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General

Periprosthetic Distal Femoral Fractures Around a Total Knee Arthroplasty: a Meta-analysis Comparing Locking compression Plating and Retrograde Intramedullary Nailing

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Purpose

The number of total knee replacements (TKRs) performed per year has been increasing annually and it is estimated that by 2030 demand would reach 3.48 million procedures per year in the United States Of America. The prevalence of periprosthetic fractures (PPFs) around TKRs has followed this trend with incidences ranging from 0.3% to 3.5%. Distal femoral PPFs are associated with significant morbidity and mortality. When there is sufficient bone stock in the distal femur and a fracture pattern conducive to fixation, locking compression plating (LCP) and retrograde intramedullary nailing (RIMN) are commonly used fixation strategies. Conversely, in situations with loosening and deficient bone stock, a salvage procedure such as a distal femoral replacement is recognized as an alternative. This meta-analysis investigates the rates of non-union, re-operation, infection, and mortality for LCPs and RIMNs when performed for distal femoral PPFs fractures around TKRs.

Method

A search was conducted to identify articles relevant to the management of distal femoral PPFs around TKRs in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. Articles meeting the inclusion criteria were then assessed for methodological quality using the methodological items for non-randomised studies (MINORS) criteria. Articles were reviewed, and data were compiled into tables for analysis.

Results

10 articles met the inclusion criteria, reporting on 528 PPFs. The overall incidence of complications was: non-union 9.4%, re-operation 12.9%, infection 2.4%, and mortality 5.5%. This meta-analysis found no significant differences between RIMN and LCP in rates of non-union (9.2% vs 9.6%) re-operation (15.1% vs 11.3%), infection (2.1% vs 2.6%), and mortality (6.0% vs 5.2%), respectively.

Conclusion

This meta-analysis demonstrated no significant difference in rates of non-union, re-operation, infection, and mortality between RIMN and LCP and both remain valid surgical treatment options.

INTRODUCTION

There are now over 1.3 million primary knee replacements recorded in the United Kingdom (UK) National Joint Registry (NJR), the world's largest arthroplasty registry. Approximately 90% of these are total knee replacements (TKRs) with the remaining being partial knee replacements.[1] The global number of primary knee replacements has been increasing tremendously annually and in the United States of America (USA) it is estimated that by 2030 demand for primary TKRs would grow to 3.48 million procedures per year.[2] In keeping with this trend, the number of knee revisions has been on a steady incline with 1,225 revisions performed in the UK in 2004 and 7,005 in 2019.[1] Although Theophilus Gluck is often credited with performing the first ever TKR in 1891, reports of periprosthetic fractures (PPFs) remained scarce and only began appearing in the late 1970s.[3] It wasn't until the last two decades that PPFs became more frequently spotlighted with published incidences ranging from 0.3% to 3.5% for distal femoral PPFs, though large joint registries estimate the rates to be between 1.1% and 1.3%.[4-6] Of the 87,535 revision procedures recorded in the UK NJR, 3,358 revisions (3.84%) were performed for a PPF. Data from the Scottish arthroplasty project has demonstrated that the number of PPFs recorded per year has more than doubled between 1997 and March 2008 in line with the increase in TKRs performed.[7] This rise in the number of procedures performed reflects the number of at-risk implants in the UK NJR dataset and the wider population.

There is significant mortality and morbidity associated with distal femoral PPFs and despite advances in our understanding of fracture management and implant design, the subsequent reduction in quality of life and joint function remains high. Mardian *et al.* reported only 20% of patients were able to mobilise without assistance postoperatively.[8] This perhaps may account for the findings of two studies by Shields *et al.* and Streubel *et al.* which demonstrated mortality rates of 14% at 3 months and 17.7% at 12 months postoperatively, with 80% of the deaths occurring within 3 months of surgery.[9,10] In the UK, the national hip fracture database has recently been collecting data on PPFs and it has been recommended that these fractures should be considered life-threatening injuries that need to be approached with the same urgency and treatment objectives as native hip fractures (e.g. early mobilisation and weight-bearing) to improve the prognosis for patients.[10-12]

Unfortunately, these fractures remain challenging to treat owing to a number of factors including the advanced age of patients and the difficulty in achieving stable fixation in patients with poor bone stock and fragile bone quality. The primary aim of this article is to provide a meta-analysis of specific outcomes (infection, non-union, re-operation, and mortality) of locking compression plates (LCPs) and retrograde intramedullary nailing (RIMN) for distal femoral PPFs around TKRs.

METHODS

LITERATURE SEARCH STRATEGY

This systematic review and meta-analysis was conducted in adherence to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.[13] Searches were conducted on PubMed/Medline looking at literature published between January 2012 and December 2022. The search terms were as follows: 'Total knee arthroplasty (All Fields) OR Total knee replacement (MeSH Terms) AND Periprosthetic Fracture (All Fields) OR Peri-prosthetic Fracture (MeSH Terms)'. Articles generated were then screened and excluded in accordance with outlined eligibility criteria.

ELIGIBILITY

Inclusion criteria: articles published in the last 10 years (January 2012 to December 2022), patients aged 55 years and older, primary procedures (revision procedures of failed fracture treatment not included), minimum post-operative follow up of 6 months, articles of evidence levels I-III and English language texts only. Procedures included were RIMNs and LCPs.

Exclusion criteria: non-traumatic indications for arthroplasty, patients under 55, native bone fractures, case series, reports, letters, conference articles and abstracts, repeated studies and data, cadaveric and animal studies and studies deemed poorly designed and of evidence levels IV-V. Procedures excluded were revision arthroplasties, distal femoral replacement (DFR), combination fixation strategies (LCP + RIMN hybrids), external fixation and conventional non-locked plating.

DATA EXTRACTIONS AND ANALYSIS

The authors independently extracted data from the selected articles, with discussions held for any disputes in extracted data. Study author, publication year, patient demographics, details of the intervention and outcomes were collated onto a spreadsheet using Microsoft Excel 16.64.

Review Manager 5.3 was used for data analysis. Mean difference was used to analyse continuous data, and odds ratio and the risk difference was used to analyse discrete data. Statistical significance was defined as $P < 0.05$, with confidence intervals of 95%. Chi squared was used to assess for heterogeneity in the pooled studies, with results represented through I^2. I^2 cut offs for defining heterogeneity were as outlined in the Cochrane Handbook for Systematic Reviews of Interventions, 0-40% = Low, 30-60% = Moderate, 50-90% = Substantial 75%-100 = Considerable.[14] Results, along with all studies featured in the meta-analysis, were presented as forest plots.

OUTCOME MEASURES

The primary outcome measures of this review were post-operative rates of non-union, re-operation, infection and mortality. Data reporting complications, time to union, malunion, post-operative range of motion, refracture and patient reported outcome measures (PROMS) were also collected.

METHODOLOGICAL QUALITY

With consideration of the non-randomised nature of the selected studies, the methodological index for non-randomized studies (MINORS) criteria was used to score their methodological quality.[15] Global scores were taken of each study, with a maximum score of 24 for comparative studies, and 16 for the non-comparative studies.

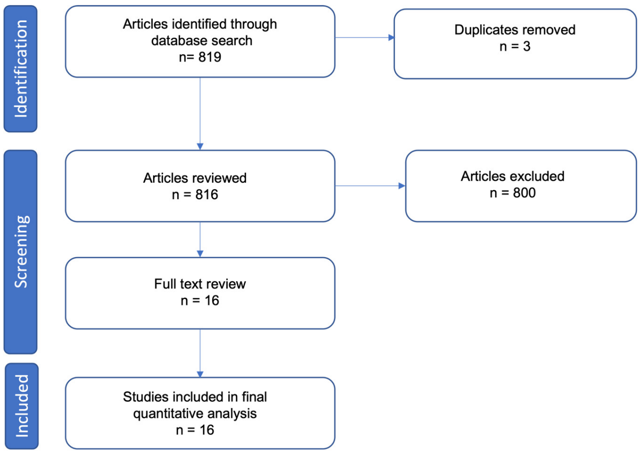

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram outlining study inclusion.

RESULTS

LITERATURE SEARCH

The literature search initially produced 969 articles. These 969 articles were screened by reviewing their title and abstract. Of the screened articles, a final 10 were included in this review for assessment. The PRISMA flow diagram is below (see Fig. 1). Exclusions were made in accordance with the listed eligibility criteria. Of the included studies, 9 were retrospective cohort studies and 1 was a prospective cohort study.

QUALITY ASSESSMENT

The methodological quality of the included studies was assessed using the methodological items for non-randomised studies (MINORS) criteria,[15] all included studies were deemed to meet quality standards (see Table 1).[16-25]

STUDY CHARACTERISTICS

Across all included studies a total of 536 PPFs were reported. 318 LCPs and 218 RIMNs were performed. The characteristics of all 10 included studies (see Table 2),[16-25] and further outcome measures (see Table 3)[16-25] have been outlined. An overall summary of our results is provided in Table 4.

NON-UNION

49 (9.4%) cases of non-union were reported in a total of 519 patients across 10 studies comparing RIMN and LCP, with moderate heterogeneity (I^2 =44%). Comparative analysis found no statistical significance (P = 0.63) (see Fig. 2).[16-25]

RE-OPERATION RATES

67 (12.9%) cases of re-operation were reported in a total of 519 patients across 10 studies comparing RIMN and LCP, with moderate heterogeneity (I^2=61%). Comparative analysis found no statistical significance (P = 0.86) (see Fig. 3).[16-25]

INFECTION

11 (2.4%) cases of infection were reported in a total of 460 patients across 7 studies comparing RIMN and LCP with low heterogeneity (I^2=0%). Comparative analysis found no statistical significance (P = 0.80) (Fig. 4).[16,18,19,22-25]

MORTALITY

14 (5.5%) mortalities were reported in a total of 253 patients across 5 studies comparing RIMN and LCP, with low heterogeneity (I^2 = 0%). Comparative analysis found no statistical significance (P = 0.68) (Fig. 5).[16,17,19,20,22]

DISCUSSION

The aim of this meta-analysis is to provide an updated review of the literature for the treatment of distal femoral PPFs over the last decade, focusing on the rates of complications of RIMN and LCP. This study suggests that the rates of complications following RIMN and LCP performed for distal femoral PPF, are comparable. The overall incidence of complications reported were: non-union 9.4%, re-operation 12.9%, infection 2.4%, and mortality 5.5%. This meta-analysis found no statistically significant difference between RIMNs and LCPs in rates of non-union (9.2% vs 9.6%), re-operation (15.1% vs 11.3%), infection (2.1% vs 2.6%) and mortality (6.0% vs 5.2%) (respectively).

The results of this meta-analysis support the findings of recent meta-analyses by Magill *et al.* and Shin *et al.*, both of which also reported no significant difference in rates of non-union and re-operation between the two surgical techniques.[26,27] In addition, Shah *et al.* described no difference in rates of non-union, but did report a significantly lower re-operation rate following LCP compared to RIMN.[28] Whilst this meta-analysis did find a lower rate of re-operation after LCP compared to RIMN, this comparison did not reach statistical significance. It is worth noting that two studies in this comparison did reach statistical significance for a lower re-operation rate post-LCP and that this comparative analysis showed moderate heterogeneity (I^2 =61%), highlighting the need for further high-quality research into re-operation rates in particular before any substantial conclusions can be made.[18,22]

The aetiology of each complication was variably reported across studies. Only Hou *et al.* and Matlovich *et al.* reported on the aetiology of non-union following RIMN, with Hou et al. citing infection and distal screw loosening for their single case of non-union and Matlovich *et al.* citing one case of infection and one case of aseptic loosening.[19,22] Hou et al. reported this case eventually requiring definitive management with above knee amputation but Matlovich *et al.* did not describe how the two cases of non-union were managed.[19,22]

Methodological Items for Non-Randomized Studies (MINORS)	Aldrian et al. [16]	Gondalia et al. [17]	Horneff et al. [18]	Hou et al. [19]	Kilucoglu et al. [20]	Lizaur- Utrilla et al. [21]	Matlovich et al. [22]	Meneghini et al. [23]	Park et al. [24]	Kyriakidis et al. [25]
1. A clearly stated aim	2	2	2	2	2	2	2	2	2	2
2. Inclusion of consecutive patients	2	1	2	2	1	2	2	1	2	2
3. Prospective collection of data	0	0	0	0	0	2	0	0	0	2
4. Endpoints appropriate to the aim of the study	2	2	2	2	2	2	2	2	2	2
5. Unbiased assessment of the study endpoint	0	0	0	0	0	0	0	0	0	0
6. Follow-up period appropriate to the aim of the study	2	2	2	2	2	2	2	2	2	2
7. Loss to follow-up <5%	2	2	2	1	1	2	2	1	2	2
8. Prospective calculation of the study size	0	0	0	0	0	0	0	0	0	0
9. An adequate control group	2	2	2	2	2	2	2	2	2	2
10. Contemporary groups	2	2	2	2	2	2	2	2	2	2
11. Baseline equivalence of groups	1	2	1	1	1	2	1	2	2	2
12. Adequate statistical analysis	2	2	2	2	2	2	2	2	2	2

Table 1. MINORS criteria scoring for included studies.

Study	Fractures	RIMN	LCP	RA	DFR	Other	Patient Sex	Time to Surgery (mean)	Follow Up (mean)
Aldrian et al. [16]	86	38	48	-	-	-	F 62 M 24	-	12 mo.
Gondalia et al. [17]	42	18	24	-	-	-	F 40 M 2	-	34.6 mo.
Horneff et al. [18]	63	35	28	-	-	-	F 44 M 19	-	36 mo.
Hou et al. [19]	52	18	34	-	-	-	F 35 M 17	LCP: 2.4 d RIMN: 1.7 d	29 mo.
Kilucoglu et al. [20]	16	7	9	-	-	-	F 13 M 3	-	1.75, 5.57 yrs
Lizaur-Utrilla et al. [21]	28	12	5	3	-	8	F 26 M 2	2.7 d	6.7 yrs
Matlovich et al. [22]	55	19	55	-	-	-	F 43 M 12	-	15.6, 13.9 mo.
Meneghini et al. [23]	85	22	63	-	-	-	F 65 M 20	-	31.8 wks
Park et al. [24]	41	20	21	-	-	-	F 37 M 4	3.5 d	30.5, 52.4 mo.
Kyriakidis et al. [25]	60	29	31	-	-	-	F 45 M 15	-	22.3, 17.4, 17.2 mo.

Table 2. Overview of study characteristics.

Four studies reported on the aetiology of non-union following LCP.[16,17,19,21] Aldrian *et al*. described three cases of plate breakage but did not disclose the aetiology of the other four cases of non-union following LCP. However, all seven of the cases reported by Aldrian *et al*. were managed by revision LCP and bone grafting.[16] Lizaur-Utrilla *et al*. reported one case of non-union after LCP caused by loss of plate fixation which was managed with revision to a dynamic condylar screw. The other two cases of non-union described by Lizaur-Utrilla *et al*. were managed by dynamic condylar screw fixation for one patient and conservatively in the other, until a delayed knee arthrodesis was performed for loosening of the femoral component.[21] Gondalia *et al*. reported all seven cases to be due to screw failure: five broken screws and two due to screw pull out.[17] Hou *et al*. reported two cases of plate breakage and one case of infection progressing to a chronically infected non-union.[19] The

	Fracture Healing				Complications						PROMs		
Study	Time to union (mean)	Non-union	Delayed Union	Malalignment/ Malunion	Revision of Primary treatment	Implant Failure	Loosening	Refracture	Infection	ROM Degrees (mean)	Score	Pre-operative (mean)	Post-operative (mean)
Aldrian et al [16]	6 mo.	LCP: 7 RIMN: 3	RIMN: 3	LCP: 2 RIMN: 3	LCP: 10 RIMN: 6	LCP: 3	RIMN: 1	0	LCP: 1	-	OKS (modified)	-	2.22, 2,20
Gondalia et al [17]	LCP: 49.8 wks RIMN: 38.3 wks	LCP: 7 RIMN: 3	0	LCP: 2 RIMN: 3	LCP: 7 RIMN: 3	LCP: 5 RIMN: 3	LCP: 2	RIMN: 2	-	LCP: 96.5 RIMN: 105.7	KSS KSS Functional		77.22, 81.81 76.5, 80.6
Horneff et al [18]	LCP: 11.5 wks RIMN: 12.4 wks	RIMN: 8	0	0	LCP: 4 RIMN: 14	RIMN:3	0	RIMN: 1	LCP: 4 RIMN: 1	-	-	-	-
Hou et al [19]	LCP: 4 mo. RIMN: 3.7 mo.	LCP: 3 RIMN: 1	LCP: 1	LCP: 3 RIMN: 1	LCP: 2 RIMN: 1	LCP: 2	RIMN:1	RIMN: 1	LCP:2 RIMN: 1	-	-	-	-
Kilucoglu et al [20]	LCP: 3.9 mo. RIMN: 3.8 mo.	0	0	0	0	0	0	0	-	82	KSS	-	78.8, 72.7
Lizaur-Utrilla et al [21]	12.4 wks	LCP: 3	0	4	LCP: 3	1	2	0	-	93.7	KSS Functional Womac Pain Womac Function SF12 Mental SF 12 Physical	89.5 90 79.6 78.4 45.7 44.8	83.1 80.7 70.4 68.7 40.2 40.4
Matlovich et al [22]	-	RIMN: 2	0	0	RIMN: 5	0	0	0	RIMN: 1	LCP: 102.9 RIMN: 101.8	-	-	-
Meneghini et al [23]	16 wks	LCP: 7 RIMN: 2	LCP: 5	LCP: 9 RIMN: 35	LCP: 6 RIMN: 1	-	-	-	RIMN: 1	-	-	-	-
Park et al [24]	LCP: 3.6 wks RIMN: 4.3 wks	0	RIMN: 1	LCP: 1 RIMN: 3	0	RIMN: 1	0	0	0	LCP: 104 RIMN: 100	WOMAC	19, 22.6	24.4, 27.4
Kyriakidis et al [25]	LCP: 5 mo. RIMN: 5.5-6 mo.	LCP: 2 RIMN: 1	LCP: 8 RIMN: 3	0	3	LCP: 2 RIMN: 1	0	0	0	LCP: 94.9 RIMN: 96.3-102	OKS	-	30.8, 30.6, 31.5

Table 3. Fracture healing, complications and patient reported outcome measures (PROMS).

ROM= range of motion, LCP= lockikng compression plate, RIMN= retrograde intramedullary nail, RA= Revision Arthroplasty, KSS= Knee Society Score, WOMAC= Western Ontario and McMaster Universities Osteoarthritis (WOMAC), OKS= Oxford Knee Score, SF12= Short form survey, HSS: Hospital for Special Surgery Score

Table 4. Incidence of complications for: RIMN, LCP, and overall cohort.

	RIMN	LCP	Overall
Non-union	20/218 (9.2%)	29/301 (9.6%)	49/519 (9.4%)
Re-operation	33/218 (15.1%)	34/301(11.3%)	67/519 (12.9%)
Infection	4/188 (2.1%)	7/272 (2.6%)	11/460 (2.4%)
Mortality	6/100 (6.0%)	8/153 (5.2%)	14/253 (5.5%)

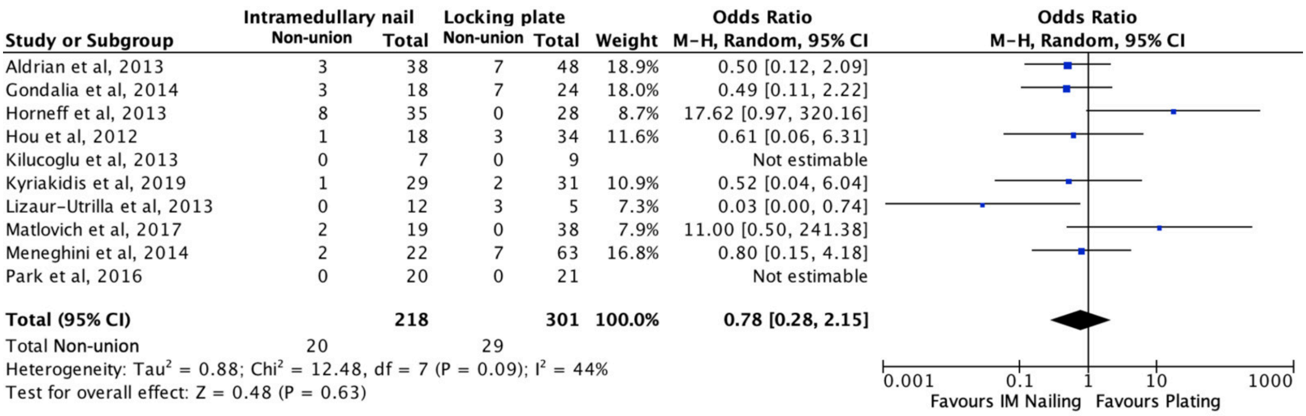

Figure 2. Forest Plot showing comparison of non-union rate between RIMN and LCP. No statistical significance found. M-H= Mantel–Haenszel, CI= Confidence Interval

latter two studies did not describe the management of non-union following LCP.[17,19]

Neither Meneghini *et al*. nor Kyriakidis *et al*. reported the aetiology of non-union following RIMN or LCP, but both described the management.[23,25] Following RIMN, Meneghini *et al*. reported one case being managed with revision to LCP and one with a bone stimulator. The seven cases of non-union after LCP cited in Meneghini *et al*. were managed as follows: four with revision LCP and bone grafting, two converted to distal femoral arthroplasty and one managed

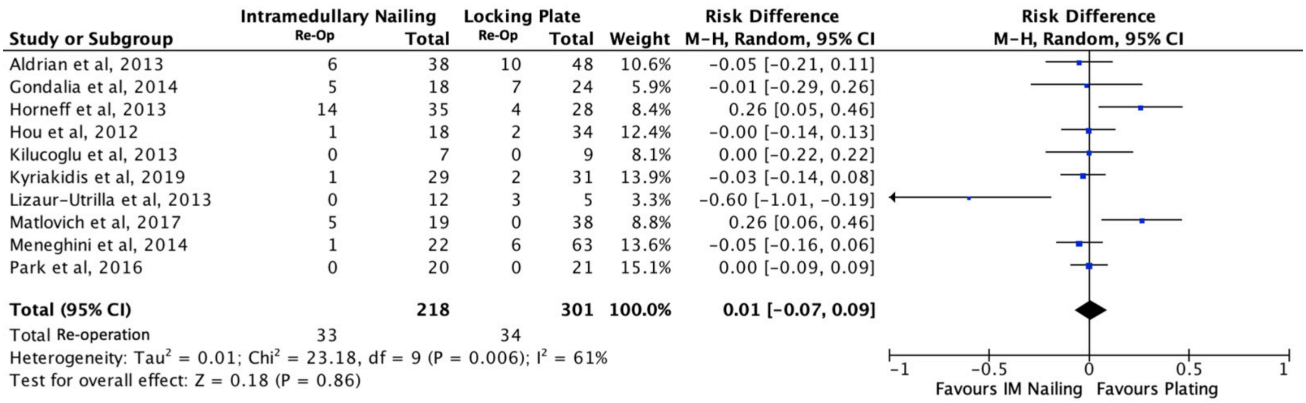

Figure 3. Forest plot showing comparison in reoperation rate between RIMN and LCP. No statistical significance found. M-H = Mantel–Haenszel, CI= Confidence Interval

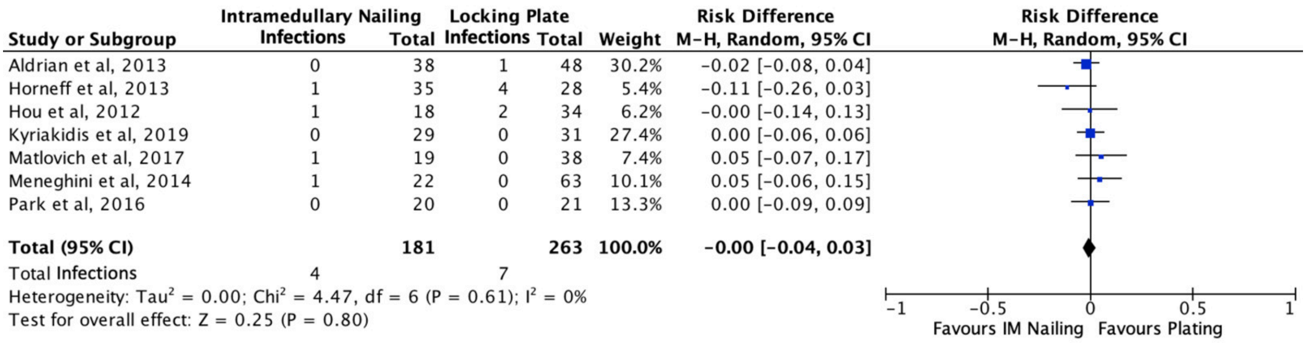

Figure 4. Forest plot showing comparison of infection rate between RIMN and LCP. No statistical significance found. M-H = Mantel–Haenszel, CI= Confidence Interval

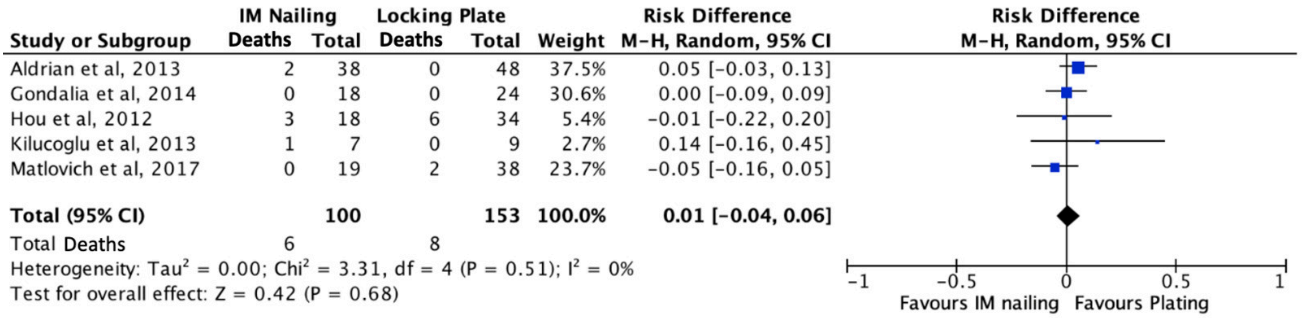

Figure 5. Forest plot showing comparison in mortality rate between RIMN and LCP. No statistical significance found. M-H = Mantel–Haenszel, CI= Confidence Interval

conservatively.[23] All three cases of non-union reported in Kyriakidis *et al*. (one post-RIMN and two post-LCP) were managed with revision total knee arthroplasty.[25]

Infection was a rarely reported complication after both RIMN and LCP. Aldrian *et al*. reported one superficial wound infection post-LCP that was successfully treated with antibiotics.[16] Horneff *et al*. reported five cases (one post-RIMN and four post-LCP) and Matlovich *et al*. one post-RIMN case of infection, that all required surgical management.[18,22] Meneghini *et al*. and Hou *et al*. both reported a case of infection progressing to chronically infected non-unions, following RIMN and LCP respectively.[19,23] As discussed above, Hou *et al*. also reported a surgical infection post-RIMN eventually necessitating amputation. Finally, Hou *et al*. described a surgical infection post-LCP that was managed successfully non-surgically.[19] Although infection was a rare complication, it had significant consequences with seven of the eleven reported cases requiring surgical management and two cases progressed to chronically infected non-unions.[18,19,22,23]

Besides non-union and infection, hardware failure/irritation was the third common cause of re-operation. There is clearly significant overlap between cases of hardware failure and non-union, as the former often precedes the latter, as described in all seven cases of non-union post-LCP by Gondalia *et al.*, both cases of non-union post-LCP by Hou *et al.* and the single case of non-union post-LCP described by Lizaur-Utrilla *et al.*[17,19,21] Aldrian *et al.* also reported four cases of hardware failure preceding non-union: one case of distal screw loosening following RIMN and three cases of plate breakage after LCP.[16] Following RIMN, Horneff *et al.* reported three cases of unspecified hardware failure and Matlovich *et al.* described three cases of distal screw irritation, all of which required surgical intervention.[18,22] Horneff *et al.* also described one case of re-fracture after RIMN necessitating surgical re-intervention.[18]

Femoral PPFs are associated with significant mortality: reported as 17.7% at one year post-operatively by Shields *et al.* and comparable to the mortality rate after a hip fracture by Bhattacharyya *et al.*[9,29] This meta-analysis found a lower mortality rate of 5.5% for distal femoral PPFs, although the follow up length was variable. Five studies reported on a total of fourteen mortalities. Aldrian *et al.* reported two mortalities from cardio-respiratory insufficiencies following RIMN.[16] Hou *et al.* reported three mortalities after RIMN and six after LCP, all within six months of surgery and from non-fracture related causes.[19] Kilucoglu *et al.* reported one mortality from pulmonary embolism, on post-operative day one following RIMN.[20] Finally, Matlovich *et al.* reported two deaths post-LCP: one on post-operative day five due to congestive cardiac failure and the other on post-operative day one hundred and eleven following complications from a prolonged stay in the intensive care unit.[22]

There is limited and conflicting literature comparing native to periprosthetic distal femoral fractures. For example, Streubel *et al.* reported shorter survival in the PPF group ($p = 0.005$) whilst Kaufman *et al.* found no significant difference in mortality ($p = 0.55$).[30,31] Bhattacharyya *et al.* reported femoral PPF to have a mortality rate comparable to that after a hip fracture, but they did not make any comparison to native distal femoral fractures.[29] Further high-quality research is required to draw any substantial conclusions on this comparison.

Six studies reported some data on PROMs using a total of nine different scoring systems.[16,17,20,21,24,25] There was no one scoring system used commonly across all six of these studies. Only two of these studies had pre-operative baseline scores to compare to.[22,24] The heterogeneity of PROMs data collected across these six studies meant no meaningful conclusion could be made about PROMs after RIMN and LCP for distal femoral PPF.

Whilst this meta-analysis contributes to the growing literature that there is no significant difference in complication rates of RIMN and LCP for distal femoral PPFs; the management strategy is a multi-factorial decision, requiring consideration of fracture pattern, implant stability, co-morbidities of the patient, bone stock and design of the in-situ TKR.[32] Non-operative management of supracondylar distal femoral PPFs yields less favourable results than operative management, particularly with regards to non-union and malunion.[33-36] Culp *et al.* reported rates of non-union and malunion as 43% for non-operative management and 13% for operative management.[37] However, non-operative management may be the only option for a patient with unacceptably high anaesthetic risk and may be considered in undisplaced epicondylar fractures, provided there is regular follow up to assess for fracture union and preservation of stability.[32]

For displaced fractures with stable implants, operative fixation is recommended. Historically this involved non-locking plates with dynamic condylar screws,[38] which provided improved rates of union compared to non-operative management but often caused significant morbidity due to the extensive incisions and considerable soft tissue stripping.[33,34,39] Minimally invasive modern surgical techniques such as RIMNs and LCPs have reduced these complications and there is increasing data to suggest that the outcomes and rates of complications between RIMN and LCP are equivocal.[26,27] Deciding between RIMN and LCP often comes down to surgeon preference and experience, but one must consider a handful of contraindications to RIMN. The nail must facilitate safe insertion and recognised contraindications preventing this include: the presence of a patella baja, a closed box design of the in situ TKR and an ipsilateral hip arthroplasty with a long femoral stem which may prevent nail insertion or risk the creation of a stress riser.

Distal femoral PPFs with unstable femoral components require revision arthroplasty or distal femoral replacement (DFR), depending on the quality of bone stock, as outlined in our treatment recommendation flowchart below (Fig. 6). Two recent meta-analyses by Wadwa *et al.*[40] and Ponugoti *et al.* have reported no significant difference between DFR compared to open reduction and internal fixation (ORIF: a combined cohort of patients who either underwent RIMN or LCP) in rates of complications, re-operation and mortality.[40,41] Wadwa *et al.* also described comparable functional outcome scores between DFR and ORIF, but better post-operative range of motion in the ORIF group.[40] These studies also highlight the advantage of early mobilisation and weight bearing post-DFR, reducing length of hospital stay and immediate sequela of immobility. This is supported by Tandon *et al.*, who reported shorter length of hospital stay and lower complication rate (19% vs 40%) following DFR when compared to ORIF.[42] These initial findings are encouraging but further research is necessary to illuminate the overall risks and outcomes of DFRs for distal femoral PPFs.

This meta-analysis is not without limitations. There is a scarcity of high-quality data that underpins the topic of distal femoral PPFs. Nine of the ten studies included in this meta-analysis, were retrospective cohort studies that lacked randomisation. There are limited case numbers involved in these studies and both aetiology and management of complications are variably reported across studies, further reducing quantity of data and the statistical power of the subsequent analyses. Surgeon preference greatly influences choice of fixation method and is a multi-factorial decision, influenced by experience with each technique, insti-

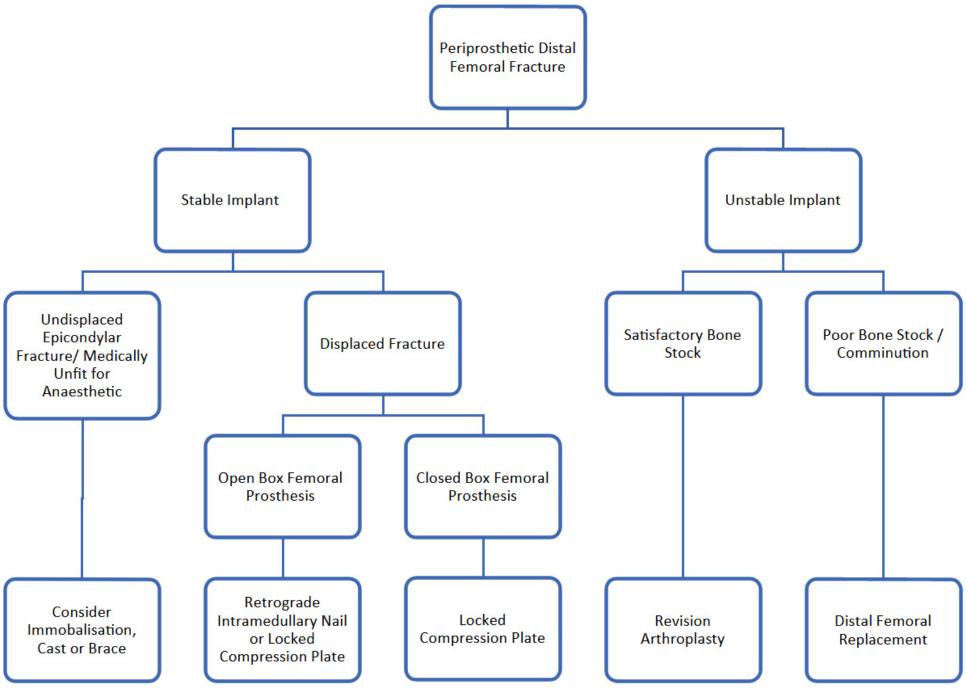

Figure 6. Recommended treatment flowchart for distal femoral peri-prosthetic fractures.

tutional trend, fracture pattern and bone quality. Fracture pattern was both variably reported and not standardised across the ten studies. Without this information, we were unable to elucidate what contribution fracture pattern had in deciding surgical technique and any potential influence on rates of complications.

CONCLUSION

This meta-analysis finds no significant difference in rates of non-union, re-operation, infection, or mortality between LCP and RIMN. At present, the framework provided, offers recommendations for the management of distal femoral PPFs. Further high-quality research is essential to evaluate both poorly reported outcomes, and emerging treatment modalities in the future.

ABBREVIATIONS

Arbeitsgemeinschaft für Osteosynthesefragen (AO)
Orthopaedic Trauma Association (OTA)
Distal femoral replacement (DFR)
Intramedullary (IM)
methodological items for non-randomised studies criteria (MINORS)
National Joint Registry (NJR)
NICE (National Institute for Health and Clinical Excellence)
Open reduction and internal fixation (ORIF)
Periprosthetic fracture (PPF)
Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)
Total knee replacements (TKRs)
United Kingdom (UK)
United States of America (USA)

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APPENDIX

APPENDIX ABBREVIATIONS

Allograft Prosthesis Composite (APC)
Deep Vein Thrombosis (DVP)
Distal Femur (DF)
Distal Femur Endoprosthesis (DFR)
Full Weight-Bearing (FWB)
Global Modular Replacement System (GMRS)
Hospital for Special Surgery (HSS)
Intramedullary nail (IM nail)
Knee Society Score (KSS)
Legacy Constrained Condylar Knee (LCCK)
Legacy Knee Posterior Stabilized (LPS)
Less Invasive Stabilization System (LISS)
Minimally Invasive Plate Osteosynthesis (MIPO)
Non-Contact Bridging (NCB)
Open Reduction Internal Fixation (ORIF)
Oxford Knee Score (OKS)
Parkinson's Disease (PD)
Pulmonary Embolism (PE)
Retrograde Inserted Supracondylar Nail (RISN)
Range of Motion (ROM)
Revision System (RSA)
Rheumatoid Arthritis (RA)
Standard Error (SE)
Standard Deviation (SD)
Supracondylar Nail (SCN)
Western Ontario and McMaster Universities Osteoarthritis (WOMAC)

Appendix Table 1. Table demonstrating raw data of studies meeting inclusion criteria, Part 1.

Study author and year of publication	Study type	Number of Patients (n)	Number of fractures (n)	Treatment	Time to Surgery	Implants used	Patients average age per treatment	Comorbidities	Patient gender per treatment
Lizaur-Utrilla et al. 2013[21]	Prospective matched cohort study comparing outcomes between 28 PPF patients with 28 age and gender matched primary TKRs for OA	56	28	1 Rorabeck type 1/ AO-33B1 – compression screws	2.7 (Range 2–6) days	ORIF, Synthes	75.6 (Range 56-86; SD 6.2)		26 females 2 males
				5 Rorabeck type 2/ AO33A1 – locking condylar plate		LISS, Synthes			
				12 Rorabeck type 2/ AO33A2 – retrograde IM nail		T2, Stryker			
				7 Rorabeck type 2/ AO33A3 – dynamic condylar screw		Nolok 95, Depuy			
				3 Rorabeck type 3/ AO33A3 – revision arthroplasty (hinged TKA)		Endo-Model, Waldemar Link			
				11 Rorabeck type 2 –locked compression plate			67.8 (Range 45-81)		8 females 3 males
				2 Rorabeck type 3 –revision arthroplasty			63 (Range 61-65)		1 female 1 male
			3 Patella	3 Ortiguera			63 (Range		3 females

Study author and year of publication	Study type	Number of Patients (n)	Number of fractures (n)	Treatment	Time to Surgery	Implants used	Patients average age per treatment	Comorbidities	Patient gender per treatment
				and Berry type 2 – ORIF with tension band wiring			55-67)		
			2 Tibia	2 Felix type 2 – revision arthroplasty			77.5 (Range 70-85)		2 males
Kyriakidis et al. 2019[25]	Multicentre Retrospective study between 2003 to 2014	60	60 Supracondylar fractures: 2 Rorabeck type I 48 Rorabeck Type 2	31 Fixed angle locking plates	NA	LISS Synthes	76.1 (SD 10.9)		8 males 23 females
				15 Uncemented retrograde IM nail		SCN Stryker	81.5 (SD 4.4)		3 males 12 females
				14 Cemented retrograde IM nail			82.7 (SD 6.6)		4 males 10 females
Matlovich et al. 2017[22]	Retrospective 2005 study to 2013	55	Rorabeck type 2s only	36 Locking plates	NA	NA	75.7 ± 11.2		9 males 27 females
				19 IM nail			75.4 ± 9.2		3 males 16 females
Meneghini et al. 2014[23]	Retrospective study	85	Rorabeck type 2s only	63 Locking plates	NA	NA	74 (Range 62-82)		51 females 12 males
				22 IM nails			74 (Range 67-61)		14 females 8 males
Gondalia et al. 2014[17]	Retrospective study between 2005 to 2009	42	Supracondylar fractures (17 33-A1, 8 33-A2, 17 33-A3)	24 Femur plate	NA	17 LISS DF (Synthes), 7NCB plate (Zimmer)	69.9		40 females 2 males
				18 Retrograde-inserted IM		18 RISN (4CIS)			

Study author and year of publication	Study type	Number of Patients (n)	Number of fractures (n)	Treatment	Time to Surgery	Implants used	Patients average age per treatment	Comorbidities	Patient gender per treatment
				nails					
Park et al. 2016[24]	Retrospective between 2003 and 2014	41	Supracondylar fractures	21 Plate (MIPO)	3.5 (range 1-14) days	Distal femoral locking plate (Zimmer)	75.0 (range 60-82)		1 male 20 females
				20 IM nail		Supracondylar IM nail (Smith and Nephews)	73.9 (Range 63-83)		17 females 3 males
Aldrian et al. 2013[16]	Retrospective between 1996 and 2010	86	32 Su Type 1 54 Su Type 2	48 Lateral plate fixation (LISS)		LISS, Synthes	75.6 (Range 59-89)		62 females 24 males
				38 Rigid interlocking nail device		SCN, Stryker			
Kilucoglu et al. 2013[20]	Retrospective	16	13 Neer Type 2 1 Neer Type 3 2 Neer Type 4	9 locking plates	NA	LISS, Synthes	76.7 (77± 4,6)		13 females 2 males
				7 retrograde IM nail	NA	TriGen Knee Nail, Smith & Nephew	68.6 (68±5,6)		
Horneff et al. 2013[18]	Retrospective between 2001 and 2009	63	63 Rorabeck type 2	28 Locking Plate	NA	NA	68.3	Average BMI – 28.4 kg/m2	10 Males 18 Females
				35 IM nail	NA	NA	69.5	Average BMI – 31.3 kg/m2	9 Males 26 Females
Hou et al. 2012[19]	Retrospective between 2004 and 2009	52	OTA classification (39 33A fractures 3 32B fractures 10 32A type fractures)	34 Locking plate	2.4 days	NA	Mean 75		23 females 11 males
				18 Retrograde IM nail	1.7 days		Mean 77		12 females 6 males

Appendix Table 2. Table demonstrating raw data of studies meeting inclusion criteria, Part 2.

Study author and year of publication	Classification	Follow-up	Postoperative rehabilitation regimen	Range of motion postoperatively	Infection	Average time to union	Non-union	Delayed union	Malalignment/ malunion
Lizaur-Utrilla et al. 2013[21]	Rorabeck and Taylor and AO classification	6.7 (Range 5–9) years	Day 1 – passive knee motion; Day 3 postop – active motion; FWB when bridging callus seen on radiographs.	93.7 (Range 75-100; SD 11.2) degrees	1 superficial wound infection – debridement and antibiotics	12.4 (Range 8–20) weeks	Plate - 3 IM nail - 0	0	3 patients with >5 degrees varus (1 retrograde nail, 2 dynamic condylar screws) 1 shortening (retrograde nail)
Kyriakidis et al. 2019[25]	Rorabeck type 1 and 2	Plate - 22.3 (SD 12.1) months	Partial and gradual weight bearing as tolerated	Plate - 94.9 (SD 21.4) degrees	0	Plate - 5 (Range 4-9) months	Plate - 2 (SD 6.5)	Plate - 8 (SD 25.8)	0
		Uncemented IM nail - 17.4 (SD 11.2) months		Uncemented IM nail - 96.3 (SD 7.9) degrees		Uncemented IM Nail - 6 (Range 5-6) months	Uncemented IM Nail - 1 (SD 6.6)	Uncemented IM Nail - 2 (SD 13.3)	0
		Uncemented IM ail - 17.2 (SD 8.05) months		Cemented IM nail - 102 (SD 14.6) degrees		Cemented IM nail - 5.5 (Range 4-6) months	Cemented IM nail - 0	Cemented IM nail - 1 (SD 7.1)	0
Matlovich et al. 2017[22]	Rorabeck	Plate - 15.6 months	Fully weightbearing by 15 weeks	Plate - 2.5±6.7 to 102.9±11.0	Plate - 0	***ONLY GRAPHS PRESENT NO NUMERICAL DATA**	Plate - 0	Plate - 0	0
		Nail - 13.9 months		IM nail - 0.3±1.2 to 101.8±16.7	IM nail - 1 infection leading to non-union		IM nail - 2 (1 aseptic, 1 infected)	IM nail - 0	
Meneghini et al. 2014[23]	Rorabeck and AO/OTA classification	31.8 (Range 6-176) weeks	Plate - FWB 11.7 weeks	NA	Plate - 0	16 weeks	Plate - 7	Plate - 5	Plate - 9
			IM nail – FWB 9.1 weeks		IM nail - 1 infection leading to non-union		IM nail - 2	IM nail - 0	IM nail - 35
Gondalia et al.	AO classification	34.6 (range 17.2-76.7)	Plate - Immobilisation for	Plate - 96.5 (extension to	N/a	Plate - 49.8 (Range	Plate - 5 with broken	Plate - 0	Plate - 2 medial

Study author and year of publication	Classification	Follow-up	Postoperative rehabilitation regimen	Range of motion postoperatively	Infection	Average time to union	Non-union	Delayed union	Malalignment/ malunion
2014[17]		months	6.1 weeks, FWB following clinical union	flexion 1.5-98) degrees		13.3-191) weeks	screws, 2 with medial translation (screw pull out)		translation
			IM nail - Immobilisation for 4.2 weeks, FWB following clinical union	IM nail - 105.7 (extension to flexion 2 to 107.7) degrees		IM nail - 38.3 (range 16-121.3) weeks	IM nail - 3 non union with varus deformity (broken screws)	IM nail – 0	IM nail - 3 varus deformity
Park et al. 2016[24]	AO/OTA classification, Su classification, Lewis and Rorabeck classification	Plate - 30.5 (Range 24-40) months	ROM exercises immediately, partial weight bear 4 weeks, full weight bear 12 weeks if evidence of union	Plate - 104 (range 60-140) degrees	0	Plate - 3.6 (range 3-5) months	Plate - 0	Plate - 0	Plate - 1 malalignment
		IM nail - 52.4 (Range 36-66) months		IM nail - 100 (range 60-130) degrees		IM nail - 4.3 (range 3-12) months	IM nail - 0	IM nail - 1 with nail breakage managed conservatively	IM nail - 3 malalignments, 1 malunion following nail breakage
Aldrian et al. 2013[16]	Su classification	At least 12 months	Gradual weight bearing from day 2-3 until 6-8 weeks	Plate – 34 excellent/ satisfactory; 14 poor	Plate – 1 superficial treated with antibiotics	Average - Within 6 months in 74 patients	Plate – 7	Plate - 0	Plate – 2 incorrect reduction, 3 secondary loss of reduction
				IM nail – 22 excellent/ satisfactory; 14 poor	IM nail – 0		IM nail – 3	IM nail -3 (radiographic union and pain free by 12 months)	IM nail – 3 incorrect reduction, 2 secondary loss of reduction
Kilucoglu et al. 2013[20]	Neer classification	1.75 (2±0.7) years	Range of motion exercises and toe-touch gait on day 2; FWB once union observed on radiograph	82 (Range 70-90) degrees	N/a	Plate - 3.9 (Range 3-6) months	Plate - 0	Plate - 0	Plate - 0
		5.57 (5±4.9) years				IM nail – 3.8 (Range 3-5) months	IM nail - 0	IM nail - 0	IM nail - 0
Horneff et	Rorabeck	Minimum 36	Partial weight	NA	Plates – 4	Plate – 11.5	Plate – 0	Plate – 0	Plate – 0

Study author and year of publication	Classification	Follow-up	Postoperative rehabilitation regimen	Range of motion postoperatively	Infection	Average time to union	Non-union	Delayed union	Malalignment/ malunion
al. 2013[18]		month	bearing immediately, FWB based on clinical data			weeks			
					IM nail – 1	IM nail – 12.4 weeks	IM nail – 8	IM nail – 0	IM nail – 0
Hou et al. 2012[19]	**OTA classification**	29 ± 2.2 (Range 12-60) months	Stability and surgeon preference	NA	Plate – 2 infections (1 resolved, 1 chronic infection)	Plate – 4.0 ± 0.27 months	Plate – 3	Plate – 1	Plate – 3 (2 inadequate reduction, 1 plate bending)
					IM nail – 1 infection with distal interlock screw loosening requiring amputation	IM nail – 3.7 ± 0.3 months	IM nail – 1	IM nail – 0	IM nail – 2

Appendix Table 3. Table demonstrating raw data of studies meeting inclusion criteria, Part 3.

Study author and year of publication	Implant failure	Loosening	Re-fracture	Revision of primary treatment	Blood loss	Blood transfusion	Other complications	PROMs	Overall complications (n)
Lizaur-Utrilla et al. 2013[21]	1	2	0	1 AO33A1 4 months post injury (revised to a dynamic condylar screw due to loss of plate fixation) 1 AO33A2 3 years post injury (knee arthrodesis due to aseptic loosening) 1 AO33A3 7 months post injury (revision dynamic condylar screw followed by revision arthroplasty due to aseptic loosening)	N/A	N/A	4 slight or occasional pain; 2 moderate or continuous pain	KSS – preop 89.5 (Range 75-100; SD 6.0), postop 83.1 (Range 61–97; SD9.0) Functional score – preop 90.0 (Range 80-100; SD 7.9), postop 80.7 (Range 50–100; SD 10.7) WOMAC pain – preop 79.6 (Range 60-100; SD 12.7), postop 70.4 (Range 40–90; SD 11.4) WOMAC function – preop 78.4 (Range 50-100; SD 10.6); postop 68.7 (Range 43-90; SD 9.7) SF12 mental – preop 45.7 (Range 28-50; SD 9.9), postop 40.2 (Range 28–42; SD 9.4) SF12 physical – preop 44.8 (Range 38-50; SD 7.7), postop 40.4 (Range 48–44;SD 7.3)	7
Kyriakidis et al. 2019[25]	0	0	0	3 revision TKAs for non-union	NA	NA	Plate - 2 PE (SD 6.5)	OKS postop 30.8 (SD 8.1)	12
							Uncemented IM nail - 1 DVT (SD 6.6)	OKS postop 30.6 (SD 10.23)	4
							Cemented IM nail – 0	OKS postop 31.5 (SD 8.6)	1
Matlovich	0	0	0	Plate - 0	NA	2 patients	Plate - 22.2%	NA	0

Study author and year of publication	Implant failure	Loosening	Re-fracture	Revision of primary treatment	Blood loss	Blood transfusion	Other complications	PROMs	Overall complications (n)
et al. 2017[22]							Chronic postoperative pain		
				IM nail - 5 cases – 2 for non-union, 3 for hardware irritation		0	IM nail - 22.7% chronic postoperative pain 17.6% subjective instability		5
Meneghini et al. 2014[23]	NA	NA	NA	4 revisions – locked plate + bone grafting; 2 distal femoral arthroplasty	NA	NA	NA	NA	12
				1 IM nail revised to locked plate					2
Gondalia et al. 2014[17]	Plate - 5 (broken screws)	Plate - 2 (screw pull out)	Plate - 0	7	NA	NA	Plate - 0	Plate - KSS 77.22 ± 12.7; KSS functional 76.5 ± 14.5	7
	IM nail - 3 (broken distal screws)	IM nail – 0	IM nail - 2 cases with fracture at level of proximal nail tip	5			IM nail - 0	IM nail - KSS 81.81 ± 8.7; KSS functional 80.6 ± 10.9	5
Park et al. 2016[24]	0	0	0	0	NA	NA	Plate - 2 skin irritations due to long distal screws	Plate - WOMAC score preop 19 (range 10-42), post op 24.4 (range 11-52)	3
	IM nail - 1 nail breakage	IM nail - 0	IM nail - 0	IM nail - 0			IM nail - 0	IM nail - WOMAC score preop 22.6 (range 15-39), post op 27.4 (range 20-50)	4
Aldrian et al. 2013[16]	Plate – 3 plate breakage	Plate – 0	Plate - 0	Plate 10 – 7 revision surgery with bone grafting	NA	NA	Plate – 2 respiratory failure, 2 pneumonia	Plate – OKS (modified) – 2.22	Plate – 21

Study author and year of publication	Implant failure	Loosening	Re-fracture	Revision of primary treatment	Blood loss	Blood transfusion	Other complications	PROMs	Overall complications (n)
	IM nail – 0	IM nail – 1 distal interlocking screw loosening (revision)	IM nail – 0	IM nail 6 – 1 patient with screw loosening	NA	NA	IM nail – 2 pneumonia, 2 deaths due to cardiorespiratory failure	IM nail - OKS (modified) 2.20	IM nail - 13
Kilucoglu et al. 2013[20]	Plate – 0	Plate – 0	Plate – 0	Plate – 0	NA	NA	Plate - 0	KSS – 78.8 (80±3.9)	Plate - 0
	IM nail – 0	IM nail – 0	IM nail – 0	IM nail – 0	NA	NA	IM nail – 1 Death (PE)	KSS – 72.7 (74±4.16)	IM nail - 1
Horneff et al. 2013[18]	Plate – 0	Plate – 0	Plate – 0	Plate – 4 (all due to infection)	NA	Plate – 8	Plate – 0	NA	Plate - 4
	IM nail – 3	IM nail – 0	IM nail – 1	IM nail – 14 (1 infection, 8 non-unions, 1 refracture, 3 hardware breakage, 1 revision arthroplasty)	NA	IM nail - 15	IM nail – 0		IM nail - 14
Hou et al. 2012[19]	Plate – 2 plate breakage	Plate – 0	Plate – 0	Revision – 2 for broken plates	Plate – 177.5 ± 23.4 mL		6 Deaths in 6 months		Plate – 7
	IM nail – 0	1 infection with interlock screw loosening	IM nail – 1 refracture following a fall	IM nail – 1 refracture requiring implant removal and anterograde IM nail fixation	IM nail – 182 ± 31.6 mL		3 Deaths in 6 months		IM nail – 3