Review Article

Outcomes following the treatment of bicondylar tibial plateau fractures with fine wire circular frame external fixation compared to open reduction and internal fixation: A systematic review

Tarek Boutefnouchet*, Ayaz S. Lakdawala, Panayiotis Makrides

Department of Trauma and Orthopaedic Surgery, Heart of England NHS Foundation Trust, Heartlands Hospital, Birmingham, B9 5SS, United Kingdom

ARTICLE INFO

Article history:

Received 25 January 2015

Accepted 1 February 2015

Available online 24 February 2015

Keywords:

Bicondylar/Schatzker 6

Tibial plateau fractures

Open reduction and internal fixation

External fixation

ABSTRACT

Purpose: The aim of this study was to determine whether circular frame external fixation provides better outcome and fewer complications when compared to open reduction internal fixation.

Methods: A systematic search was carried out and studies were critically appraised with narrative data synthesis.

Results: The systematic search yielded 131 titles and following a rigorous review only five articles were found to directly compare the two treatment methods.

Conclusions: Fine wire frame external fixation offers a modest advantage of better soft tissue outcomes. All in all, there is no current high-level evidence to suggest that newer osteosynthesis plates provide better results.

© 2015 Prof. PK Surendran Memorial Education Foundation. Published by Elsevier, a division of Reed Elsevier India, Pvt. Ltd. All rights reserved.

1. Introduction

Bicondylar tibial plateau fractures present significant challenges both in terms of treatment and outcomes.^{1–3} They constitute high-energy injuries with associated insult on the soft tissue envelope.⁴ Displaced bicondylar tibial plateau fractures (Schatzker type V and IV, AO/OTA types C1 C2 C3) remain relatively rare at an estimated 1% of all adult fractures and 10–30% of all tibial fractures.^{5–8} They have a bimodal distribution determined by mechanism, magnitude of energy and quality of bone stock.⁹ Albuquerque et al found a peak incidence among male patients and in the fifth decade. The same study showed a rate of 22.6% associated injuries.¹⁰ Moreover, intra-articular tibial plateau fractures have a significant impact on knee function. Mehin et al reported an incidence of post-traumatic end-stage osteoarthritis of 13% at 10 years.¹¹ Equally, a five-fold increase in the likelihood of needing a total knee arthroplasty compared with the general population has been shown.¹² Such consequences have been linked to the ensuing quality of alignment restoration and joint congruity following fracture treatment.^{11,13} The resulting abnormal joint kinematics and load transmission remain the principal

contributing factors.¹⁴ These are compounded by an altered post-traumatic articular biology. An analysis of cartilage and synovial fluid following tibial plateau fractures found decreased lubrication properties with a nine-fold fall in hyaluronic acid concentration.¹⁵

Treatment principles for these injuries consist of minimising secondary surgical insults while aiming for anatomic reduction and rigid fixation of the skeletal element of the injury.¹⁶ Achieving articular congruity and proximal tibial alignment conventionally required open reduction and internal fixation with plates and screws through an extensile anterior approach.^{2,17} Such techniques offered the advantage of optimal visualisation and direct reduction of fracture at the expense of soft tissue preservation.^{8,18} Such approach has however lost popularity over the last two decades owing to a higher rate of wound complications and infection.^{1,19} Despite the evolution of treatment strategies and quality of fixation implants, the literature continued to report poor outcomes and a high rate of complications associated with these fractures.²⁰ Barei et al demonstrated a deep infection rate of 8.4% despite the introduction of osteosynthesis with soft tissue preserving techniques.²¹ Similar observations led to the adaptation of alternative techniques in the form of percutaneous wire fixation frames and adjuvant percutaneous lag screw fixation. Early results from single-arm studies reported comparable clinical and functional outcomes, with reduced complications rate.^{22,23} Nevertheless, these early studies had limited impact on practice.²⁴ It is

* Corresponding author. Tel.: +44 78096677302.

E-mail address: tboutefnouchet@hotmail.com (T. Boutefnouchet).

important to underline here the difference in terminology between *hybrid-fixator* a combination of proximal fine wire ring fixation and distal half pin fixation, from *hybrid-fixation* a fine wire frame fixation with adjuvant percutaneous screw fixation.²⁵ It is equally crucial to highlight that analyses of modern internal fixation implants under simulated load established the need for dual-plate fixation in this type of injury.^{26,27}

This subject received wide attention in the literature. Mahadeva et al conducted a systematic review comparing open reduction internal fixation with hybrid fixation.²⁵ The authors concluded that there was a modest advantage over internal fixation in relation to soft tissue preservation.²⁵ They however, included monoplanar external fixation and laboratory studies. Additionally, since the publication of these results, there have been newer treatment developments. Low profile periarticular locking plates have become more widespread and often combined with minimally invasive techniques.²⁰ They demonstrated satisfactory reduction and fixation compared to earlier studies.²⁸ Similarly, the use of fine wire circular frame as primary fixation was potentiated by the introduction of modern frames.^{29,30} Despite this relatively wide interest, general consensus remains absent. Unanswered questions prevail on the superiority of fine wire circular frame fixation in terms of reduced soft tissue complication and their non-inferiority in terms of quality of fracture reduction and stabilisation. Hence, this systematic review aimed to address the question: whether fine wire circular frame external fixation provides better outcomes and fewer complications when compared to open reduction and internal fixation? The objective of this review was to appraise the evidence pertinent to the research question. Using a systematic approach the authors aimed to determine if treatment recommendations can be made on the basis of improved outcomes as well as reduced complications.

2. Methods

A systematic review of the literature was performed according to the methods described in the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA)³¹ using terms related to: *Bicondylar tibial plateau fracture; Schatzker Type V and VI;*

Open reduction and internal fixation; Fine wire external fixation; Circular frame external fixation; Taylor spatial frame. The search syntax, alternative keywords, term variations and search strategy are outlined in Table 1. Search database utilised were: MEDLINE[®], Embase[™], CINAHL[®] (cumulative index to nursing and allied health literature) and the Cochrane Central Register of Controlled Trials (CENTRAL). Search dates intervals included were from their year of inception to the first week of December ending 05/12/2014 and limited to English language and humans. PubMed was used as the primary source and search engine for MEDLINE and MeSH (Medical Subject Headings) were used.³² The same terms were used as search keywords for the other sources.

2.1. Eligibility criteria

Eligibility criteria were derived from the research question outlined above and the following research parameters:

- I Participants – skeletally mature patients with displaced bicondylar tibial plateau fracture (Schatzker type V and VI) undergoing primary operative management.
- II Intervention – Periarticular open reduction and internal fixation (ORIF).
- III Comparison – fine wire circular frame external fixation (ExFix).
- IV Outcomes – Primary outcome measure: specific knee function outcome scores. Secondary outcome measure: clinical outcomes, health status questionnaire, and patients satisfaction.

Primary inclusion criteria were studies which reported outcomes of surgical treatment of acute traumatic bicondylar tibial plateau fractures with open reduction and internal fixation compared to fine wire circular frame fixation with or without adjuvant percutaneous screw fixation. Therefore, only published studies directly comparing the two methods with reported outcome measures were included. This review focused on specific knee function scores as primary outcome measure such as the validated Western Ontario McMaster University (WOMAC) score. A multidimensional, self-administered health status instrument, which has been shown to fulfill face, content and construct validity as well as reliability and responsiveness.³³ This score has been

Table 1
Database, search terms and search strategy used.

Database	Search Terms	Alternative Terms and Search Strategy
PubMed	<i>Bicondylar tibial plateau fracture</i>	("tibia"[MeSH Terms] OR "tibia"[All Fields] OR "tibial"[All Fields]) AND
EMBASE	<i>Schatzker Type V and VI</i>	plateau[All Fields] AND bicondylar[All Fields] AND ("fractures, bone"[MeSH
CINHAL	<i>Open reduction and internal fixation</i>	Terms] OR ("fractures"[All Fields] AND "bone"[All Fields]) OR "bone
Cochrane-CENTRAL	<i>Fine wire external fixation</i>	fractures"[All Fields] OR "fracture"[All Fields])
	<i>Circular frame external fixation</i>	schatzker[All Fields] AND v[All Fields] schatzker[All Fields] AND vi [All Fields]
	<i>Taylor spatial frame</i>	open[All Fields] AND reduction[All Fields] AND ("fracture fixation,
		internal"[MeSH Terms] OR ("fracture"[All Fields] AND "fixation"[All Fields]
		AND "internal"[All Fields]) OR "internal fracture fixation"[All Fields] OR
		("internal"[All Fields] AND "fixation"[All Fields]) OR "internal fixation"
		[All Fields])
		Less[All Fields] AND invasive[All Fields] AND locking[All Fields] AND ("bone
		plates"[MeSH Terms] OR ("bone"[All Fields] AND "plates"[All Fields]) OR "bone
		plates"[All Fields] OR "plate"[All Fields]) AND ("fracture fixation,
		internal"[MeSH Terms] OR ("fracture"[All Fields] AND "fixation"[All Fields]
		AND "internal"[All Fields]) OR "internal fracture fixation"[All Fields] OR
		("internal"[All Fields] AND "fixation"[All Fields]) OR "internal fixation"[All
		Fields])
		Fine[All Fields] AND ("bone wires"[MeSH Terms] OR ("bone"[All Fields] AND
		"wires"[All Fields]) OR "bone wires"[All Fields] OR "wire"[All Fields]) AND
		external[All Fields] AND fixation[All Fields]
		Circular[All Fields] AND ("reading frames"[MeSH Terms] OR ("reading"[All
		Fields] AND "frames"[All Fields]) OR "reading frames"[All Fields] OR
		"frame"[All Fields]) AND external[All Fields] AND fixation[All Fields]
		Ilizarov[All Fields]
		Taylor[All Fields] AND spatial[All Fields] AND "frames"[All Fields] OR
		"frame"[All Fields])

previously shown to have a minimal clinically important difference (MCID) of 9.7, 9.3 and 10 for pain, function and stiffness respectively.³⁴ Studies that fulfilled eligibility criteria and utilised another knee function score were also included. The secondary outcome measure considered were health status and satisfaction such as the Short Form (SF) 36 questionnaire, a reliable marker of such parameters.^{35,36} In addition, this review considered the following secondary outcome measures: complications rate, number of operations, and radiological outcomes on quality of articular reduction and fixation.

2.2. Exclusion criteria

The principal exclusion criteria from this work were: abstract only publications conference proceedings, paediatric cases, pathological fractures, comparison with non-operative management, periprosthetic fractures and treatment of non or malunions. Equally, studies which looked at cadaveric models only, biomechanics or laboratory analyses only, protocol and study design publications were excluded. Similarly, expert opinions, single arm studies, historic comparison of two therapeutic groups were also excluded.

2.3. Review process and systematic analyses

References obtained from the search criteria, were transferred into Endnote referencing software (Thomson Reuters™) and duplicates were discarded. Firstly titles and abstracts were reviewed for relevance according to the research question. The remaining studies were analysed in their entirety. Access to full text articles was obtained from Athens (Eduserv®) and Warwick University Library. References of full texts were also reviewed to identify other potential relevant studies prior to final inclusion. The acquisition of articles is summarised as a flow diagram in Fig. 1. The final studies were reviewed according to study design, analysis and interpretation of results. Eligible studies were critically appraised with narrative data synthesis relevant to the study design to identify the best evidence. Assessment of study design and content followed a systematic narrative approach, which was guided by criteria from the consolidated standards of

reporting trials (CONSORT)³⁷ for randomised studies, the validated Methodological Index for Non-Randomised Studies (MINORS)³⁸ and Critical Appraisal Skills Programme (CASP).^{39,40} Two independent reviewers (TB and AL) critically appraised all relevant studies. Where there was discrepancy, an agreement was reached by consensus with a third reviewer (PM).

3. Results

3.1. Results of systematic search

A total of 232 articles were generated from the search, limited to 155 human and English publications. This yielded 131 titles for initial screening after removal of 24 duplicates. Following initial screening and application of the inclusion/exclusion criteria 80 titles and 40 abstracts were excluded from the review. A further search including the cited references did not yield additional studies. The numbers and reasons for exclusion following rigorous titles screening, abstracts assessment and review of full texts are detailed in Table 2. Overall 11 studies met the eligibility criteria and full-text review was carried out on all. A significant degree of heterogeneity was found among the surgical techniques proposed and a further six articles were excluded due to inclusion of all types of tibial plateau fractures, lack of clinical outcome measures, and/or combination of internal and external fixation. The systematic search therefore generated a total of five studies addressing the key question and suitable for appraisal (Table 3). Direct comparison of the results reported by each study was not possible because study designs and outcome measures were greatly variable. The authors therefore intended to assess whether each study had made a valid attempt at comparing the two treatment methods and reached a justified conclusion.

3.2. Critical appraisal

McKee et al.⁴¹ Aimed to compare the outcome of dual-plate open reduction internal fixation to that of circular frame fixator. Although the research question was not clearly outlined, this study remains to date the only randomised controlled trial addressing this topic. The patients were recruited from five different Canadian

Fig. 1. Flow diagram of the systematic literature search.

Table 2

Exclusion following title screening, abstract assessment and full text review.

Titles excluded n=80	Abstracts excluded n=40	Full text articles excluded n=6
Surgical technique description n=14 Review articles and current concepts n=11 Paediatric cases n=9 Radiological studies n=7 Biomechanics studies n=7 Post traumatic deformities n=6 Case reports n=5 Non and/or Malunion treatment n=5 Deformity correction n=4 Service evaluation n=3 Epidemiological study n=3 Conservative vs. operative management n=2 Cadaveric studies n=2 Animal studies n=2	Conference proceedings/abstract n=7 Frame only fixation n=5 Studies comparing different external fixators n=5 Radiological and/or cadaveric studies n=4 Biomechanical analysis n=4 Single therapeutic series n=4 Paediatric patients n=3 Poly trauma patients and/or damage control surgery n=3 Surgical technique description n=3 Pathological fractures n=2	Interventions included monoplanar external fixation n=1 arthroscopic assisted reduction with percutaneous fixation n=1 Intervention included variation in internal fixation method n=1 All types of tibial plateau fractures n=1 Laboratory study with no clinical outcomes n=1 All patients treated with combination of internal and external fixation n=1

trauma centres between November 1998 and May 2003. A total of 116 displaced bicondylar fractures belonging to 114 patients were selected, the final study inclusion was 83 fractures. Although the authors considered the sample size sufficient according to their own power calculation, the article did not specify how exclusion was addressed and how it could have affected the results. Randomisation was carried using sealed opaque envelopes. Risk of loss of randomisation and introduction of bias has been associated with this method, especially if envelopes are opened too early in the allocation process.^{42,43} Treatment was delivered by 16 different surgeons, which adds pragmatism and external validity in the interpretation of the results.⁴⁴ Inadvertently it can also lead to great variation in the treatment approaches based on differing training and expertise. The authors did not explain how they controlled such variables. Primary and secondary outcome measures were clearly outlined, and validated outcome measure scores as well as subjective clinical data were used. There were limitations in reporting who carried the assessments, for instance radiographic evaluation was done by a research nurse, however an undeclared number of difficult cases were also evaluated by either the treating surgeon or lead investigator. Moreover, a vast amount of data was collected during this study, although adequately presented throughout the article there was a lack of adjustment of significance such as the Bonferroni correction to account for multiple outcomes.^{45,46} The study reported two statistically significant results: worse postoperative outcome compared to pre-injury status; and better outcome up to one year after treatment for the ExFix group. The authors did not delineate the minimal clinically important difference in their treatment effect. A power calculation was done using the primary outcome measure and the sample size collected accordingly. Nevertheless, the tendency of the results favouring the external fixator treatment group and yet remaining just outside the statistical significance indicates potential under-powering of the study, and possible introduction of type 2 error. Confounding factors such as polytrauma and open fractures were identified in this study. Greater incidence of polytrauma, more meniscal injuries and open fractures were reported in the ORIF group, which inadvertently affects both patients reported outcome measures and subjective clinical results. The authors did not include further discussion on baseline differences being statistically insignificant, but still clinically significant. Equally, no subgroup analysis of open or associated injuries was carried out. Finally, surgical techniques have significantly changed since the start of this study both in terms of implant design and soft tissue handling which also affects the external validity of the trial.^{20,28}

Hall et al.⁴⁷ Republished the results from the Canadian trauma society study presented above with an updated discussion on surgical techniques. Despite being published three years following

the initial article, there were no additional longer-term results reported. It was important to include this article since the authors attempted to offer further observations on the two different treatment approaches. They provided a detailed presentation of the surgical techniques, concluding that both techniques were mutually complementary. Intra-articular comminution was considered more suitable for ORIF, while meta-diaphyseal comminution with soft tissue compromise for ExFix. Nevertheless, the results derived from the original study did not fully support the new conclusions. In addition, the suggested modification of surgical technique with the introduction of locking plates cannot be drawn from the results of the original article. With sample size being an issue for this study, it is crucial to note that the authors did not comment whether there was continuing work to address this. They introduced recommendations on the surgical strategy, suggesting the use of a delayed ORIF, and expressing reservation about the use of a single axially stable lateral locking plate combined to a minimally invasive approach. Although, the group of authors in this article have accumulated significant experience in the management of such rare and complex injuries, their new conclusions amount to an expert opinion not supported by the results of the original study.

Krupp et al.⁴⁸ Aimed to determine if clinical outcomes of patients with bicondylar tibial plateau fractures were better with ORIF compared to ExFix. The research question related to whether soft tissue preserving techniques are likely to improve clinical outcomes. This was a series of 58 cases, treated at a single centre between January 2000 and August 2004, with no declaration if these were consecutive. There was a clear lack of research protocol, with no inclusion or exclusion criteria employed. Operations were performed by one of three specialist orthopaedic trauma surgeons, which raised questions on pragmatism and external validity of the study. The authors presented a clear description of the operative treatment. It appeared however that the treatment options changed during the study period with no mention of the reasons for such change. No sample calculation or estimation of treatment effect was given. 13 patients treated with ORIF received a spanning external fixator initially; neither the criteria for conversion from spanning to definitive fixation nor quantification of soft tissue injury severity were outlined in this article. There was also significant heterogeneity of treatment especially in the ExFix group; two patients received percutaneous screw fixation, and three patients underwent bone grafting. It was also unclear whether physiotherapy followed a standardised protocol in both groups. In addition there was no evidence of blinding of outcome evaluation. Over half and one third of cases treated with ExFix and ORIF respectively were classed as polytrauma by the authors. They reported a similar incidence of open fractures in both groups. Despite being a retrospective analysis there was a substantial 19%

Table 3
Summary of the final studies included reporting the outcome following fixation of bicondylar tibial plateau fractures.

Study	Design	Sample Size	Intervention (s)	Follow up	Outcome Measures	Results
McKee et al 2006 ⁴¹	Multicentre randomised controlled trial	Initial = 83 Final = 66	ORIF = 40 Circular frame ± percutaneous screws = 43	6, 12, 24 months	Primary: HSS Secondary: WOMAC, reoperations, complications, SF36, radiological results	External fixator trend towards better results Generally poor outcome in both groups Higher reoperation rate in ORIF
Hall et al 2009 ⁴⁷	Multicentre randomised controlled trial	Initial = 83 Final = 66	ORIF = 40 Circular frame ± percutaneous screws = 43	6, 12, 24 months	Primary: HSS Secondary: WOMAC, reoperations, complications, SF36, radiological results	External fixator trend towards better results Generally poor outcome in both groups Higher reoperation rate in ORIF
Krupp et al 2009 ⁴⁸	Case Series	Initial = 58 Final = 47	ORIF dual plating = 8 Lateral locking plate (LISS) + medial screws or buttress plate = 20 ^b Circular or Hybrid frame = 30 ORIF dual plate = 9 Circular frame + medial percutaneous screws = 12	2, 6 weeks 3, 6, 12 months Until union	Clinical outcomes: union rate, time to union, malunion, ROM, complications, re-operations	Tendency for better results with lateral locking plate. Faster union, better ROM, less articular malunion and infection rate.
Pun et al 2014 ⁴⁹	Case Series	Total = 21		Outcomes at 1 year Mean f/u 29 months	Honkonen and Jarvinen score: clinical, functional, radiological outcomes WOMAC Infection rates	No direct comparison between treatment groups made; reported better results for ORIF in closed articular displaced fractures, and for frame in fractures with significant soft tissue compromise.
Ahearn et al 2014 ⁵¹	Two centres Parallel case series	Initial = 55 Final = 36	Periarticular locking plate = 34 (8 of 34 had medial plate) Circular frame + percutaneous screws = 21	Outcomes at 1 year Mean f/u (months) 40.5 ORIF 31 Frame	Primary: WOMAC, Short Form 36 Secondary: satisfaction scale, VAS, complications, reoperations, radiological outcomes	No significant difference in clinical and radiological outcomes between the two groups

^a Re-publication of results from the Canadian trauma society study with an updated discussion on surgical techniques.^b 13 cases treated with an initial spanning external fixator, average time to conversion 13 days (2–60).

overall loss of cases, 23% in the ExFix group and 14% in the ORIF group. Results were statistically significant in the rate of malunion defined as articular depression with 43% in the ExFix group and 14% in the ORIF group. Similarly more delayed union >6 months was noted in the ExFix group 37% compared to 25%, with a trend towards a better range of motion in the ORIF group. Although these were the principal differences, it remained difficult to interpret the results since baseline similarity of both groups was not established. The lack of objective measures of functional outcomes mitigates these results further. More complications were reported in the ExFix group, but not adequately quantified with lack of significance level, P value and confidence intervals. This study reported a difference in relation to open fractures and polytrauma cases favouring ORIF, however the authors did not indicate whether this was statistically and/or clinically significant. Overall several and recurring methodological limitations have been identified, small sample size and significant heterogeneity of case selection as well as treatment. Hence, it remains difficult to support the conclusion that ORIF offers better clinical results.

Pun et al.⁴⁹ Presented results of treatment of bicondylar tibial plateau fractures with open reduction internal fixation or frame depending on pre-selected treatment criteria based on soft tissue conditions and articular displacement. The article was a case series of patients treated for displaced bicondylar tibial plateau fractures between 2006 and 2010 with no clear outline of a research question. The authors excluded grade 3C open fractures, injuries with other lower limb fractures or severe head injury. It was not apparent if all other fractures were included and whether cases were consecutive. The treatment groups were divided according to a pre-agreed algorithm, which was presented, adding clarity to the article. Nevertheless, it was of limited value due to the lack of evidence to substantiate its content. In addition, there was no agreed protocol for data collection and patients' evaluation. Articular displacement of <2 mm with soft tissue compromise were treated with ExFix. Patients with articular displacement of >2 mm were treated with ORIF or with either ExFix or staged spanning fixator then ORIF if soft tissue was compromised, the article did not specify the numbers or provide separate outcomes. Moreover, the authors did not include how the decision to apply one or the other treatment was reached and who performed the surgery. Outcome measures consisted of knee function WOMAC scores and the Honkonen and Jarvinen scores. The latter was originally published as descriptive classification criteria for proximal tibial fractures derived from the clinical and radiological characteristics, but never validated as outcome measure.⁵⁰ It was difficult to determine loss of cases during the study since only a selection of patients with completed follow-up at one year were presented. In terms of results the authors provided a singular post-operative average WOMAC score of 7.23. They reported unexpected excellent subjective symptomatic scores among 76.2% of patients and excellent walking score in 20 of 21 patients. Similarly they reported a high percentage of excellent functional results in 19 of 21 cases. The articles showed significant variations on radiological outcomes, in addition the modalities and the assessor of radiological evaluation remained unclear. This article on the whole only informs the reader that this centre has the capacity to treat such injuries with one or the other method. Given the heterogeneous cases presented and the small sample size no conclusive evidence can be derived from this study. With such methodological limitations, and inclusion of patients with one-year follow up only, interpretation of this study remains limited.

Ahearn et al.⁵¹ Aimed to determine the clinical and functional outcomes of bicondylar tibial plateau fractures treatment. The research question was not clearly outlined, however the authors highlighted the utilisation of two key advances in treatment, periarticular locking plates with minimally invasive technique, and

the Taylor spatial frame. In this retrospective analysis of two parallel consecutive case series from two centres, they included patients who were treated between December 2005 and May 2010 with a minimum follow up of one year. They included an outline of their exclusion criteria, and utilised well-defined primary and secondary outcome measures. Circular frames were only performed at one of the institutions and periarticular locking plate ORIF was performed in both institutions. This study had a clearly stated objective and included all potential eligible cases. Patient selection and analysis were not however performed according to a registered protocol. Treatment was delivered by an unknown number of surgeons with an interest in tibial plateau fractures. There was also variation in the post-operative physiotherapy regime but this difference was not clarified. A total of 55 displaced bicondylar fractures belonging to 54 patients were selected, the final number was 36 fractures, with a significant one third of cases not analysed due to uncompleted outcome scores. The authors did not indicate whether their final results would have been markedly offset by the excluded cases. There was an occult higher rate of multifragmentary fractures in the ExFix group. The mean follow up period was 40.5 and 31 months for the ORIF and ExFix groups respectively. The authors did recognise this limitation since the true impact on knee function might be delayed. Outcomes measures employed reflected the aim of the study, and consisted primarily of the WOMAC score and SF36 health questionnaire. Secondary outcome measures consisted of patient satisfaction scale, complication rates, reoperations and quality of reduction and fixation. There was no evidence of blind evaluation of outcomes. In addition, statistical significance level was set at 5% but not according to specific effect size. Equally, they reported numerous outcomes in this study with no evidence of adjustment of significance levels hence the potential introduction of the so-called 'family wise error' or type 1 error occurring with multiple hypothesis testing,⁵² which is considered relevant here since the study showed no statistically significant difference between the two groups. Given the statistical values this also indicates potential under powering and introduction of type 2 error. In addition the two groups were not similar at baseline since more displaced fractures were treated with ExFix. Equally, the authors did not specify distribution of open fractures or injuries associated with compartment syndrome between the two groups. There was no comment made about the presence of concomitant injuries. A subset of patients received an initial spanning external fixator and then converted into one or the other definitive method of fixation and this was not accounted for in terms of results analysis. The authors showed no statistically significant difference in fracture reduction or alignment and no relationship with WOMAC or SF36 scores. The ExFix group showed greater complication rates, more outpatient visits and reoperations. Finally the critical points raised above, suggest that better analyses and larger sample could have potentially improved estimation of treatment effect in this study.

4. Discussion

Since the publication of the first study presented above in 2006, the paradigm of bicondylar tibial plateau fracture management has witnessed new developments. The two key elements consist of the widespread use of contoured locking periarticular plates,^{20,28} in addition to the wider use of modern circular frame external fixation in the primary management of fractures.^{29,30} Despite such shift in the treatment approaches there has been paucity of high-level research comparing the newer techniques. The studies presented here constitute the best available evidence to date addressing our research question. Combined results from these studies demonstrate overall poor medium-term clinical outcomes. The severity of these injuries is compounded by intra-articular

displacement and soft tissue compromise. A balanced approach based on the latter factors is suggested to be the answer. Nevertheless, due to various limitations the results do not provide evidence of superiority of one treatment over the other in terms of clinical or functional outcomes.

This work highlighted numerous recurring limitations in the conduct and presentation of the studies and this inadvertently will mitigate the interpretation of their results. Only the first and last articles demonstrated generalisability of their results in relation to the patient population, type of treatment and outcome measures utilised. In terms of their relevance to clinical practice further key issues are raised. In general there was no clear outline of fracture classification assessment especially in relation to the imaging methods utilised. Previous authors have shown a change in fracture treatment plan in 26% of cases after the addition of computerised tomography (CT) scan.⁵³ In addition there was marked heterogeneity in the treatment methods. The so-called 'hybrid fixator' has been used, yet previously shown to produce significantly less bending and axial stiffness when compared to standard circular frames.^{54–56} All the studies had a limited follow up period, which may not reflect the true impact of the injury. It was considered that significant loss of knee function related to secondary osteoarthritis occurs at an average of 4.6 years post-injury.¹¹ Although all the studies included a report of complication rates, there was paucity in objective measure of adverse outcomes related to treatments. This has introduced the potential risk of selective reporting bias and is especially crucial in the series with significant loss of cases and incomplete outcome reporting.^{57,58}

The only randomised controlled trial by McKee and colleagues was carried out before the widespread introduction of anatomic locking periarticular plates. The addition of methodological issues raised above, limits the validity and estimation of treatment effects presented in this article. The remaining articles shared recurring limitations, which raise concerns about bias and external validity of their results.⁴⁴ They consisted all of small retrospective series with inadequately defined selection criteria suggesting the possible introduction of selection bias. This led to difficulties in comparing outcomes of individual treatment options. There was a lack of clear statement indicating the research question of the study and whether a comparison of the efficacy of treatment methods was the primary endpoint. Exclusion of patients who received treatment but did not have their outcomes reported was not clearly addressed. Due to the lack of intransigent evidence supporting one or more treatment options there was no scope for adequate control comparison groups. In order to address the clinical question raised in this systematic review and produce robust evidence based practice, future work will need to address the shortcomings highlighted in this review.

5. Conclusions

It is the authors' conclusion that fine wire circular frame fixators may offer some advantages in terms of soft tissue healing. However, clinical recommendations cannot be made in relation to the utilisation of minimally invasive internal fixation locking plates. Based on the published literature there is currently insufficient evidence to determine whether circular frame external fixation, in the treatment of bicondylar tibial plateau fracture, provides better outcome and fewer complications when compared to open reduction and internal fixation. Therefore, longer term results from studies comparing modern implants and soft tissue preserving techniques are required. Given the variation in the level of surgical expertise and the rarity of such injuries, there is an emergent need for pragmatic multicentre trials. These studies will need to address the relevant research question using a robust research protocol as well as validated and reliable outcome measures.

Conflicts of interest

All authors have none to declare.

References

- Young MJ, Barrack RL. Complications of internal fixation of tibial plateau fractures. *Orthop Rev.* 1994;23:149–154.
- Covall DJ, Fowble CD, Foster TE, Whitelaw GP. Bicondylar tibial plateau fractures: principles of treatment. *Contemp Orthop.* 1994;28:115–122.
- Graves ML. Periarticular tibial fracture treatment in the obese population. *Orthop Clin North Am.* 2011;42:37–44[v–vi].
- Brem MH, Bail HJ, Biber R. Value of incisional negative pressure wound therapy in orthopaedic surgery. *Int Wound J.* 2014;1:3–5.
- Schatzker J, McBroom R, Bruce D. The tibial plateau fracture. The Toronto experience 1968–1975. *Clin Orthop Relat Res.* 1979;94:104.
- Rockwood CA, Green DP, Bucholz RW. *Rockwood and Green's Fractures in Adults*. 7th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2010.
- Walton NP, Harish S, Roberts C, Blundell C. AO or Schatzker? How reliable is classification of tibial plateau fractures? *Arch Orthop Trauma Surg.* 2003;123:396–398.
- Tscherne H, Lobenhoffer P. Tibial plateau fractures. Management and expected results. *Clin Orthop Relat Res.* 1993;87–100.
- Mallina R, Kanakaris NK, Giannoudis PV. Peri-articular fractures of the knee: an update on current issues. *Knee.* 2010;17:181–186.
- Albuquerque RP, Hara R, Prado J, Schiavo L, Giordano V, Amaral N. d. Epidemiological study on tibial plateau fractures at a level I trauma center. *Acta Ortop Bras.* 2013;21:109–115.
- Mehin R, O'Brien P, Broekhuysen H, Blachut P, Guy P. Endstage arthritis following tibia plateau fractures: average 10-year follow-up. *Can J Surg.* 2012;55:87–94.
- Wasserstein D, Henry P, Paterson JM, Kreder HJ, Jenkinson R. Risk of total knee arthroplasty after operatively treated tibial plateau fracture: a matched-population-based cohort study. *J Bone Joint Surg Am.* 2014;96:144–150.
- Kiefer H, Zivaljevic N, Imbriglia JE. Arthroscopic reduction and internal fixation (ARIF) of lateral tibial plateau fractures. *Knee Surg Sports Traumatol Arthrosc.* 2001;9:167–172.
- Wegner T, Claes L, Simon U. Internal loads in the human tibia during gait. *Clin Biomech (Bristol Avon).* 2009;24:299–302.
- Ballard BL, Antonacci JM, Temple-Wong MM, et al. Effect of tibial plateau fracture on lubrication function and composition of synovial fluid. *J Bone Joint Surg Am.* 2012;94:e64.
- Cole PA, Zlowodzki M, Kregor PJ. Treatment of proximal tibia fractures using the less invasive stabilization system: surgical experience and early clinical results in 77 fractures. *J Orthop Trauma.* 2004;18:528–535.
- Benirschke SK, Agnew SG, Mayo KA, Santoro VM, Henley MB. Immediate internal fixation of open, complex tibial plateau fractures: treatment by a standard protocol. *J Orthop Trauma.* 1992;6:78–86.
- Waddell JP, Johnston DW, Neidre A. Fractures of the tibial plateau: a review of ninety-five patients and comparison of treatment methods. *J Trauma.* 1981;21:376–381.
- Moore TM, Patzakis MJ, Harvey JP. Tibial plateau fractures: definition, demographics, treatment rationale, and long-term results of closed traction management or operative reduction. *J Orthop Trauma.* 1987;1:97–119.
- Nikolaou VS, Tan HB, Haidukewych G, Kanakaris N, Giannoudis PV. Proximal tibial fractures: early experience using polyaxial locking-plate technology. *Int Orthop.* 2011;35:1215–1221.
- Bareil DP, Nork SE, Mills WJ, Henley MB, Benirschke SK. Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. *J Orthop Trauma.* 2004;18:649–657.
- Stamer DT, Schenk R, Staggers B, Aurori K, Aurori B, Behrens FF. Bicondylar tibial plateau fractures treated with a hybrid ring external fixator: a preliminary study. *J Orthop Trauma.* 1994;8:455–461.
- Watson JT. High-energy fractures of the tibial plateau. *Orthop Clin North Am.* 1994;25:723–752.
- Mallik AR, Covall DJ, Whitelaw GP. Internal versus external fixation of bicondylar tibial plateau fractures. *Orthop Rev.* 1992;21:1433–1436.
- Mahadeva D, Costa ML, Gaffey A. Open reduction and internal fixation versus hybrid fixation for bicondylar/severe tibial plateau fractures: a systematic review of the literature. *Arch Orthop Trauma Surg.* 2008;128:1169–1175.
- Higgins TF, Klatt J, Bachus KN. Biomechanical analysis of bicondylar tibial plateau fixation: how does lateral locking plate fixation compare to dual plate fixation? *J Orthop Trauma.* 2007;21:301–306.
- Ali AM, Saleh M, Bolongaro S, Yang L. The strength of different fixation techniques for bicondylar tibial plateau fractures—a biomechanical study. *Clin Biomech (Bristol Avon).* 2003;18:864–870.
- Biggi F, Di Fabio S, D'Antimo C, Trevisani S. Tibial plateau fractures: internal fixation with locking plates and the MIPO technique. *Injury.* 2010;41:1178–1182.
- Fragomen AT, Rozbruch SR. The mechanics of external fixation. *Hss J.* 2007;3:13–29.
- Dendrinios GK, Kontos S, Katsenis D, Dalas A. Treatment of high-energy tibial plateau fractures by the Ilizarov circular fixator. *J Bone Joint Surg Br.* 1996;78:710–717.
- Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol.* 2009;62:e1–34.
- Medical Subject Headings. In: *US National Library Medicine: National Institute for Health.* 2014.
- Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *J Rheumatol.* 1988;15:1833–1840.
- Ehrich EW, Davies GM, Watson DJ, Bolognese JA, Seidenberg BC, Bellamy N. Minimal perceptible clinical improvement with the Western Ontario and McMaster Universities osteoarthritis index questionnaire and global assessments in patients with osteoarthritis. *J Rheumatol.* 2000;27:2635–2641.
- Ware Jr JE, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care.* 1992;30:473–483.
- Benaiges I, Prat G, Adan A. Health-related quality of life in patients with dual diagnosis: clinical correlates. *Health Qual Life Outcome.* 2012;10:106.
- Moher D, Hopewell S, Schulz KF, et al. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *BMJ.* 2010;340:c869.
- Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg.* 2003;73:712–716.
- CASP Critical Appraisal Skills Programme. In: Oxford, 2014.
- Guyatt GH, Sackett DL, Cook DJ. Users' guides to the medical literature. II. How to use an article about therapy or prevention. A. Are the results of the study valid? Evidence-Based Medicine Working Group. *JAMA.* 1993;270:2598–2601.
- McKee MD, on behalf of the Canadian Trauma Society. Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures. Results of a multicenter, prospective, randomized clinical trial. *J Bone Joint Surg Am.* 2006;88:2613–2623.
- Randelli P, Arrigoni P, Lubowitz JH, Cabitza P, Denti M. Randomization procedures in orthopaedic trials. *Arthroscopy.* 2008;24:834–838.
- Schulz KF, Grimes DA. Allocation concealment in randomised trials: defending against deciphering. *Lancet.* 2002;359:614–618.
- Akobeng AK. Assessing the validity of clinical trials. *J Pediatr Gastroenterol Nutr.* 2008;47:277–282.
- P C, Parsons N, Hiskens R, Achten J, Costa M. An evaluation of the quality of statistical design and analysis of published medical research: results from a systematic survey of general orthopaedic journals. *BMC Med Res Methodol.* 2012;12:60. <http://dx.doi.org/10.1186/1471-2288-1112-1160>.
- Bland JM, Altman DG. Multiple significance tests: the Bonferroni method. *BMJ.* 1995;310:170.
- Hall JA, Beuerlein MJ, McKee MD. Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures. Surgical technique. *J Bone Joint Surg Am.* 2009;91(suppl 2 Pt 1):74–88.
- Krupp RJ, Malkani AL, Roberts CS, Seligson D, Crawford 3rd CH, Smith L. Treatment of bicondylar tibial plateau fractures using locked plating versus external fixation. *Orthopedics.* 2009;32:.
- Pun TB, Krishnamoorthy VP, Poonnoose PM, Oommen AT, Korula RJ. Outcome of Schatzker type V and VI tibial plateau fractures. *Indian J Orthop.* 2014;48:35–41.
- Honkonen SE, Jarvinen MJ. Classification of fractures of the tibial condyles. *J Bone Joint Surg Br.* 1992;74:840–847.
- Ahearn N, Oppy A, Halliday R, et al. The outcome following fixation of bicondylar tibial plateau fractures. *Bone Joint J.* 2014;96-b:956–962.
- Alosh M, Bretz F, Huque M. Advanced multiplicity adjustment methods in clinical trials. *Stat Med.* 2014;33:693–713.
- Chan PS, Klimkiewicz JJ, Luchetti WT, et al. Impact of CT scan on treatment plan and fracture classification of tibial plateau fractures. *J Orthop Trauma.* 1997;11:484–489.
- Yilmaz E, Belhan O, Karakurt I, Arslan N, Serin E. Mechanical performance of hybrid Ilizarov external fixator in comparison with Ilizarov circular external fixator. *Clin Biomech (Bristol Avon).* 2003;18:518–522.
- Baran O, Havticioglu H, Tatari H, Cecen B. The stiffness characteristics of hybrid Ilizarov fixators. *J Biomech.* 2008;41:2960–2963.
- Podolsky A, Chao EY. Mechanical performance of Ilizarov circular external fixators in comparison with other external fixators. *Clin Orthop Relat Res.* 1993;61–70.
- Reeves BC. Reporting of harms in systematic reviews and their primary studies. *BMJ.* 2014;349:g6819.
- Smyth RM, Kirkham JJ, Jacoby A, Altman DG, Gamble C, Williamson PR. Frequency and reasons for outcome reporting bias in clinical trials: interviews with trialists. *BMJ.* 2011;342:c7153.