Single *versus* separate implant fixation for concomitant ipsilateral femoral neck and shaft fractures: A systematic review

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Abstract

Concomitant ipsilateral femoral neck and shaft fractures are uncommon, occurring in 1-9% of femoral shaft fractures. While this injury typically occurs in young patients following high-energy trauma, little consensus has been established regarding the optimal fixation approach. A multitude of treatment strategies exist, with limited evidence as to which is more favorable. The aim of this study was to appraise current evidence, comparing management with either one single or separate devices for both fractures. A systematic review was undertaken in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Studies published between 1992 and 2018 comparing the rate of postoperative nonunion, malunion, delayed union, avascular necrosis, infection or reoperation between at least one method of single device fixation and one method of separate device fixation were included. Six non-randomized cohort studies assessing 173 patients were suitable for inclusion, each comparing single device cephalomedullary nail fixation of both fractures with a combination of devices. All patients presented following high-energy trauma, at a median age of 32 years. While low complication rate and favorable outcomes were found across both groups, no significant difference could be inferred between either treatment strategy. This injury continues to occur in the traditionally described patient group, and results in acceptable postoperative outcomes. A paucity of randomized studies limits the ability to recommend a single or separate device treatment approach, and as such prospective, randomized trials with adequately powered sample sizes are required to definitively compare surgical management strategies in this rare but complex injury.

Introduction

Femoral fractures occur frequently, with the annual incidence of proximal femoral fractures in the United States estimated at 250,000 and shaft fractures ranging from 9.5 to 18.9 per 100,000 population.[1,2] Typically, femoral neck fractures occur in the elderly,[3] whereas shaft fractures occur bimodally in younger patients following high-energy trauma and elderly patients as fragility fractures.[4] Proximal and diaphyseal femoral fractures have been shown to comprise 27% and 3% of all fractures requiring admission respectively,[5] with both best managed surgically.[6,7]

While femoral neck and shaft fractures occur frequently in isolation, both occurring concomitantly on the same side is uncommon,[8] with only 1-9% of shaft fractures presenting with a proximal neck fracture.[9] This injury occurs mostly following high-energy trauma such as a motor accident or a fall from height and often occurs in the younger patient,[9,10] presenting with accompanying distracting injuries in 73-100% of patients.[8] It is usually associated with comminuted fractures,[11] with a higher level of management complexity. This is exacerbated by the historical diagnostic difficulty, with up to 50% of femoral neck fractures missed on initial review,[12] owing to either the high incidence of a distracting injuries or low diagnostic sensitivity of CT and radiographs in this context.[13]

The associated fracture complexity, diagnostic and management challenges can lead to increased risk of complications, thereby impacting outcomes.[9] Femoral head avascular necrosis (AVN) and neck nonunion are two sequelae which can occur after fixation of displaced femoral neck.[14] To prevent this, prompt fracture stabilization should be performed, with early diagnosis and treatment improving patient outcomes in this injury.[15] While the associated mechanism, population and challenges are well described, little consensus has been established regarding management of these fractures,[10,16] other than that they should be managed operatively.[17] An issue adding complexity to its management is that preferential treatment of one fracture may affect treatment of the second.[8] While some advocate for priority to be given to management of the femoral neck fracture,[17-19] to reduce the risk of AVN,[8] others recommend prioritization of the shaft fracture.[20] Definitive management of both fractures during the same procedure, however, is preferable.[10]

Up to 30 different fixation strategies are described,[10] often classified by the number of devices used, with either a single device used to fix both fractures, or separate devices used to fix each fracture.[9,10,16,21] Debate exists regarding whether this injury is optimally treated by single or separate devices, with successful outcomes having been found in both.[21] The rare nature of this injury has limited the existence of prospective or randomized data that may alter treatment.[10] A previous systematic review of retrospective studies published over 20 years ago,[12] while finding that outcomes are favorable given appropriate treatment, found no superior treatment choice, attributing this to the heterogeneity associated with retrospective studies. Other publications have shown differing conclusions in both single and separate device cohorts. Single-device fixation with cephalomedullary nails, while having been shown to be less invasive and more cost-effective,[19,22-24] is also associated with a higher rate of femoral neck nonunion and AVN.[12,25] However, sep-

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arate device fixation, while being associated with fewer reoperations,[25] is also associated with infection and nonunion.[26]

Given this lack of agreement regarding fixation technique for this injury, and the most recent review occurring over 15 years ago,[25] a systematic and contemporary appraisal of recent literature assessing whether using either one single or two separate implants is more favorable in regards postoperative outcomes was undertaken.

Materials and Methods

This systematic review was undertaken in accordance with PRISMA guidelines.[27]

Eligibility criteria included peer-reviewed randomized controlled trials (RCTs), non-RCTs, prospective and retrospective cohort studies and case-control studies published from January 1992 to March 2018 in English language evaluating surgical management of concomitant ipsilateral femoral neck and shaft fractures. This time period was selected to capture all temporal evidence on current fixation strategies. Included studies were required to compare at least one method of single and separate implant fixation in at least ten patients and evaluate at least one of the study's primary outcomes, namely nonunion, delayed union, malunion, femoral head AVN, reoperation or infection.

Studies not published in English or published before January 1992, narrative reviews, opinion papers, case reports or series of one fixation strategy and comparative studies either including less than 10 patients or not evaluating one of the primary outcomes were excluded.

Studies were identified by searching four major electronic databases; PubMed, Ovid MEDLINE, Embase and Scopus, with additional reference list review. The exact search strategy is outlined in Figure 1.

Initial database search, exclusion of duplicate studies and screening of the titles or abstracts was performed by the primary author (KM). Following this, titles and abstracts of remaining studies were scrutinized by KM and a senior orthopedic surgeon (PE). The full-text articles of those remaining were then assessed for eligibility by KM and PE, with the suitability confirmed by a supervising author (HF). In cases of disagreement, consensus was to be obtained following discussion with a supervising consultant orthopedic surgeon author (NH/TMC), however consensus was reached in all cases.

Methodological quality assessment of each included trial was evaluated by KM and PE using the Newcastle Ottawa Scale (NOS),[28] designed for evaluation of non-randomized studies,[29] with strong levels of validity and reliability,[29] with consensus obtained after review by HF. Scores were allocated if respective treatment groups were representative of a typical injury population, as well as reliable record keeping and appropriate length and loss to follow-up. As the average time to diagnosis of post-operative femoral head AVN has been shown to be 18 months,[30] two years was agreed upon as follow-up.

All included studies in this review were non-randomized and observational in design, and hence associated with inherent limitations including loss to follow-up, selection and recall bias. Additional differences in study design, sample size, patient selection, and exposure measurement between studies inferred a high level of heterogeneity,[31] and inclusion of a quantitative meta-analysis of the cumulative results was deemed inappropriate. Consequently,

Table 1. Included studies characteristics.

First Author	Study design	Primary outcome(s) studied	Secondary outcome(s) studied	Patient Number	Group 1. Single implant fixation type	Group 2. Separate implants fixation types
Mohapatra 2017[34]	Prospective cohort	Delayed Union, Nonunion, Avascular Necrosis	Time To Union, Operative Time, Functional Outcomes	18	Cephalomedullary Nail (Recon IM Nail Or Long Femoral Nail) *N=10 (8M, 2F)*	Neck: Cancellous Screw OR Dynamic Hip Screw (DHS) Shaft: IM Nail OR Plate *N=8 (6M, 2F)*
Kharel 2017[33]	Retrospective cohort	Nonunion, Avascular Necrosis	Union, Time To Union, Operative Time, Functional Outcomes	24	Cephalomedullary Nail (Recon IM Nail) *N=11*	Neck: Cancellous Screws OR DHS Shaft: Compression Plate *N=13*
Mardani-Kivi 2014[32]	Prospective cohort	Avascular Necrosis	Time To Union, Operative Time, Functional Outcomes	40 (34 included)	Cephalomedullary Nail (Recon IM Nail) *N=15 (1M, 14F)*	Neck: Cancellous Screws Shaft: Compression Plate *N=19 (2M, 17F)*
Wang 2010[15]	Retrospective cohort	Delayed Union, Nonunion, Avascular Necrosis, Reoperation, Infection	Union, Time To Union, Operative Time, Functional Outcomes	21	Cephalomedullary Nail (PFNA Long) *N=10 (9M, 1F)*	Neck: DHS Cancellous Screws OR Shaft: Compression Plate *N=11 (9M, 2F)*
Tsai 2009[9]	Retrospective cohort	Malunion, Nonunion, Avascular Necrosis, Infection, Revision	Union, Operative Time, Functional Outcomes	43	Cephalomedullary Nail (Recon IM Nail) *N=5*	DHS (FN) + Low-Contact Dynamic Compression Plate (LC-DCP) (FS) N=8 Cancellous Screws (FN) + LC-DCP (FS) N=9 Cancellous Screws (FN) + Antegrade IM Nail (FS) N=21 *N=38*
Singh 2008[19]	Retrospective cohort	Delayed Union, Nonunion, Avascular Necrosis, Reoperation	Union, Time To Union, Functional Outcomes, Operative Time	27	Cephalomedullary Nail (Recon IM Nail) *N=12 (11M, 1F)*	Neck: Cancellous Screws OR DHS Shaft: Compression Plate *N=15 (13M, 2F)*

results synthesis primarily took the format of a qualitative narrative synthesis, summarizing and comparing the incidence primary and secondary outcomes in the included studies as well as discussing the relevance of each individual study in drawing generalized conclusions of the summated evidence.

Results

Search results and screening

Following exclusion of duplicate citations, searching of the PubMed, Ovid MEDLINE, Embase and Scopus, as well as additional literature searches resulted in 2027 citations. Twenty-four records progressed to full text assessment, with six studies meeting inclusion criteria (Figure 2). Characteristics of included studies are shown in Table 1. Appendix 1 outlines excluded studies.

Included studies

All six included studies were single-center cohort studies, four retrospective and two prospective in design (Table 1). No suitable RCTs were found. All studies evaluated at least one single and one separate implant strategy for management of concomitant ipsilateral femoral neck and shaft fractures. Median postoperative follow-up of all studies was 26 months (range: 20-48), consisting of clinical and radiographic evaluation.

A total of 173 patients were recruited in the included studies, with a median of 25.5 per study (range: 18-43) (Table 1). Of these, 167 patients were suitable for analysis, with six patients excluded by Mardani-Kivi as they did not complete final functional evaluation.[32] Median age of all included patients was 32 years. Data regarding gender was not available for in two studies.[9,33] Of the remaining 100 patients, 59 were male and 41 females. All patients presented following high-energy trauma, with 91% presenting following a road traffic accident (152 patients) and 9% following high-energy fall (15 patients). 50.9% (85 patients) suffered concomitant injuries and 3.6% of femoral shaft fractures were open (6 patients). Four studies (103 patients) used the Garden and Winquist Hansen Classifications to classify neck and shaft fractures respectively.[19,32-34] Of these, 66% of the neck fractures were Garden 2 (68/103), whereas 62.8% (44/102) of shaft fractures were either Winquist Hansen 1 or 2. Detailed fracture classifications are found in Table 2.

The primary intervention group consisted of those treated with a single device for both fractures, with the comparison group consisting of those treated with separate devices for each fracture. Perioperative strategy was outlined in five studies,[15,19,32-34] amounting to 124 patients, each including performed fluoroscopic guidance and perioperative antibiotic prophylaxis. The mean time to surgery from injury, evaluated in four studies (103 patients),[19,32-34] was 4.7 days. In each included study, the single-device fixation strategy ("Group 1") consisted of a femoral cephalomedullary nail, totaling 63 patients. The Stryker Recon Nailing System™ was the most commonly used device, utilized in at least 68.3% (43/63) of patients.[9,19,32,33] A total of 15.9% (10/63) of patients undergoing nail fixation were treated using the DePuy Synthes Proximal Femoral Nail Antirotation (PFNA) System™.[15] The exact fixation device utilized for the remaining 15.9%

Table 2. Included study demographics.

Study	Group 1, mean age	Group 2, mean age	Group 1, mode of injury	Group 2, mode of injury	Group 1, number of patients by fracture type Neck	 Shaft	Group 2, number of patients by fracture type Neck	 Shaft	Group 1, follow-up (months)	Group 2, follow-up (months)
Mohapatra 2017[34]	31.2 (20-51)	32 (22-43)	Road traffic accident *N=10*	Road traffic accident *N=8*	Garden 1 (n=0) Garden 2 (n=8) Garden 3 (n=2) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=5) Winquist 2 (n=3) Winquist 3 (n=1) Winquist 4 (n=1)	Garden 1 (n=0) Garden 2 (n=6) Garden 3 (n=2) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=2) Winquist 2 (n=3) Winquist 3 (n=1) Winquist 4 (n=2)	28 (20-32)	23.4 (18-35)
Kharel 2017[33]	34	31	Road traffic accident *N=11*	Road traffic accident *N=13*	Garden 1 (n=0) Garden 2 (n=7) Garden 3 (n=4) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=2) Winquist 2 (n=5) Winquist 3 (n=3) Winquist 4 (n=1)	Garden 1 (n=0) Garden 2 (n=10) Garden 3 (n=3) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=3) Winquist 2 (n=6) Winquist 3 (n=1) Winquist 4 (n=3)	20.2	19.9
Mardani-Kivi 2014[32]	31.46 (±7.26)	30.15 (±6.64)	Road traffic accident *N=15*	Road traffic accident *N=19*	Garden 1 (n=4) Garden 2 (n=7) Garden 3 (n=3) Garden 4 (n=1)	Winquist 0 (n=6) Winquist 1 (n=4) Winquist 2 (n=1) Winquist 3 (n=2) Winquist 4 (n=1)	Garden 1 (n=9) Garden 2 (n=7) Garden 3 (n=3) Garden 4 (n=0)	Winquist 0 (n=7) Winquist 1 (n=7) Winquist 2 (n=3) Winquist 3 (n=2) Winquist 4 (n=0)	23.13 (±9.87)	32.84 (±9.36)
Wang 2010[15]	43 (27-60)	41 (25-55)	Road traffic accident N=4; Fall N=6 *(Tot. N=10)*	Road traffic accident N=6; Fall N=5 *(Tot. N=11)*	Basicervical: 10	AO 32-B (n=2) AO 32-C1 (n=3) AO 32-C2 (n=3) AO 32-C3 (n=2)	Basicervical: 11	AO 32-B (n=2) AO 32-C1 (n=4) AO 32-C2 (n=2) AO 32-C3 (n=3)	20.8 (12-34)	22.2 (16-48)
Tsai 2009[9]	43 (17-73)	43 (17-73)	Road traffic accident N=39; Fall N=4 *(Tot. N=43)*	Road traffic accident N=39; Fall N=4 *(Tot. N=43)*	Minimally-displaced: 5 Displaced: 0	Stable Winquist: 3 Unstable Winquist: 3	Minimally-displaced: 33 Displaced:50	Stable Winquist: 29 Unstable Winquist: 9	48 (6-70)	48 (6-70)
Singh 2008[19]	37.9 (22-51)	33.2 (22-45)	Road traffic accident *N=12*	Road traffic accident *N=15*	Garden 1 (n=0) Garden 2 (n=10) Garden 3 (n=2) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=5) Winquist 2 (n=5) Winquist 3 (n=1) Winquist 4 (n=1)	Garden 1 (n=0) Garden 2 (n=13) Garden 3 (n=2) Garden 4 (n=0)	Winquist 0 (n=0) Winquist 1 (n=3) Winquist 2 (n=7) Winquist 3 (n=1) Winquist 4 (n=4)	27.1 (20-31)	24.2 (19-34)

(10/63) was not explicitly stated;[34] however these were operated on using a Recon™ device or long proximal femoral nail. The separate device fixation group ("Group 2"-104 patients) consist of multiple treatment strategies, with the femoral neck fractures fixed using either cancellous screws or DHS, and the femoral shaft fractures with either plate or intramedullary nailing. Exact strategies are presented in Table 1.

Each included study evaluated at least one of the review's primary outcomes; nonunion (n=5), delayed union (n=3), malunion (n=1), AVN (n=6), revision (n=3) and infection (n=2). Union was assessed in four studies, and functional outcomes were assessed in all studies using the Friedman and Wyman Criteria. Time to union and operative time were presented in weeks when evaluated. Details of outcomes assessed are presented in Table 1. Union was broadly defined as painless full-weight bearing with accompanying radiological evidence by Singh,[19] and as the absence of symptoms with radiological evidence of union in three of four affected cortices by Wang.[15] Tsai and Kharel did not provide a definition for union.[9,33] A definition for nonunion was only provided in one of five relevant studies, defined by Wang as the "lack of radiological union at twelve months for both fractures". [15] Delayed union was defined as "lack of radiological union at six months" by Wang, Singh and Mohapatra.[15,19,34] Malunion was evaluated in one study,[9] however was not defined. Assessment of methodological quality of each study was performed using the Newcastle Ottawa Scale (NOS),[28] with the respective scores outlined in detail in Table 3. In-depth NOS scoring and rationale is presented in Appendix 2 and 3 respectively. The overall median NOS score was 5.5 (range 5-8).

The results of each individual study are presented in Tables 2, 4 and 5 and described cumulatively below. No statistically significant difference was found in the primary outcomes between the single and separate treatment groups in any of the included studies by the original authors.

Primary outcomes

Nonunion

Five studies evaluated neck nonunion.[9,15,19,33,34] 4.2% (2/48) of patients managed with a single device cephalomedullary nail fixation for both fractures suffered from neck nonunion, in comparison to 1.2% (1/85) of patients undergoing separate device fixation. Four studies directly compared femoral shaft nonunion, [9,15,19,33] with none (0/38) in the single device cohort, in comparison to 5.2% (4/77) in the separate device cohort.

Delayed union

Delayed femoral neck union was compared only by Wang,[15] with no cases reported in either the single (0/10) or separate (0/11) device cohorts. Delayed union of the femoral shaft was compared in three studies,[15,19,34] with 18.8% (6/32) of the single device group suffering from delayed union, in comparison to 13.6% (4/34) of the separate device group.

Malunion

Postoperative femoral shaft malunion was evaluated only by Tsai,[9] with 7.9% (3/38) of the separate fixation cohort experiencing malunion, compared to no patients (0/5) in the single device cohort. Neck malunion was not evaluated in any study.

Avascular necrosis

Femoral head AVN was assessed in all studies, with 4.8% (3/63) of patients with cephalomedullary nail fixation of both fractures developing AVN postoperatively, compared to 6.7% (7/104) of the separate device group.

Table 3. Newcastle outcomes scale (NOS) scores.

Total	Mohapatra[34]	Kharel[33]	Mardani-Kivi[32]	Wang[15]	Tsai[9]	Singh[19]
Selection	2	2	3	2	3	2
Comparability	1	1	2	1	0	1
Outcome	2	2	3	2	3	3
Total NOS Score	5	5	8	5	6	6

Search Strategy
fracture AND femur AND neck AND shaft
fracture AND femoral AND neck AND shaft
fracture AND femur AND neck AND diaphysis
fracture AND femoral AND neck AND diaphysis
femur AND neck AND shaft AND outcome
femoral AND neck AND shaft AND outcome
femur AND neck AND diaphysis AND outcome
femoral AND neck AND diaphysis AND outcome

Figure 1. Database Search Strategy.

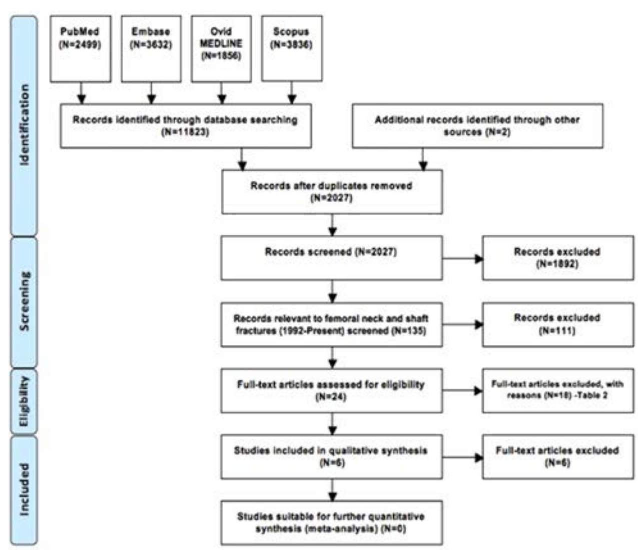

Figure 2. Study Selection Flow Diagram.

Reoperation

Three studies evaluated the proportion of patients who went on to reoperation, occurring in 11.1% (3/27) and 6.25% (4/64) of the single and separate device fixation cohorts respectively.[9,15,19] Four procedures were performed for the three patients undergoing reoperation in the single device group, with nail dynamization required in two patients with delayed femoral shaft union, and one patient undergoing initial valgus osteotomy and ender nailing for nonunion, with subsequent revision osteotomy. In the separate device cohort, five revision procedures were performed for four patients. Two patients underwent total hip arthroplasty for femoral head AVN post cancellous screw fixation, and revision cephalomedullary nailing was performed for one patient with femoral neck nonunion. One patient suffered from femoral shaft fixation failure with subsequent nonunion and underwent two revision procedures.

Infection

Postoperative infection was evaluated in two studies,[9,15] occurring in 6.25% (1/15) of the single device and 2% (1/49) of the separate device cohort. The single case of infection in the single device cohort was a superficial infection of an open shaft fracture, managed with intravenous antibiotics. In the separate device cohort, one patient developed a deep postoperative infection, treated with surgical debridement and intravenous antibiotics.

Union

Femoral neck union was assessed in three studies,[9,15,19] with uncomplicated postoperative union being found in 92.6% (25/27) of the cohort with single cephalomedullary nail fixation, in comparison to 78.1% (50/64) of the separate device group. Uncomplicated postoperative union of the femoral shaft was compared in four studies,[9,15,19,33] occurring in 89.5% (34/38) of the single device group and 88.3% (68/77) of the separate device cohort.

Secondary outcomes

Time to union

Time to union in both treatment groups was evaluated directly in five studies,[15,19,32-34] with a total of 58 and 66 patients in the

Table 4. Outcomes union.

Study	Group 1, % union	Group 2, % union	Group 1, % non-union	Group 2, % non-union	Group 1, % mal-union	Group 2, % mal-union	Group 1, % delayed union	Group 2, % delayed union	Group1, time to union (weeks)	Group 2, time to union (weeks)
Mohapatra 2017[34]	N/A	Neck: 100% (8/8) Shaft: N/A	Neck: 10% (1/10) Shaft: N/A	Neck: 0% (0/8) Shaft: N/A	N/A	N/A	Neck: N/A Shaft: 20% (2/10)	Neck: N/A Shaft: 25% (2/8)	Neck: 28 (14-32) Shaft: 18 (14-32)	Neck: 15 (14-18) Shaft: 20 (17-28)
Kharel 2017[33]	Neck: N/A Shaft: 100% (11/11)	Neck: N/A Shaft: 92.3% (12/13)	Neck: 0% (0/11) Shaft: 0% (0/11)	Neck: 0 (0/13) Shaft: 7.7% (1/13)	N/A	N/A	Neck: N/A Shaft: 8.33% (Both Groups) (2/24)		Neck: 15.1 Shaft: 21	Neck: 13.7 Shaft: 19
Mardani-Kivi 2014[32]	N/A	N/A	N/A	Neck: 15.8%(3/19) Shaft: 5.3% (1/19)	N/A	N/A	N/A	Neck: 15.8% (3/19) Shaft: 10.6% (2/19)	Neck: 17.32(±3.88) Shaft: 20 (±2.6)	Neck: 34.44 (±30.68) Shaft: 29.68 (±17.88)
Wang 2010[15]	Neck: 100% (10/10) Shaft: 90% (9/10)	Neck: 100% (11/11) Shaft: 90.9% (10/11)	Neck: 0% (0/10) Shaft: 0 (0/10)	Neck: 0% (0/11) Shaft: 9.1% (1/11)	N/A	N/A	Neck: 0% (0/10) Shaft: 10% (1/10)	Neck: 0% (0/11) Shaft: 0% (0/11)	Neck: 16 (12-20) Shaft: 20.3 (16-24)	Neck: 15.6 (12-20) Shaft: 21.1 (20-32)
Tsai 2009[9]	Neck: 80% (4/5) Shaft: 100% (5/5)	Neck: 63.2% (24/38) Shaft: 86.8% (33/38)	Neck: 0% (0/5) Shaft: 0% (0/5)	Neck: 2.6% (1/38) Shaft: 5.3% (2/38)	Neck: N/A Shaft: 0% (0/5)	Neck: N/A Shaft: 7.9% (3/38)	N/A	N/A	Neck: 2.5 months (Both Groups) (2-5) Shaft: 6.5 months (Both Groups) (3-12)	
Singh 2008[19]	Neck: 91.7% (11/12) Shaft:75% (9/12)	Neck: 100% (15/15) Shaft: 86.7% (13/15)	Neck: 9.3% (1/12) Shaft: 0% (0/12)	Neck: 0% (0/15) Shaft: 0% (0/15)	N/A	N/A	Neck: 0% (0/12) Shaft: 25% (3/12)	Neck: 0% (0/15) Shaft: 13.3% (2/15)	Neck: 17.1 (13-31) Shaft: 22.8 (17-33)	Neck: 15.26 (14-17) Shaft: 20.3 (18-30)

Table 5. Other outcomes.

Study	Group 1, % avascular necrosis	Group 2, % avascular necrosis	Group 1, % revision (min)	Group 2, % revision	Group 1, % infection (min)	Group 2, % infection	Group 1, operative time	Group 2, operative time	Group 1, Functional outcomes (Friedman and Wyman). Patients/Category	Group 2, Functional outcomes (Friedman and Wyman). Patients/Category
Mohapatra 2017[34]	10% (1/10)	0% (0/8)	N/A	N/A	N/A	N/A	90 (80-130)	75	Good: 7 Fair: 1 Poor: 2	Good: 6 Fair: 2 Poor: 0
Kharel 2017[33]	0% (0/11)	0% (0/13)	N/A	N/A	N/A	N/A	96	75	Good: 8 Fair: 2 Poor: 1	Good: 8 Fair: 4 Poor: 1
Mardani-Kivi 2014[32]	6.67% (1/15)	26.3% (5/19)	N/A	N/A	N/A	N/A	76 (±7.83)	99.21 (±11/45)	Good: 13 Fair: 2 Poor: 0	Good: 14 Fair: 4 Poor: 1
Wang 2010[15]	0% (0/10)	0% (0/11)	0% (0/10)	9.1% (1/11)	10% (1/10-Superficial)	9.1% (1/11-Deep)	217 (155-335)	255 (215-230)	Good: 8 Fair: 1 Poor: 1	Good: 8 Fair: 2 Poor: 1
Tsai 2009[9]	0% (0/5)	5.26% (2/38)	0% (0/5)	7.9% (3/38)	0% (0/5)	0% (0/38)	301 (180-480)	278	Good: 4 Fair: 1 Poor: 0	Good: 29 Fair: 7 Poor: 2
Singh 2008[19]	13.6% (3/12)	0% (0/15)	25% (3/12)	0% (0/15)	N/A	N/A	115.2 (75-139)	72.5 (59-88)	Good: 10 Fair: 1 Poor: 1	Good: 13 Fair: 1 Poor: 1

single and separate device cohorts respectively. Mean time to femoral neck union was 18.1 weeks in the single device group compared to a mean of 20.5 weeks undergoing separate device fixation. Mean time to femoral shaft union was 20.5 weeks in Group 1 and 22.8 weeks in Group 2.

Functional outcomes

Functional postoperative outcomes were assessed in all included patients, using the Friedman and Wyman Criteria. Of the 63 patients in single device treatment cohort, 79.4% (50/63) of them reported "Good" outcomes, with 12.7% (8/63) and 7.9% (5/63) reporting "Fair" and "Poor" outcomes respectively. Of the 104 patients undergoing separate device fixation, 75% (78/104) reported "Good" outcomes, with 19.2% (20/104) and 5.8% (6/104) reporting "Fair" and "Poor" outcomes respectively.

Operative time

Operative time was compared in all studies. Mean operative time was 129.4 and 172.3 minutes in the single and separate device groups respectively.

Discussion

Management of concomitant, ipsilateral femoral neck and shaft fractures remains a polarizing topic.[15] However, consensus exists regarding the type of patient and mechanism of injury,[12] usually occurring in young patients following high-energy trauma.[9] This pattern is well represented in this study, in terms of both median age (32) and mechanism of injury, as all patients presented following a high-energy trauma with a high rate of concomitant injuries (50.9%). This may be of importance as it permits increased clinical suspicion in diagnosing this rare injury. Historically, diagnosis of an associated femoral neck fracture can be missed or delayed in up to 30% of cases,[12] with delayed stabilization associated with increased complications.[10] Early suspicion for this injury pattern in patients presenting with multiple injuries following high-energy trauma may allow for earlier diagnosis and potentially improve outcomes.[18]

Nonunion

Problems with union can occur following both femoral neck and shaft fixation. Neck nonunion occurs in up to 10%,[35] and can require multiple procedures to remedy, creating significant functional and economic challenges for both patient and surgeon.[36] It occurs in up to 6.7% in the femoral neck in the combined injury pattern.[10] Our review found proportionally a higher rate of femoral neck nonunion (4.2%) in those managed with single device nail in comparison to separate devices (1.2%). However, significance of this result is limited by the small sample size, study heterogeneity and the fact that no individual study found a statistically significant difference between both groups. The overall rate of nonunion for both groups is 2.3%, comparing well when compared to the isolated neck of femur fracture cohort.[10]

The higher rate of neck nonunion in the single device cohort may be attributable to the increased technical difficulty in achieving adequate femoral neck reduction, which in turn may affect union.[23] Starr first postulated that any advantage of Recon™ nail utilization is outweighed by the technical difficulty in femoral neck fixation.[37] Watson has argued that cephalomedullary nails are designed primarily to stabilize the femoral shaft, with the femoral head screws designed only for additional stabilisation.[38] This may affect the accuracy of femoral neck reduction and cause displacement following nail insertion which may explain the disparity in nonunion rates. Issues with femoral neck reduction in this ipsilateral fracture group were also discussed by Bedi,[39] who queried the accuracy of femoral neck during cephalomedullary nail fixation, concluding that the accuracy of femoral neck reduction was found to be higher in those managed with separate implant in comparison to only a cephalomedullary nail. Another potential reason for this is a separate device strategy may allow prioritization of initial neck fixation prior to shaft fixation, which has been previously recommended to confer better neck stability and reduce nonunion rates. [8,40]

Comparing femoral shaft nonunion, the rate was lower in the single implant cohort, with no cases occurring in comparison to the separate implant group (5.22%). The importance of this, however, is limited by the fact intramedullary (IM) nailing of the femoral shaft makes up part of the separate device fixation group, used in addition to separate neck fixation, and consequently, direct comparison between both groups in this outcome is inappropriate. The overall rate of shaft nonunion (3.5%) appeared to reflect well, with ranges of up to 23% reported for this group previously.[10] Femoral nailing is known to be associated with a low rate of nonunion, particularly when reamed,[38] and the presence of IM nailing in the separate implant group as well as single implant group may explain these results.

Avascular necrosis

Femoral head AVN occurs in up to 22% of cases following isolated intracapsular femoral neck fractures,[41] and is associated with poor patient outcomes.[42] The quality of intraoperative fracture reduction is an important factor associated with AVN.[30] In our review, the proportion of postoperative femoral head AVN was lower (4.8%) in the single device group than the separate device cohort (6.7%). However, caution is advised in interpreting this result, due to the lack of a statistically significant difference between treatment groups in any individual study, small sample sizes and study heterogeneity, limiting meta-analysis. Previous reviews found single device cephalomedullary nail fixation in these injuries were associated with higher rates of AVN,[25] suggesting a potential relationship between the accuracy of femoral neck reduction and AVN, hence limiting any potential inference from our results.

The overall rate of AVN across both groups (5.98%), however, appeared favorable in this cohort when compared to isolated femoral neck fractures.[41] This has previously been attributed to dissipation in force affecting the femoral neck to the associated shaft fracture,[12] which may explain the low rate in this review.

Reoperation

Up to 1.9% of patients undergoing an orthopedic trauma procedure have been shown to require an unplanned reoperation,[43] and in the context of the significant costs associated with a hospital bed day,[44] reduced rate of reoperation can be associated with an improvement in economic burden in addition to the obvious patient benefits. In previous studies, the rate of reoperation was lower in the separate device cohort,[25] which is consistent with the findings of this review, in which 11.1% of the nail cohort proceeded on to having at least one further orthopedic intervention, *versus* 6.25% of the separate device cohort.

Infection

Postoperative infection was reported in only two cases.[15] Of these, only one case, presenting in the separate device group, required surgical debridement. Deep infection has been shown to occur in up to 1.6% of hip fractures following fixation,[45] and is a known outcome following femoral shaft fixation.[46] It is associated with worse patient outcomes, revision surgery and a higher mortality rate.[45,46] A systematic review has confirmed that antibiotic prophylaxis preoperatively helps reduce deep infections in those undergoing long bone fixation,[47] making up a cornerstone of surgical management. While fixation with Recon™ IM nailing is known to be less invasive than fixation with separate devices,[22] and may therefore theoretically infer less exposure to infection, our study is unable to draw any meaningful conclusions regarding this.

Secondary outcomes

Time to union and postoperative functional outcomes were assessed in all studies. Time to femoral neck and shaft union was less (18.1 and 20.5 weeks respectively) in the single than the separate device group (20.5 and 22.8 weeks). Femoral neck union following fracture can take up to 6 months to occur,[48] and time to femoral shaft union in concomitant femoral neck and shaft fractures has previously been shown to be associated with higher union times than isolated femoral shaft fractures.[22] The time to union in both fractures across both groups therefore appears to be acceptable.

It has been established that primary treatment of an isolated femoral shaft fracture should ideally be with an intramedullary nail,[49] due to the associated reduction in time to union and rate of nonunion. This may explain the potentially favorable outcomes in comparison to the separate implant group, in which plate osteosynthesis was the primary mode of shaft fixation.

The majority of patients (76.6%) across both groups had "Good" postoperative functional outcomes, with 79.4% and 75% of the single and separate device cohorts scoring in this category respectively. This may be because the progression from index injury to surgery is prompt, at a mean of 4.7 days across both groups. Delays to surgical fixation in both femoral neck and shaft in isolation are associated with worse outcomes, [50,51] and prompt fixation of both is therefore also recommended when these occur concomitantly.[10] Fulfilling this criterion may contribute to good postoperative function and reduce complication rates.

Limitations

A number of limitations existed in this review. The lack of prospective randomized evidence regarding concomitant ipsilateral femoral neck and shaft fractures, as previously described by Alho and Bhandari,[12,31] continued to persist. While stringent inclusion criteria were applied, included studies were all non-randomized and heterogeneous, with only 167 eligible patients, limiting this review to descriptive analysis only. Furthermore, given that case series make up a large proportion of the published literature on this injury, exclusion of these may arguably limit the significance of our results.

Despite these limitations, this review adds to the current evidence on this topic. An ipsilateral concomitant femoral neck and shaft fracture is a rare fracture pattern,[8] and as such the potential for large, multi-center randomized trials is potentially restricted. This systematic analysis and qualitative appraisal of the most recent literature regarding treatment of this complex injury may be of benefit in guiding management as it allows for evidence accumulation in what is a sporadically described treatment algorithm.

Conclusions

This review has demonstrated that ipsilateral concomitant femoral neck and shaft fractures which occur in young patients following high-energy trauma, are associated with relatively low rate of complications, successful union and favorable functional outcomes following prompt fixation.

While it appears that the complication rate may potentially differ between single and separate device fixation strategies, a paucity of randomized studies limit the ability to recommend a single or separate device treatment approach. As such studies with adequately powered sample sizes are required to definitively compare management strategies in this rare but complex injury.

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