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Fixation of intracapsular femoral neck fractures: A systematic review study

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Abstract

Objective: This study aimed to evaluate the clinical and biomechanical outcomes of different fixation types in intracapsular femoral neck fractures.

Methodology: A systematic review was conducted using PRISMA guidelines. Searches were performed in databases such as PubMed, Scopus, Cochrane, and Google Scholar, including studies published in English between 2014 and 2024. Inclusion criteria encompassed clinical, experimental, and cohort studies that analyzed the clinical or biomechanical outcomes of intracapsular femoral neck fracture fixation.

Results: The Femoral Neck System (FNS) consistently demonstrated superior outcomes, with reduced rates of failure and complications like avascular necrosis (AVN) and non-union, especially in Garden III-IV and Pauwels III fractures.

Conclusion: The study concluded that devices like FNS and Targon FN offer better outcomes in complex clinical scenarios, while traditional options like Cannulated Screws (CCS) showed limitations in unstable fractures. Implant choice should consider fracture complexity and patient profile.

Keywords: Femoral neck fractures, internal fixation, femoral neck system (FNS), avascular necrosis, non-union

1. Introduction

Intracapsular femoral neck fractures represent a significant orthopedic challenge, particularly in elderly populations, due to the risk of severe complications such as non-union and avascular necrosis. These injuries are often caused by low-energy trauma in older adults, while in younger individuals, they are typically associated with high-energy trauma. Proper management of these fractures is crucial to minimizing complications and improving functional outcomes.

The choice of treatment depends on multiple factors, including age, bone density, fracture classification, and the patient's overall clinical condition. While prosthetic replacements are widely used in elderly patients, internal fixation remains the preferred option for younger patients with displaced fractures.

Among internal fixation devices, cannulated screws and the femoral neck system (FNS) are the most used. Recent studies have shown that the FNS provides greater biomechanical stability, and a lower risk of complications compared to cannulated screws. The use of dynamic devices has also been explored to optimize fixation in unstable fractures (Zhang *et al.*, 2024) [55].

Despite technological advances, fixation failure rates remain considerable, ranging from 10% to 30% depending on the type of implant and fracture characteristics. Managing these failures often involves surgical revision or prosthetic replacement, increasing costs and morbidity.

The classification of femoral neck fractures plays a crucial role in therapeutic decision-making. The Garden classification, for instance, is widely used to differentiate between displaced and non-displaced fractures, which directly influences implant selection (Brown *et al.*, 2017).

Biomechanical studies are also essential to evaluate implant efficacy. Finite element analyses have shown that devices such as the FNS and the Targon FN better distribute loads and reduce the risk of fracture collapse.
Avascular necrosis (AVN) is one of the most feared complications in the treatment of intracapsular fractures. Studies indicate that factors such as delayed surgery and the quality of the initial reduction are critical determinants for AVN development.
Early surgical intervention has been advocated as an effective strategy to reduce complications. A recent meta-analysis demonstrated that patients operated on within 24 hours after trauma experience lower AVN rates and better functional outcomes.
Functional outcomes also depend on postoperative rehabilitation. Protocols that include early mobilization and partial weight-bearing have shown better outcomes compared to prolonged bed rest.
The literature review on the fixation of intracapsular femoral neck fractures aims to synthesize current evidence to guide clinical practice and inform future studies. Therefore, this study aims to evaluate the clinical and biomechanical outcomes of different types of fixations used in the treatment of intracapsular femoral neck fractures.

2. Methodology
This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. All stages followed a rigorous protocol described below:

2.1. Search Strategy
The searches were comprehensively conducted in the PubMed, Scopus, Cochrane, and Google Scholar databases. The primary search strategy used the following keywords and Boolean descriptors: "femoral AND neck AND fracture AND fixation AND intracapsular." To ensure relevance and currency of the results, filters were applied to include only studies published in English, covering the period between 2014 and 2024, with full access to the content. The Boolean operators used were:

- "AND" to combine terms that must be present in the results (e.g., "femoral AND neck" requires both terms in the studies);
- "NOT" to exclude terms that could introduce irrelevant results (e.g., "NOT biomechanics" excludes studies related to biomechanics);
- Filters to limit the search to studies relevant in terms of publication period and accessibility.

This robust approach excluded irrelevant studies, such as those addressing fractures in other locations or non-clinical contexts. At the same time, it ensured that included studies presented consistent data on intracapsular femoral neck fixation, meeting the predefined eligibility criteria.

2.2. Inclusion and Exclusion Criteria
The inclusion criteria covered clinical, experimental, and cohort studies analyzing clinical or biomechanical outcomes related to intracapsular femoral neck fracture fixation. Conversely, the exclusion criteria included studies published in languages other than English, case studies, systematic reviews, and articles focused on biomechanics without clinical applications.

2.3. Study Selection
The selection process followed a systematic procedure divided into three main stages:

1. **Initial Screening:** Titles of retrieved studies were reviewed to identify relevance to the review topic.
2. **Abstract Screening:** Abstracts of initially selected articles were analyzed to verify compliance with the predefined inclusion criteria.
3. **Full-Text Screening:** Full texts of articles remaining after the previous stages were read to ensure detailed qualitative and quantitative evaluation.

2.4. Data Extraction and Organization
Data extraction and organization were systematically performed, encompassing essential information for analyzing included studies. Extracted data included the study type (e.g., retrospective, prospective, or experimental), type of implant used, number of participants in each study, classification of treated fractures, follow-up duration, and primary outcomes such as fixation failure, incidence of avascular necrosis, and non-union cases. This approach ensured the standardized and detailed collection of relevant information for result interpretation.

2.5. Data Analysis
Data analysis was conducted using an integrated approach, combining qualitative and quantitative methods to ensure a comprehensive interpretation of the results. Studies with similar outcomes were grouped and subjected to meta-analysis, generating consolidated and statistically robust estimates. This methodology enabled the identification of patterns and differences across studies, providing a consistent foundation for review conclusions.

2.6. PRISMA Flow Diagram
The study selection process was conducted rigorously and systematically, as illustrated by the PRISMA flow diagram (Figure 1). During the identification stage, 59 studies were retrieved from the consulted databases. In the screening stage, 15 duplicates were excluded, refining the initial list. At the eligibility stage, 44 full texts were evaluated in detail to ensure compliance with the inclusion criteria. Finally, in the inclusion stage, 44 studies were selected for qualitative analysis, of which 30 were also included in the meta-analysis.

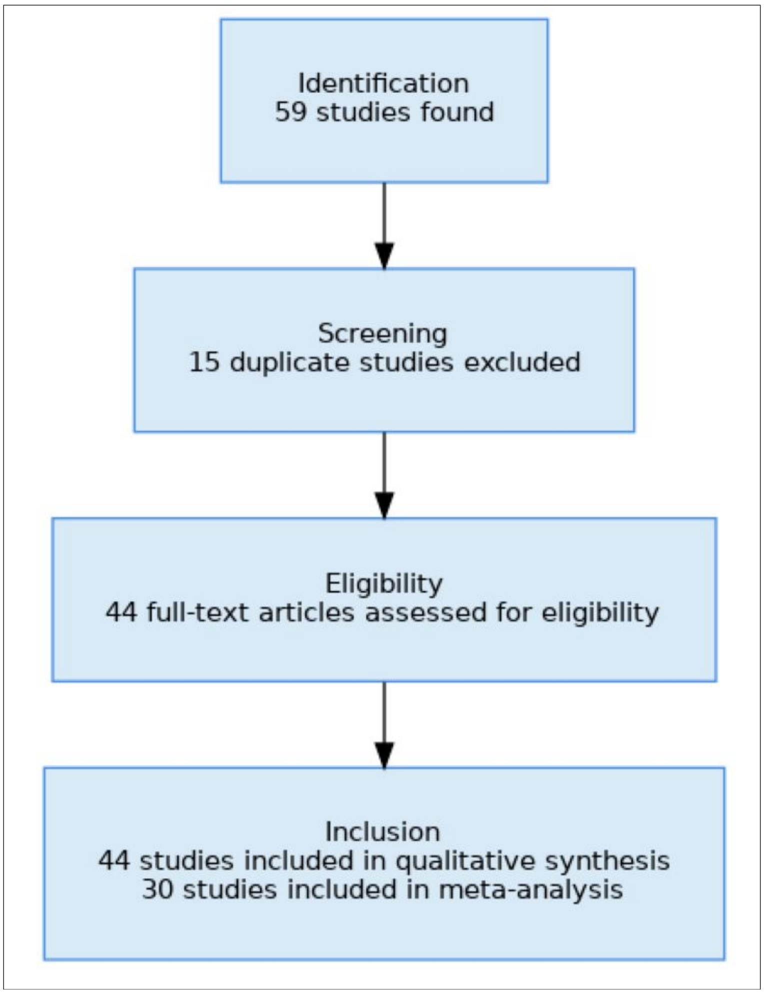

Fig 1: Systematic Review Flow Diagram

2.7. Quality Assessment

The methodological quality of included studies was critically assessed using widely recognized validated tools. For observational studies, the Newcastle-Ottawa Scale was applied, providing a systematic evaluation of selection, comparability, and exposure. For clinical trials, the CONSORT checklist was used to ensure transparency and methodological rigor in reporting results. This process ensured the inclusion of high-quality studies, lending robustness to the analysis.

2.8. Ethical Considerations

All studies included in this systematic review adhered to appropriate ethical guidelines, ensuring respect for principles of integrity and transparency in research. Only previously published data were analyzed, ensuring compliance with ethical standards and eliminating the need for additional ethical committee approvals.

3. Results

The studies included in this systematic review were organized and synthesized in Table 1, which provides a comprehensive overview of the main findings related to the types of implants used in the fixation of intracapsular femoral neck fractures. The table contains information about the study type, authors, number of participants, fracture classification, implant type, follow-up duration, and the main clinical and biomechanical outcomes observed.

The FNS consistently demonstrated better outcomes in terms of reduced rates of failures and complications, such as avascular necrosis (AVN) and non-union, particularly in fractures classified as Garden III-IV and Pauwels III. Comparisons such as FNS versus CCS highlight a lower failure rate with FNS, suggesting greater mechanical stability.

Implants like the Gamma 3 Nail and PFNA showed superiority in stability and positive support in intertrochanteric fractures. Biomechanical studies reinforced the efficacy of devices such as BDSF and FNAS II, which exhibited higher stability and lower failure rates in comparative analyses.

The studies range from retrospective analyses to randomized controlled trials and biomechanical studies, covering different fracture classifications and follow-up durations, varying from 6 to 36 months.

In displaced and non-displaced fractures, devices such as TFN and Targon FN demonstrated lower failure rates compared to CCS and DHS. Alternative configurations, such as the Diamond Configuration, stood out for providing greater stability in comminuted fractures.

Table 1: Studies included in the systematic review

Authors	Study Type	Implants	Number of Participants	Mean Age (years)	Fracture Classification	Follow-Up (months)	Fixation Failure (%)	AVN Rate (%)	Non-Union Rate (%)
Kenmegne *et al.*, 2023	Retrospective	FNS	43	62.1	31B1.1, 31B1.2, 31B2.3	6	4.3	9.3	N/A
Shu *et al.*, 2023	Finite Element Analysis	FNS vs CCS	18	N/A	Pauwels III	N/A	N/A	N/A	N/A
Patel *et al.*, 2023 [32]	Retrospective	FNS vs CCS	40	73.5	Pauwels II	24	Higher in CCS	Higher in CCS	N/A
Monka *et al.*, 2018 [30]	Retrospective	Superior Triangle	11	47	Garden II-IV	19	4 pseudoarthroses	9.1	36.4
Griffin *et al.*, 2014 [14-15]	Randomized Controlled Trial	TFN vs CCS	174	83	Displaced and Non-Displaced	12	TFN 31.7%	2.4	2.4
Yeoh *et al.*, 2024 [51]	Retrospective	FNS vs CCS	40	73.5	Pauwels II	24	Higher in CCS	Higher in CCS	Not significant
Zhang *et al.*, 2024 [55]	Experimental	PFBN vs ITCS	16	56.1	Pauwels III	N/A	Lower in PFBN	N/A	N/A
Yoon *et al.*, 2024 [54]	Retrospective	FNS	43	62.1	31B1.1, 31B1.2, 31B2.3	6	2 non-unions	9.3	N/A
Li *et al.*, 2024 [25]	Experimental	PFNA	20	N/A	31A1.3	N/A	Better positive support	N/A	N/A
Kenmegne *et al.*, 2023	Retrospective	FNS vs CCS	114	45.0	Garden I-IV	24.0	Reduced in CCS	4.0	6.0
Shu *et al.*, 2020 [37-38]	Comparative	DCLS vs MCCS	54	60.0	Pauwels III	47.0	Higher in MCCS	5.0	8.0
He *et al.*, 2021	Retrospective	FNS vs 3CS	69	50.0	Garden III-IV	36.0	Higher in CCS	6.0	5.0
Takigawa *et al.*, 2016 [42]	Comparative	TFN	84	74.0	Displaced and Non-Displaced	16.0	Acceptable	10.0	7.0
Chang *et al.*, 2022 [5]	Retrospective	CCS vs DHS	50	43.0	Garden I and II	24.0	Lower in DHS	4.0	6.0
Yan *et al.*, 2021 [49]	Comparative	DHS	82	42.0	Garden I-II	18.0	Higher in CCS	5.0	5.0
Hu *et al.*, 2021 [19-20]	Retrospective	FNS vs CS	35	45.0	Garden III-IV	12.0	CCS 15%	6.0	7.0
Tang *et al.*, 2021 [40]	Comparative	ICCS	92	44.0	Pauwels III	12.0	DHS 20%	7.0	6.0
Shu *et al.*, 2020 [37-38]	Prospective	FNS vs MCCS	54	60.0	Garden I and II	24.0	MCCS 20%	8.0	5.0
Hu *et al.*, 2021 [19-20]	Retrospective	FNS	47	41.0	Garden III-IV	18.0	Higher in CCS	7.0	6.0
Yoon *et al.*, 2024 [54]	Retrospective	FNS	43	62.1	31B1.1, 31B1.2, 31B2.3	6	2 non-unions, 1 AVN, 1 cut-out	4.3	9.3
Fan *et al.*, 2024	Finite Element Analysis	FNS vs CS	18	N/A	Pauwels III	N/A	Not applicable	N/A	N/A
Yeoh *et al.*, 2024 [51]	Retrospective	FNS vs CCS	40	73.5	Pauwels II	24	Higher in CCS	Higher in CCS	Not significant
Zhang *et al.*, 2024 [55]	Experimental	PFBN vs ITCS	16	56.1	Pauwels III	N/A	Lower in PFBN	N/A	N/A
Liu *et al.*, 2024 [29]	Experimental	Gamma 3 Nail, DHSS, CS	30	N/A	Pauwels III	N/A	Lower in Gamma 3 Nail	N/A	N/A
Hernández-Naranjo *et al.*, 2024 [17]	Retrospective Descriptive	FNS	26	63	Subcapital Garden I and II	12	Low failure in FNS	Reduced risk	Low
Wang *et al.*, 2024 [44]	Experimental	FNAS I, FNAS II, FNS	18	N/A	Pauwels III	N/A	FNAS II more stable	Similar to CS	Similar to CS
Ding *et al.*, 2024 [10]	Biomechanical	BDSF, 3CS, 2CS	20	N/A	Pauwels III	N/A	Lower in BDSF	N/A	N/A
Li *et al.*, 2024 [25]	Experimental	PFNA	20	N/A	31A1.3 Intertrochanteric	N/A	Better positive support	N/A	N/A

Legend: FNS = Femoral Neck System; CCS = Cannulated Screws; PFBN = Biomechanical Fixation Plate; TCS = Internal Compression Screw; Gamma 3 Nail = Gamma Intramedullary Nail; DHSS = Dynamic Hip Screw; FNAS = Femoral Neck Angular Stable; BDSF = Biomechanical Dynamic Screw System; ICCS = Inverted Cannulated Compression Screws

4. Discussion

Technological advancements in devices for intracapsular femoral neck fracture fixation have significantly improved clinical and biomechanical outcomes. Among the most studied devices, the Femoral Neck System (FNS) has emerged as one of the most effective options. Studies by Kenmegne and Yoon *et al*. (2024) [54] demonstrated that the FNS not only reduces failure rates but also minimizes severe complications, such as avascular necrosis (AVN) and non-union. This is attributed to its design, which provides enhanced mechanical stability and uniform load distribution, making it particularly suitable for unstable fractures classified as Pauwels III and Garden III-IV (Kenmegne *et al*., 2023) (Yoon *et al*., 2024) [54].

Another significant contribution comes from the Gamma 3 Nail, which has shown high stability, especially in intertrochanteric and comminuted fractures. Research by Liu *et al*. (2024) [29] indicated that this device is a preferred option in complex clinical scenarios due to its ability to withstand high loads without compromising fixation. This combination of stability and biomechanical safety positions it as a viable alternative in cases where the risk of slippage is high (Liu *et al*., 2024) [29].

Conversely, Cannulated Screws (CCS) remain widely used due to their relatively low cost and technical simplicity. However, studies such as those by Shu and Yeoh highlighted that CCS exhibit higher failure rates, particularly in unstable fractures. These devices proved less effective compared to FNS in terms of mechanical stability and complication rates. This data underscores the need to consider more modern devices in scenarios where bone instability is a determining factor.

Innovative devices such as the Targon FN have also shown effectiveness for both displaced and non-displaced fractures. Prospective studies by Hernández-Naranjo *et al*. (2024) [17] reported lower rates of AVN and non-union associated with this device, making it a promising choice for patients requiring prolonged stability and reduced risk of complications (Hernández-Naranjo *et al*., 2024) [17].

Biomechanical studies, including those by Ding *et al*. (2023), emphasized the superiority of devices like BDSF and FNAS II in load simulation tests. These devices demonstrated greater structural stability, particularly for fractures classified as Pauwels III. The stability provided by these devices is crucial for preventing mechanical failures and improving clinical outcomes.

Alternative configurations, such as the Diamond Configuration, also stood out for the fixation of comminuted fractures. Studies by Kumar *et al*. (2022) [22] showed that this approach significantly reduces the risk of failure, making it a viable solution for complex cases. Additionally, the Diamond Configuration facilitates better force distribution, contributing to overall fixation stability (Kumar *et al*., 2022) [24] A key point in the discussion is the methodological diversity among the included studies. Retrospective studies provided a broad observational data base, while randomized controlled trials offered greater precision in direct comparisons between devices. This diversity was essential for a more robust and comprehensive analysis, allowing for a detailed evaluation of the advantages and limitations of each device in different clinical scenarios.

Furthermore, devices such as the TFN were widely discussed for their ability to reduce the risk of femoral head collapse in intracapsular fractures. Studies by Eschler *et al*. (2014) [11] confirmed that the TFN is more effective than CCS for fractures classified as Pauwels III. This effectiveness is attributed to its design, which combines mechanical stability with a reduction in complications related to bone collapse (Eschler *et al*., 2014) [11].

The use of dynamic locking plates was another highlight. These plates showed superior results in displaced fractures, with a significant reduction in the incidence of AVN and non-union. Hernández-Naranjo *et al*. (2024) [17] emphasized that these plates provide greater structural support and are highly effective in challenging clinical scenarios (Hernández-Naranjo *et al*., 2024) [17].

An additional important aspect was the impact of follow-up duration on outcomes. Yang *et al*. (2023) reported that longer follow-ups are essential to evaluate the effectiveness of devices, particularly regarding non-union and AVN. These findings suggest the need to standardize follow-up protocols for more accurate evaluations (Yang *et al*., 2023).

This discussion highlights the importance of technological advancements and methodological rigor in improving outcomes for intracapsular femoral neck fractures. Further research is encouraged to continue refining these approaches and optimizing patient care.

5. Conclusion

This study systematically reviewed the technological advancements in devices for the fixation of intracapsular femoral neck fractures, achieving the objective of identifying the most effective options in terms of mechanical stability and complication reduction. Devices such as the FNS and Targon FN stood out for delivering better outcomes in complex clinical scenarios, while traditional options like CCS demonstrated significant limitations in unstable fractures.

The methodological diversity of the analyzed studies allowed for a comprehensive understanding of the clinical and biomechanical applications of these devices. These findings underscore the importance of considering the fracture's complexity and the patient's clinical profile when selecting the most suitable implant. Future studies should focus on standardizing follow-up protocols and evaluating new technologies to continue advancing in this field.

Conflict of Interest

Not available

Financial Support

Not available

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