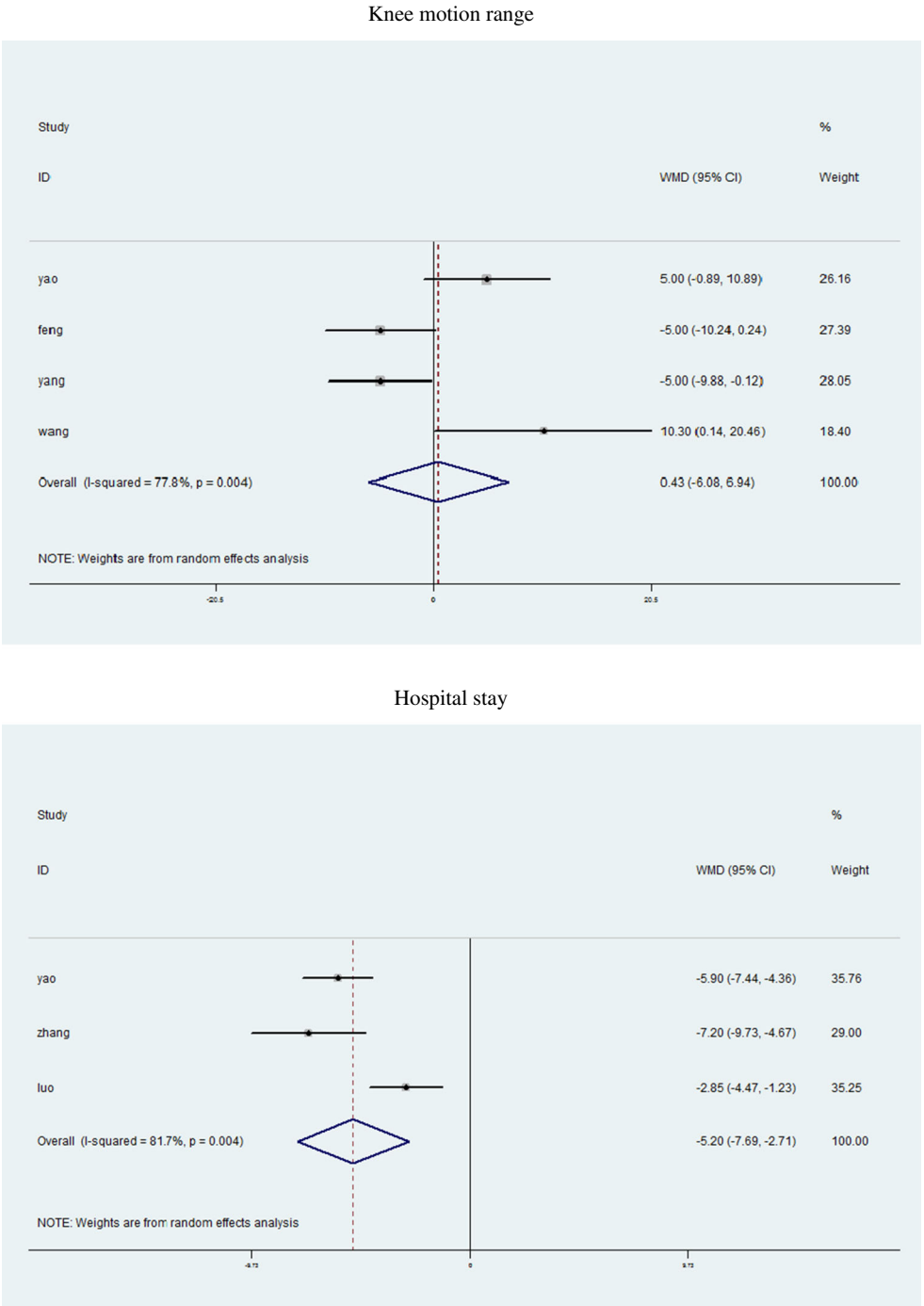
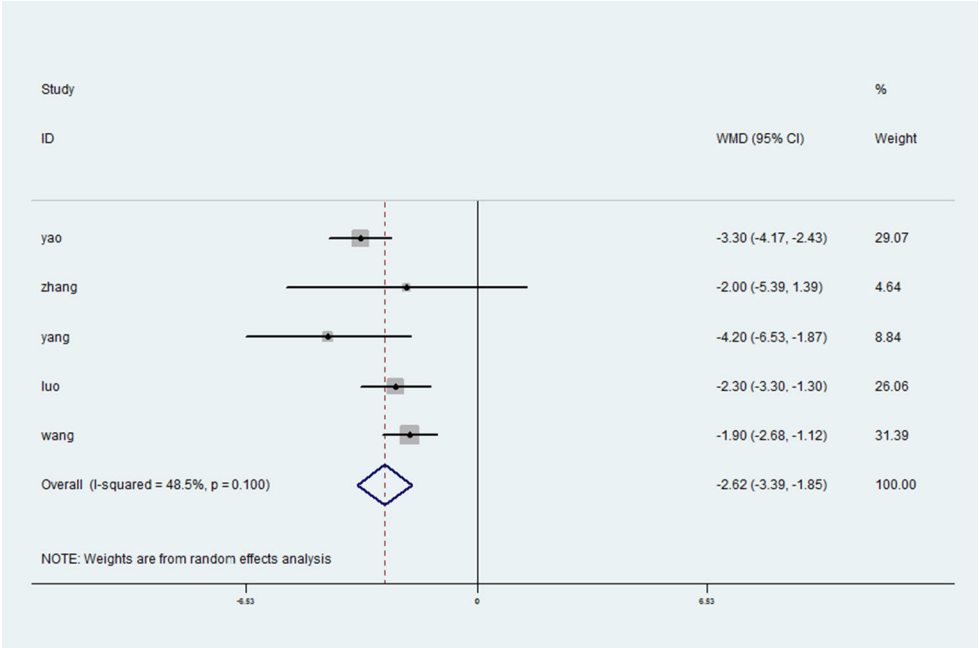


Fig. 4 Forest plots of comparison of knee motion range, hospital stay, union time and 12-month HSS score between SP fixation and DP fixation for bicondylar tibial plateau fractures. The horizontal line represents the 95%CI and each square represents the proportional weight of the study

radiographs mostly because the intra-operative reduction was often disturbed by metaphysis fracture and the comminution of tibial plateau. When treated with DP fixation, the incidence of malalignment and malreduciton ranged from 0 % to 37.9 % [4, 10, 29]. For SP fixation, the overall incidence of these two problems ranged from 0 % to 27 % [3, 10, 33, 34]. Moreover, the final outcomes of loss of alignment and loss of reduction which demonstrated the further stability of different fixation methods were also concluded. The overall incidence of loss of alignment and loss of reduction ranged from 8.7-12.7 % after the operation with DP fixation [7, 28, 29, 31]. When managed with SP techniques, this figure became 0-20 % [3, 17, 33, 34]. In our meta-analysis, although no significant difference was found in malalignment, malreduction and secondary loss of reduction, a significantly higher rate of loss of alignment was found in the SP fixation group. This result indicated that the

Union time



12-month HSS score

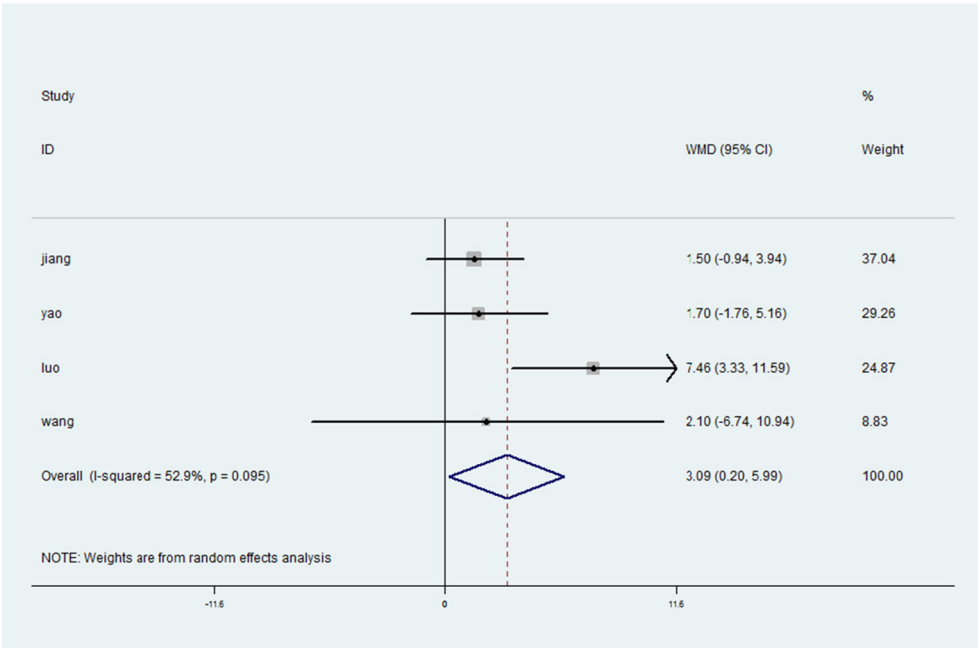


Fig. 4 continued.

isolate SP fixation might not be able to provide the equal effect in maintaining the lower extremity alignment compared to the DP fixation. Considering the fact that the included studies used different types of implants in their DP fixation group, this conclusion might not be ultimate. For example, the non-angle stable buttress plate and cannulated screws which emphasized the ability of compression was unlikely to provide comparable effectiveness of fixation like the locking plate did. Meanwhile, the resistance to breakage was also different from each locking plate system [35]. Therefore, further subgroup analysis should be conducted to improve the reliability of these results.

For other clinical outcomes, pooled data from these studies indicates that patients treated with SP fixation underwent less surgical time, hospital stay and union time compared to DP fixation group. Besides, patients managed with SP fixation might have an advantage in 12-month HSS score compared

to DP fixation. Although no difference was found in knee motion range between SP and DP fixation, the figure of the forest plot showed more RCTs should be included for conclusion. Considering the substantial heterogeneity of these continuous variables, we should make further efforts to obtain more reliable databases for final conclusions.

This meta-analysis had several limitations. First, relatively short follow-up term is the main restriction for long-term complications and functional outcomes analysis. Focusing on the development of post-operative osteoarthritis and bone loss, Mattiassich et al conducted a long-term follow-up examination of the patients with tibial plateau fractures and pointed out short-term follow-up examination may contribute little value to these two complications' diagnosis [36]. Second, nine prospective studies with only one RCT and 559 patients were included, which might influence the accuracy of clinical results. Third, different fracture characteristics, follow-up terms and medical conditions in each article were the objective reasons leading to the significant heterogeneity which may influence the results' reliability. Last, taking the different types of DP fixation into consideration, subgroup analysis should be conducted to improve the accuracy of the final results. Therefore, in terms of these limitations, more high quality RCTs with large number of patients and long-term clinical evaluations are required to determine the optimal strategy for bicondylar tibial plateau fractures.

In conclusion, despite the poor qualities of the included articles, this meta-analysis still has guiding significance for clinical practice in dealing with bicondylar tibial plateau fractures. It seems that SP fixation had no clear advantages in reducing the soft-tissue complications over DP fixation except for incision necrosis. However, DP fixation had an advantage over SP fixation in maintaining the anatomic alignment of lower extremities in the follow-up examination. Although clinicians should notice the differences in these two complications, both SP fixation and DP fixation are acceptable strategies for managing this type of fracture.

Compliance with ethical standards

Conflicts of interest The authors reported no conflicts of interest to declare in this article.

Ethical approval Not applicable.

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