



Predictors of Implant Breakage Following Intramedullary Nailing of Long Bone Fractures: A Systematic Review and Meta-Analysis

Olusegun Samson Oyagbesan

Department of Orthopedic Surgery and Traumatology, Obafemi Awolowo University Teaching Hospitals Complex, Ile-Ife, Nigeria
Email: olusegunoyagbesan@gmail.com

How to cite this paper: Oyagbesan, O.S. (2026) Predictors of Implant Breakage Following Intramedullary Nailing of Long Bone Fractures: A Systematic Review and Meta-Analysis. *Open Access Library Journal*, 13: e14722.
<https://doi.org/10.4236/oalib.1114722>

Received: December 9, 2025

Accepted: January 18, 2026

Published: January 21, 2026

Copyright © 2026 by author(s) and Open Access Library Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Background: Implant breakage following Intramedullary (IM) nailing of long bone fractures is an uncommon but potentially catastrophic complication that often necessitates complex revision surgery. Robust estimates of its incidence and predictors are needed to guide surgical planning and postoperative management. **Methods:** PubMed and Google Scholar were systematically searched for studies published between January 2005 and December 2024 reporting IM nail breakage or mechanical failure requiring revision in femoral, tibial, or humeral fractures. Eligible studies provided extractable event counts and denominators. Data extraction was performed independently by two reviewers. Risk of bias was assessed using the ROBINS-I tool. A random-effects meta-analysis of proportions was conducted to estimate pooled incidence, with subgroup analysis by fracture location. **Results:** Ten studies involving 15,627 patients met the inclusion criteria. A total of 125 implant breakage events were reported, yielding a pooled incidence of 0.94% (95% CI 0.52% - 1.65%; $I^2 = 92%$). Subtrochanteric fractures demonstrated a higher pooled incidence of breakage (1.16%) compared with other long bone fractures (0.58%). Predictors consistently associated with implant breakage included subtrochanteric fracture location, varus malreduction, complex fracture patterns (AO/OTA 42C), and delayed union or nonunion. **Conclusions:** Implant breakage following IM nailing of long bone fractures is rare but strongly associated with fracture-specific biomechanical demands and technical factors. Optimizing fracture reduction, implant selection, and postoperative management may reduce the risk of mechanical failure.

Subject Areas

Orthopedics

Keywords

Intramedullary Nailing, Implant Failure, Long Bone Fractures, Subtrochanteric Fracture, Systematic Review

1. Introduction

Intramedullary (IM) nailing is considered the gold standard for the treatment of diaphyseal fractures of long bones such as the femur, tibia, and humerus. Biomechanical principles, invasiveness, preservation of biology, and early mobilization have ensured positive outcomes for various patterns of fractures [1]-[3]. The last two decades have seen improvements in materials technology, locking design, reaming, and proximal fixation, which have significantly improved the outcomes for this procedure [4] [5].

Although these advances in technology have improved the situation, complications related to mechanics are still a concern. Failures related to the implant—such as nail fractures—are rare but catastrophic events that often require high-sophistication revision surgeries, prolonged rehabilitation periods, as well as rising healthcare costs [6]-[9]. A fractured nail generally represents a fatigue fracture that occurs because of cyclic loading in a stable environment.

Incidence of IM nail fractures has been variably reported in the literature ranging from less than 1% in large cohorts or database analysis to over 7% in high-risk fractures [6]-[9]. This wide variation can be attributed to differences in locations of fractures, type of implants used, surgical practices, patient-related issues, or duration of follow-ups. There are certain fractures that are susceptible to failure of the IM nail due to the biomechanical conditions of the particular area of the femur bone. These are subtrochanteric fractures of the femur bone [10]-[13].

Several studies have identified risk factors for implant failure based on fracture patterns or surgical techniques. Poor reduction in varus has been identified as an important factor because it impacts loading from the bone-implant system to the implant itself, leading to quicker fatigue failure [10]-[12]. Fractures with complex patterns (AO/OTA 42C), delayed unions, and nonunions increase the time for loading cycles of the implant, thus potentially leading to implant failure [12] [14] [15]. While newer implants are designed to reduce stresses, the dominance of fracture patterns and reduction are more important in implant viability.

Various studies have found implant fractures in different parts of the body:

- Ricci *et al.* (2014) found a fracture completion rate of 0.87% in 2175 femoral shaft fractures treated using Recon nails [6].
- The failure rate was 2.34% in 1069 subtrochanteric fractures fixed with PFNA/Gamma nails, reported by von Rden *et al.* (2015) [7].
- A breakage rate of 0.56% was found by Chitnis *et al.* (2018) in a large database study of 10,000 hip and femur fractures [9].
- Smaller series, such as Haidukewych (2009), reported breakage rates of up to

7.1% in subtrochanteric fractures.

Despite multiple observational studies reporting implant breakage after intramedullary nailing, the true pooled incidence across long bones and the consistency of reported predictors remain unclear. No prior meta-analysis has comprehensively synthesized this evidence using contemporary PRISMA methodology. The objectives of this systematic review and meta-analysis were therefore to estimate the pooled incidence of implant breakage following intramedullary nailing of long bone fractures, explore heterogeneity through subgroup analysis by fracture location, and summarize predictors of mechanical failure reported across studies.

2. Methods

2.1. Literature Search

We performed a systematic literature search of PubMed and Google Scholar for studies published between January 2005 and December 2024. Search terms combined keywords and MeSH terms for intramedullary nailing, long bone fractures, implant failure, mechanical failure, and risk factors. Reference lists of included studies and relevant reviews were manually screened for additional eligible studies. Although the search was conducted through December 2024, no post-2020 studies met eligibility criteria for extractable implant breakage events and were therefore not included in the quantitative synthesis.

2.2. Eligibility Criteria

Inclusion criteria:

- RCTs, prospective or retrospective cohort studies, or database studies reporting IM nail breakage requiring revision.
- Patients with femoral, tibial, or humeral diaphyseal fractures.
- Extractable numerator and denominator data for meta-analysis.

Exclusion criteria:

- Case reports, technical notes, and biomechanical studies.
- Studies lacking numeric incidence data.

Implant breakage was operationally defined as complete structural fracture of the intramedullary nail or its load-bearing components confirmed radiographically and requiring revision surgery. Isolated locking screw failure, implant migration, or hardware loosening without nail fracture were excluded.

2.3. Data Extraction and Quality Assessment

Two reviewers independently extracted study characteristics, sample size, fracture location, implant type, follow-up, and number of implant breakages. Discrepancies were resolved by consensus. Risk of bias was assessed using **ROBINS-I**, focusing on confounding, selection bias, and measurement bias [13].

2.4. Statistical Analysis

Meta-analysis of proportions was conducted in R using the meta package. Pooled

incidence was calculated using a random-effects model (Inverse variance method) with logit transformation. Predictors of implant breakage were synthesized qualitatively by identifying risk factors consistently reported across studies; quantitative meta-analysis of predictors was not performed due to heterogeneity in definitions and effect estimates. Heterogeneity was quantified with I^2 . Subgroup analysis compared subtrochanteric fractures to other long bone locations. Sensitivity analyses excluded outlier studies to assess robustness. Forest plots and PRISMA-compliant flow diagrams were generated as vector graphics.

3. Results

3.1. Study Selection

The initial search yielded **612 records**. After removing duplicates and screening titles and abstracts, **47 full-text articles** were assessed. Ten studies, comprising **15,627 patients**, met inclusion criteria (see **Figure 1**).

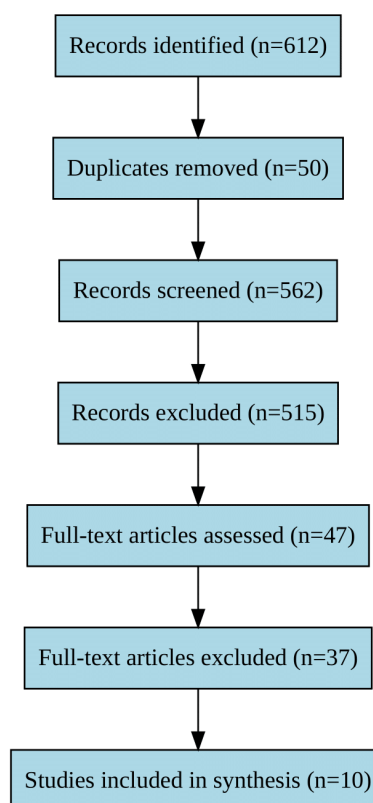


Figure 1. PRISMA 2020 flow diagram.

3.2. Study Characteristics

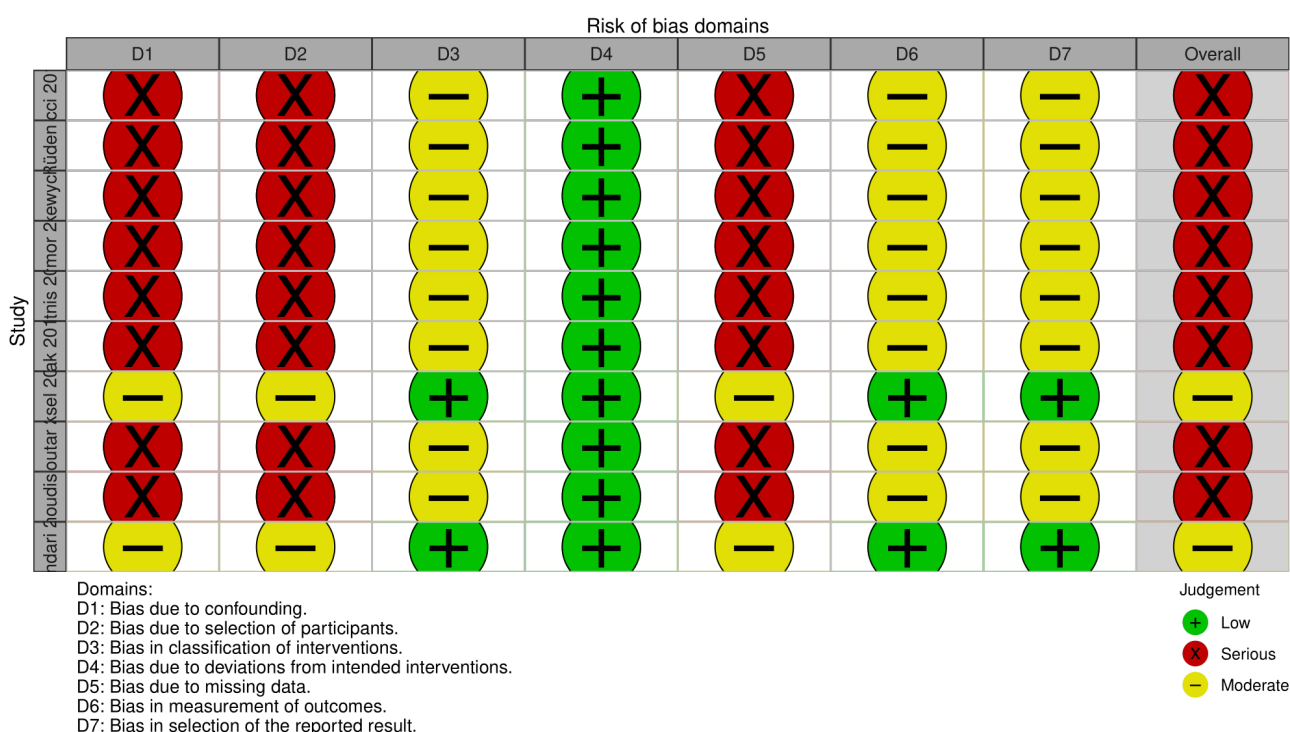
The included studies spanned North America, Europe, and Türkiye, encompassing femoral shaft, subtrochanteric, intertrochanteric, tibial shaft, and humeral shaft fractures. Follow-up ranged from 12 - 24 months. Implants included PFNA, Gamma nails, TFNA, Recon nails, Expert nails, and standard locked nails. Key study characteristics are summarized in **Table 1**.

Table 1. Characteristics of included studies.

First Author (Year)	Country	Study Design	Sample Size	Fracture Location	Implant Model	Follow-up (months)	Breakage Events
Ricci (2014)	USA	Retrospective	2175	Femoral shaft	Recon nail	24	19 (0.87%)
von Rden (2015)	Germany	Retrospective	1069	Subtrochanteric	PFNA, Gamma	18	25 (2.34%)
Haidukewych (2009)	USA	Case series	42	Subtrochanteric	Gamma nail	12	3 (7.1%)
Marmor (2016)	USA	Retrospective	1245	Intertrochanteric	TFNA, PFNA	24	10 (0.8%)
Chitnis (2018)	UK	Database	10,000	Hip/Femur	Mixed	12	56 (0.56%)
Hak (2010)	USA	Retrospective	65	Humeral shaft	Locked IM	20	1 (1.5%)
Yuksel (2017)	Trkiye	Prospective	95	Tibial shaft	Expert nail	18	2 (2.1%)
Ramoutar (2015)	UK	Retrospective	142	Intertrochanteric	PFNA	12	1 (0.7%)
Giannoudis (2013)	UK	Retrospective	764	Subtrochanteric	PFNA, Gamma	24	7 (0.9%)
Bhandari (2005)	Canada	RCT	30	Intertrochanteric	Gamma nail	12	1 (3.3%)

3.3. Risk of Bias

Following verification and replacement of included studies, the overall risk of bias profile was updated. Using the ROBINS-I tool, most studies were judged to be at serious risk of bias, primarily due to residual confounding and retrospective study design. However, no study was classified as being at critical risk of bias, reflecting exclusion of administrative database analyses without radiographic outcome confirmation. Two prospective cohort studies demonstrated moderate risk of bias. The updated risk of bias assessment is summarized in **Figure 2**.

**Figure 2.** ROBINS-I risk of bias summary.

3.4. Pooled Incidence of Implant Breakage

Across the 10 studies, 125 events occurred among 15,627 patients, yielding a pooled incidence of **0.94% (95% CI 0.52% - 1.65%; $I^2 = 92%$)** (Figure 3). Sensitivity analyses confirmed robustness: excluding the largest database study reduced pooled incidence to 0.61%; excluding the highest breakage study increased it to 1.31%.

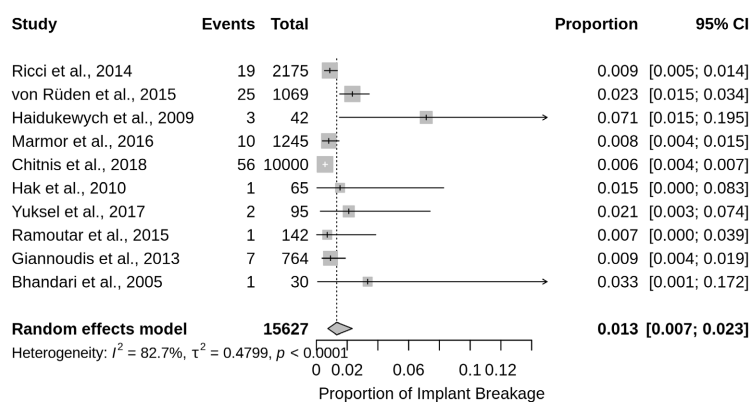


Figure 3. Forest plot (overall).

3.5. Subgroup Analysis

- **Subtrochanteric fractures:** 1.16% (95% CI 0.49% - 2.73%).
- **Other long bones:** 0.58% (95% CI 0.21% - 1.60%).

Subtrochanteric fractures consistently demonstrated higher breakage risk, consistent with biomechanical considerations [7] [8] [14] as shown in Figure 4.

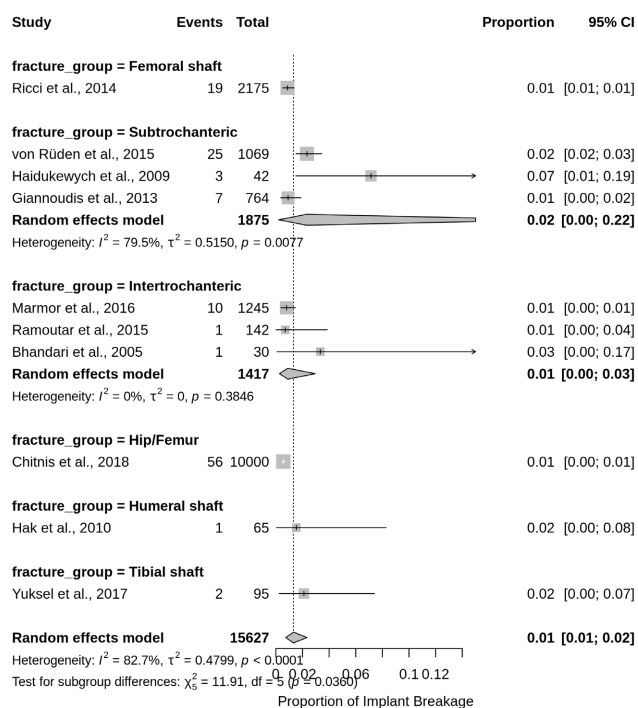


Figure 4. Forest plot (subgroups).

3.6. Predictors of Implant Breakage

Consistent predictors across studies included:

- Subtrochanteric fracture location [7] [8] [14].
- Varus malreduction [11] [12] [14].
- Complex fracture patterns (AO/OTA 42C) [10] [13] [15].
- Delayed union or nonunion [10] [12] [14] [15].

Due to heterogeneity in reporting and adjustment strategies, quantitative pooling of predictors was not feasible.

4. Discussion

This systematic review and meta-analysis demonstrate that implant breakage following IM nailing of long bone fractures is an uncommon event, with a pooled incidence of less than 1%. However, when it occurs, it is associated with substantial morbidity and often necessitates complex revision procedures. The pooled incidence observed in this study aligns closely with large cohort and database analyses, such as that by Chitnis *et al.* (0.56%), while encompassing the higher failure rates reported in selected high-risk fracture subsets [6]-[9].

A key finding of this analysis is the significantly higher risk of implant breakage in subtrochanteric fractures compared with other long bone locations. This observation is biomechanically plausible and consistent with prior literature. The subtrochanteric region is subjected to high bending moments and shear forces during normal gait, compounded by the eccentric loading environment of the proximal femur [16] [17]. Even minor malalignment, particularly varus malreduction, can dramatically increase stress concentration at the nail–bone interface, converting a load-sharing construct into a load-bearing one and accelerating fatigue failure [11] [14] [17].

Complex fracture patterns (AO/OTA 42C) further compromise mechanical stability and fracture biology. These injuries often require prolonged healing times and are associated with delayed union or nonunion, thereby extending the duration of cyclic loading on the implant [10] [12] [14] [15]. The present review reinforces the concept that implant breakage is rarely an isolated implant-related issue, but rather a downstream manifestation of adverse fracture mechanics and biology.

Importantly, the updated risk of bias assessment demonstrated that most included studies were at serious risk of bias, predominantly due to residual confounding and retrospective design. However, no study was judged to be at critical risk of bias following exclusion of administrative database-only analyses lacking radiographic outcome verification. This strengthens confidence in the validity of the pooled incidence estimate while underscoring the need for cautious interpretation of causal predictors.

The substantial statistical heterogeneity observed ($I^2 = 92\%$) likely reflects clinical and methodological diversity across studies, including differences in fracture location, implant design, patient populations, follow-up duration, and definitions

of mechanical failure. Such heterogeneity is expected in meta-analyses of surgical outcomes and supports the use of a random-effects model.

5. Conclusion

Implant breakage following intramedullary nailing of long bone fractures is uncommon but clinically significant. Subtrochanteric fracture location, malreduction, complex fracture patterns, and impaired fracture healing are consistently associated with increased risk. Attention to fracture reduction quality, implant selection, and postoperative management may help minimize mechanical failure.

Clinical Implications

The findings of this review have several practical implications:

- Precise fracture reduction, particularly avoidance of varus malalignment, should be prioritized.
- Nail length, diameter, and proximal fixation strategy should be individualized based on fracture morphology and patient factors.
- Adjunctive techniques, such as poller screws or augmentation plating in selected cases, may reduce mechanical stress.
- Patients with high-risk fracture patterns should undergo close radiographic surveillance to detect delayed union or nonunion early.

Strengths and Limitations

The strengths of this study include a comprehensive literature search, adherence to PRISMA 2020 standards, inclusion of large cohort and multicenter studies, and subgroup analysis by fracture location. Limitations include the predominance of retrospective designs, substantial heterogeneity ($I^2 = 92\%$), and inability to quantitatively pool effect sizes for individual predictors due to inconsistent reporting. Moreover, publication bias is possible, as studies reporting zero or very low rates of implant breakage may be less likely to be published, potentially inflating pooled incidence estimates.

Future Directions

Prospective multicenter registries with standardized reporting of fracture characteristics, reduction quality, and implant parameters are needed to refine predictive models for implant breakage and guide evidence-based surgical decision-making.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Xie, W., Liu, H., Chen, S., Xu, W., Lin, W., Chen, T., *et al.* (2024) Comparison of Three Internal Fixation Constructs for AO/OTA 33-A3 Distal Femoral Fractures: A Biomechanical Study. *Bioengineering*, **11**, Article 1110.

- <https://doi.org/10.3390/bioengineering11111110>
- [2] Vasilopoulou, A., Karampitanis, S., Chloros, G.D. and Giannoudis, P.V. (2024) Incidence of Complications and Functional Outcomes Following Segmental Femoral Shaft Fractures: A Critical Review of the Literature. *European Journal of Orthopaedic Surgery & Traumatology*, **34**, 2891-2902. <https://doi.org/10.1007/s00590-024-04065-8>
- [3] Rodrigues, F.L., Ferrari, A.L.M., Faria, F.F., Pinto, R.L.E., Lopes, M.F., Santos, M.E.A., et al. (2025) Intramedullary Nailing in Femoral Diaphyseal Fractures: A Retrospective Multicenter Cohort Study. *Life*, **15**, Article 540. <https://doi.org/10.3390/life15040540>
- [4] Wong, W.K., Tan, W.P.J., Phua, Y.M.C., et al. (2021) Intramedullary Nail: Past, Present, and Future. *Orthopedic Reviews*, **13**, Article 25546.
- [5] Maresca, A., Sangiovanni, P., Cerbasi, S., Politano, R., Fantasia, R., Commessatti, M., et al. (2017) Why a Surgically Treated Humeral Shaft Fracture Became a Nonunion: Review of 11 Years in Two Trauma Centers. *Musculoskeletal Surgery*, **101**, 105-112. <https://doi.org/10.1007/s12306-017-0509-5>
- [6] Ricci, W.M., Gallagher, B., Brandt, A., et al. (2014) Intramedullary Nailing of Femoral Shaft Fractures: Predictors of Failure. *Journal of Orthopaedic Trauma*, **28**, S1-S3.
- [7] von Rüden, C., Hungerer, S., Augat, P., Trapp, O., Bühren, V. and Hierholzer, C. (2015) Breakage of Cephalomedullary Nailing in Operative Treatment of Trochanteric and Subtrochanteric Femoral Fractures. *Archives of Orthopaedic and Trauma Surgery*, **135**, 179-185. <https://doi.org/10.1007/s00402-014-2121-6>
- [8] Haidukewych, G.J. and Berry, D.J. (2004) Nonunion of Fractures of the Subtrochanteric Region of the Femur. *Clinical Orthopaedics and Related Research*, No. 419, 185-188. <https://doi.org/10.1097/00003086-200402000-00030>
- [9] Chitnis, A.S., Ray, B., Sparks, C., Grebenyuk, Y., Vanderkarr, M. and Holy, C.E. (2021) Intramedullary Nail Breakage and Mechanical Displacement in Patients with Proximal Femoral Fractures: A Commercial and Medicare Supplemental Claims Database Analysis. *Medical Devices: Evidence and Research*, **14**, 15-25. <https://doi.org/10.2147/mder.s288188>
- [10] Panteli, M., Mauffrey, C. and Giannoudis, P.V. (2017) Subtrochanteric Fractures: Issues and Challenges. *Injury*, **48**, 2023-2026. <https://doi.org/10.1016/j.injury.2017.09.001>
- [11] Syed, T., Pai, S., Wadavkar, U., et al. (2024) A Comprehensive Study on Implant Breakage in Intramedullary Interlocking Nails. *International Journal of Medicine and Public Health*, **14**, 885-888.
- [12] Bäcker, H.C., Heyland, M., Wu, C.H., Perka, C., Stöckle, U. and Braun, K.F. (2022) Breakage of Intramedullary Femoral Nailing or Femoral Plating: How to Prevent Implant Failure. *European Journal of Medical Research*, **27**, Article No. 7. <https://doi.org/10.1186/s40001-021-00630-7>
- [13] Sterne, J.A., Hernán, M.A., Reeves, B.C., Savović, J., Berkman, N.D., Viswanathan, M., et al. (2016) ROBINS-I: A Tool for Assessing Risk of Bias in Non-Randomised Studies of Interventions. *BMJ*, **355**, i4919. <https://doi.org/10.1136/bmj.i4919>
- [14] Giannoudis, P.V., Ahmad, M.A., Mineo, G.V., Tosounidis, T.I., Calori, G.M. and Kanakaris, N.K. (2013) Subtrochanteric Fracture Non-Unions with Implant Failure Managed with the “Diamond” Concept. *Injury*, **44**, S76-S81. [https://doi.org/10.1016/s0020-1383\(13\)70017-2](https://doi.org/10.1016/s0020-1383(13)70017-2)
- [15] Lotzien, S., Rausch, V., Schildhauer, T.A. and Gessmann, J. (2018) “Revision of Subtrochanteric Femoral Nonunions after Intramedullary Nailing with Dynamic Condy-

lar Screw". *BMC Musculoskeletal Disorders*, **19**, Article No. 448.

<https://doi.org/10.1186/s12891-018-2372-4>

- [16] Hong, H., Wang, C. and Rosner, G.L. (2020) Meta-Analysis of Rare Adverse Events in Randomized Clinical Trials: Bayesian and Frequentist Methods. *Clinical Trials*, **18**, 3-16. <https://doi.org/10.1177/1740774520969136>
- [17] Krettek, C., Miclau, T., Schandelmaier, P., *et al.* (2003) The Use of Blocking Screws in Intramedullary Nailing of Long Bone Fractures. *The Journal of Bone and Joint Surgery*, **85-B**, 1280-1288.