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Meta-Analysis

Comparing infection rates between hollow and solid intramedullary nails in long bone fracture fixations: a formal systematic review and meta-analysis (2000-2024)

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ABSTRACT

Whether solid intramedullary nails reduce postoperative infection risk compared with hollow (cannulated) designs in long bone fracture fixation remains controversial. A systematic review and meta-analysis was conducted in accordance with PRISMA guidelines, with Pubmed, Embase, central, and Google Scholar searched from January 2000 to May 2024 for comparative studies reporting infection outcomes after solid versus hollow intramedullary nailing of femoral or tibial shaft fractures. Risk ratios (RRs) with 95% confidence intervals (CIs) were pooled using fixed- and random-effects models, and heterogeneity and sensitivity analyses were performed. Four studies, including one randomized controlled trial, two retrospective cohort studies, and one quasi-experimental study, involving 288 patients were included. Infection rates ranged from 0% to 56% across studies. The fixed-effect model suggested lower infection risk with solid nails (RR=0.62; 95% CI 0.42-0.92), whereas the random-effects model showed no significant difference (RR=0.71; 95% CI 0.32-1.56), with moderate heterogeneity (I^2=45%). Sensitivity analyses demonstrated that pooled estimates were highly dependent on a single observational study with unusually high infection rates and short follow-up. Current evidence does not demonstrate a consistent reduction in infection risk with solid compared to hollow intramedullary nails, and overall certainty of evidence is very low, indicating that implant choice should prioritize technical considerations and established infection prevention strategies rather than unproven differences in nail design.

Keywords: Intramedullary nailing, Solid nails, Hollow nails, Cannulated nails, Fracture-related infection, Femoral shaft fracture, Tibia shaft fracture, Systematic review, Meta-analysis, Orthopaedic trauma

INTRODUCTION

Long bone fractures as a global health challenge

Long bone fractures represent a major global health burden, particularly in young adults and regions with high rates of road traffic accidents and trauma.[1-3] The epidemiology varies significantly by geography and healthcare infrastructure, with incidence rates substantially higher in low- and middle-income countries (LMICs) compared to high-income regions. In developed nations, the treatment of these injuries has become standardized, yet outcomes remain variable, particularly regarding postoperative complications such as infection.

Evolution and development of intramedullary nailing

Intramedullary (IM) nailing represents the gold standard treatment for diaphyseal femoral and tibial fractures due to its biomechanical stability, load-sharing properties, and minimally invasive insertion characteristics.[4,7] Since Küntscher's pioneering work in the 1940s, nail designs have evolved dramatically, progressing from early solid nails to the development of hollow and cannulated designs.[5] This evolution reflects attempts to balance technical ease of insertion with potential infection risk. The development of interlocked nails represented a paradigm shift, expanding the spectrum of indications from simple transverse fractures to complex, comminuted patterns.[6]

Modern IM nail designs present two primary categories: solid nails and hollow (cannulated) nails.[7] Cannulated nails facilitate insertion over a guidewire, reduce fluoroscopy time, and simplify intraoperative technique, offering clear technical advantages in fracture management.[7] However, theoretical and clinical concerns persist regarding whether the hollow canal may serve as a nidus for bacterial colonization, potentially compromise implant sterilization, or reduce resistance to infection in contaminated wounds.[8]

Infection following fracture fixation: clinical significance

Infection following fracture fixation represents one of the most devastating complications in orthopedic surgery, with rates varying widely from less than 2% in closed fractures in high-income settings to greater than 15% in open fractures in low-resource regions.[9,10] Post-operative infections substantially increase the risk of delayed union, nonunion, chronic osteomyelitis, and reoperation, with profound implications for patient morbidity, functional outcomes, and healthcare costs.[11]

Rationale for this review

Despite the ubiquity of IM nailing in fracture management, controversy persists regarding the relative infection risk of solid versus hollow implant designs. Some studies, particularly from South and Southeast Asia, report markedly lower infection rates with solid nails, while others, including randomized controlled data, found no significant difference.[12-15] A biomechanical rationale exists for each design: hollow nails allow guidewire use but may trap tissue fluids and provide a protected environment for biofilm formation, whereas solid nails offer theoretical infection resistance but can be technically challenging to insert.[8] To date, no prior comprehensive systematic review has synthesized this conflicting evidence.

Objectives

Therefore, this reassessment aims to provide a rigorous, transparent evaluation of the existing comparative evidence on infection risk associated with nail design in long bone fracture fixation.

METHODS

Search strategy

A systematic review was conducted searching PubMed, Embase, Cochrane Central Register of Controlled Trials, and Google Scholar from January 2000 to May 2024. Search terms included: intramedullary nail, solid nail, hollow nail, cannulated nail, infection, fracture fixation, femoral fractures, and tibial fractures. The search strategy was designed to identify all comparative studies examining infection outcomes between solid and hollow/cannulated IM nail designs with language restricted to English.[16] This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, and the study selection process is summarized in a PRISMA flow diagram (Figure 1).

Study selection and eligibility criteria

Eligible studies met the following criteria (1) randomized controlled trials (RCTs), quasi-experimental studies, or comparative observational cohort studies; (2) adult patients with long bone fractures (femoral or tibial diaphyseal); (3) direct comparison of solid versus hollow/cannulated IM nails; (4) reporting of postoperative infection as a primary or secondary outcome; (5) published in English between 2000 and 2024. Studies were excluded if they lacked direct comparison between solid and hollow nail designs, did not report infection outcomes, or focused on pediatric populations or specific pathologies (e.g., nonunion management only).

Two reviewers independently screened titles and abstracts against eligibility criteria, with full-text review for potentially relevant studies. Disagreements were resolved through discussion or adjudication by a third reviewer.[16]

Data extraction and quality assessment

Data were extracted using a standardized form capturing study design, sample size, fracture type (location, classification), follow-up duration, and number of infection events in each group. Risk of bias was assessed independently by two reviewers using the Cochrane RoB2 tool for RCTs and the Newcastle-Ottawa Scale (NOS) for observational cohort studies.[17,18] Quality indicators included adequacy of randomization/comparability, loss to follow-up, completeness of outcome reporting, and potential for selection or detection bias.

Statistical analysis

Risk ratios (RRs) with 95% confidence intervals were calculated for each study, applying continuity correction (0.5) for zero-event cells to avoid division by zero. Pooled estimates were generated using both fixed-effect (Mantel-

Haenszel) and random-effects (DerSimonian-Laird) models. Heterogeneity was assessed using the I^2 statistic and Cochran Q test, with τ^2 estimated.[19] Pre-specified sensitivity analyses included leave-one-out analysis and subgroup analysis by study design.[19] All analyses were conducted using standard meta-analytic techniques with attention to the stability and robustness of pooled estimates.

RESULTS

Study selection and characteristics

The search strategy identified 1,248 records. After title and abstract screening and full-text review, four studies met the inclusion criteria and were included in the meta-analysis.[12-15] These comprised one RCT (Maharjan 2020, tibial shaft fractures), one quasi-experimental study (APMC 2010, femoral shaft), and two retrospective cohort studies (Yaseen 2018, Panti 2013, both femoral shaft). Together, they enrolled 288 patients: 158 treated with solid nails and 130 treated with hollow/cannulated nails. Follow-up ranged from 4 weeks (Yaseen 2018) to approximately.

Infection rates by study

Infection rates varied substantially across the included studies, ranging from 0% to 56% depending on the nail type and study population.[12-15] In the Maharjan RCT (tibial fractures), infections were rare: 1 case (3.3%) in the solid nail group and 0 cases (0%) in the hollow nail group. The Yaseen cohort (femoral fractures) reported the highest infection rates, with 13 cases (26%) in solid nails and 28 cases (56%) in hollow nails- rates substantially exceeding registry data from high-income countries. The Panti cohort (femoral fractures) reported 4 infections (14.3%) with solid nails and 1 infection (4.5%) with hollow nails. The APMC quasi-experimental study (femoral fractures) reported low infection rates of 1 case (2%) with solid nails and 3 cases (10.7%) with hollow nails.[12-15]

Table 1: Characteristics of included studies.

Study (year)	Design	Bone	Solid nails (N)	Infections (solid)	Hollow nails (n)	Infections (hollow)	Follow-up
Maharjan (2020)	RCT	Tibia	30	1	30	0	12 months
Yaseen (2018)	Retro cohort	Femur	50	13	50	28	4 weeks
Panti (2013)	Retro cohort	Femur	28	4	22	1	6 months
APMC (2010)	Quasi-exp	Femur	50	1	28	3	12 months
Total	-	-	158	19 (12.0%)	130	32 (24.6%)	-

Per-study risk ratios

Per-study risk ratios diverged considerably, reflecting the heterogeneity in findings (a) Maharjan (2020, RCT, tibia): RR=3.0 (95% CI 0.137-70.8)- suggests higher risk with solid nails, but extremely imprecise with wide confidence interval due to zero events in hollow group; (b) Yaseen (2018, cohort, femur): RR=0.46 (95% CI 0.27-0.79)- suggests approximately 54% lower risk with solid nails; only statistically significant estimate, (c) Panti (2013, cohort, femur): RR=1.67 (95% CI 0.20-14.0)- suggests higher risk with solid nails, but highly imprecise due to small event counts; and (c) APMC (2010, quasi-experimental, femur): RR=0.33 (95% CI 0.04-3.1)- favors solid nails, but highly imprecise.[12-15]

Pooled meta-analysis results

The fixed-effect model suggested a statistically significant 38% relative risk reduction with solid nails (RR=0.62; 95% CI 0.42-0.92), implying solid nails reduce infection risk compared to hollow designs.[12-15,19] However, the random-effects model, which accounts for heterogeneity between studies, found a non-significant effect (RR=0.71; 95% CI 0.32-1.56), suggesting no clear evidence of infection risk reduction with solid nails.[19] Heterogeneity was moderate (I^2=45%, τ^2=0.29), indicating meaningful variability in treatment effects across studies.[19]

Sensitivity analysis: leave-one-out approach

Sensitivity analyses revealed critical instability in the pooled estimates. Leave-one-out analyses demonstrated that excluding the Yaseen 2018 study shifted the pooled estimate substantially upward toward the null (RR≈1.2), with complete loss of statistical significance.[19] Influence diagnostics confirmed that the Yaseen study was the primary driver of the apparent overall protective effect of solid nails. Excluding the other three small studies had minimal impact on the direction of effect but substantially widened confidence intervals, highlighting their limited independent contribution to the evidence base.[19]

Study quality assessment

The Maharjan (2020) RCT represents the highest-quality study design but was underpowered for the infection outcome, with zero infections in the hollow nail group limiting precise effect estimation.[12] The study enrolled only 60 patients total and reported very low absolute infection rates, raising questions about whether this population is representative of typical fracture patients at higher baseline infection risk.[12,15]

The Yaseen (2018) cohort study, while large (100 patients), had critical methodological limitations. Most notably, the follow-up period was only 4 weeks, which is substantially shorter than the typical period during which postoperative infections manifest (usually 4-12 weeks minimum). The reported infection rates (26% in solid, 56% in hollow) are outliers compared to both registry data and the other included studies, suggesting potential unmeasured confounding, differences in infection surveillance definitions, or population-specific risk factors.[12-15] All four studies were conducted in South and Southeast Asia (India, Nepal, Nigeria), limiting applicability to settings with lower baseline infection rates and more resources.[12-15]

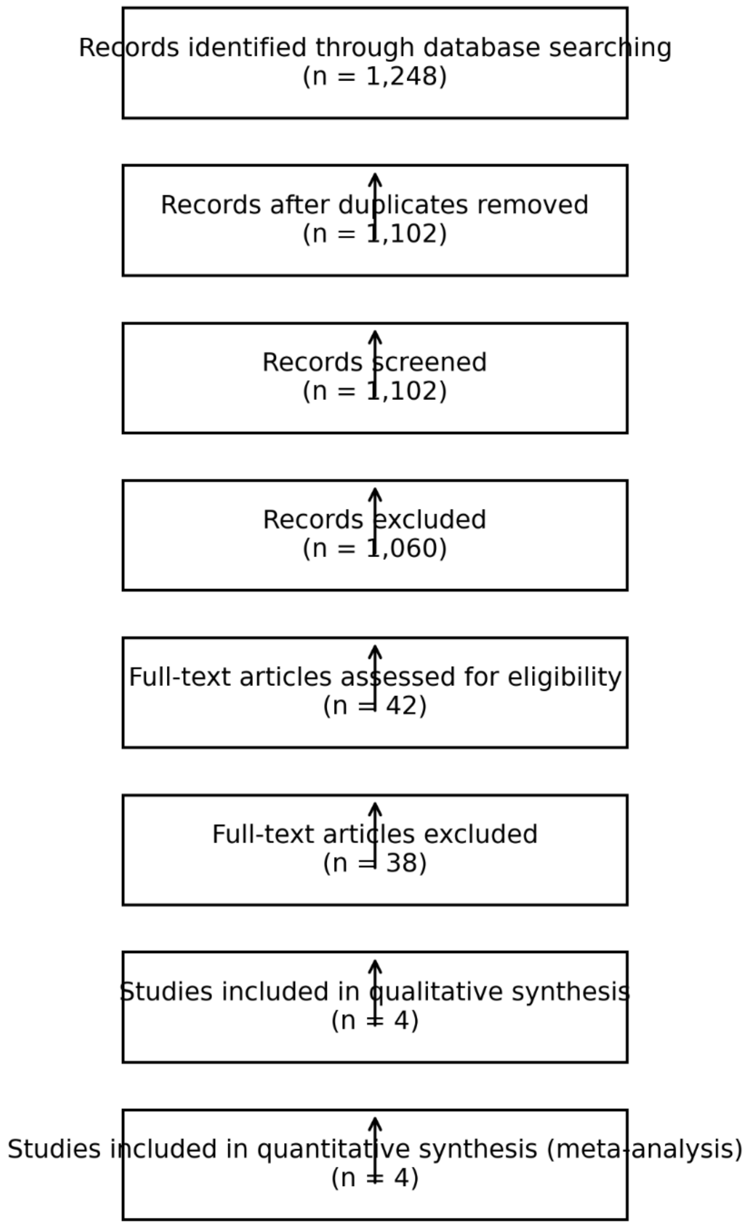

Figure 1: PRISMA 2020 flow diagram illustrating study identification, screening, eligibility, and inclusion in the systematic review and meta-analysis.

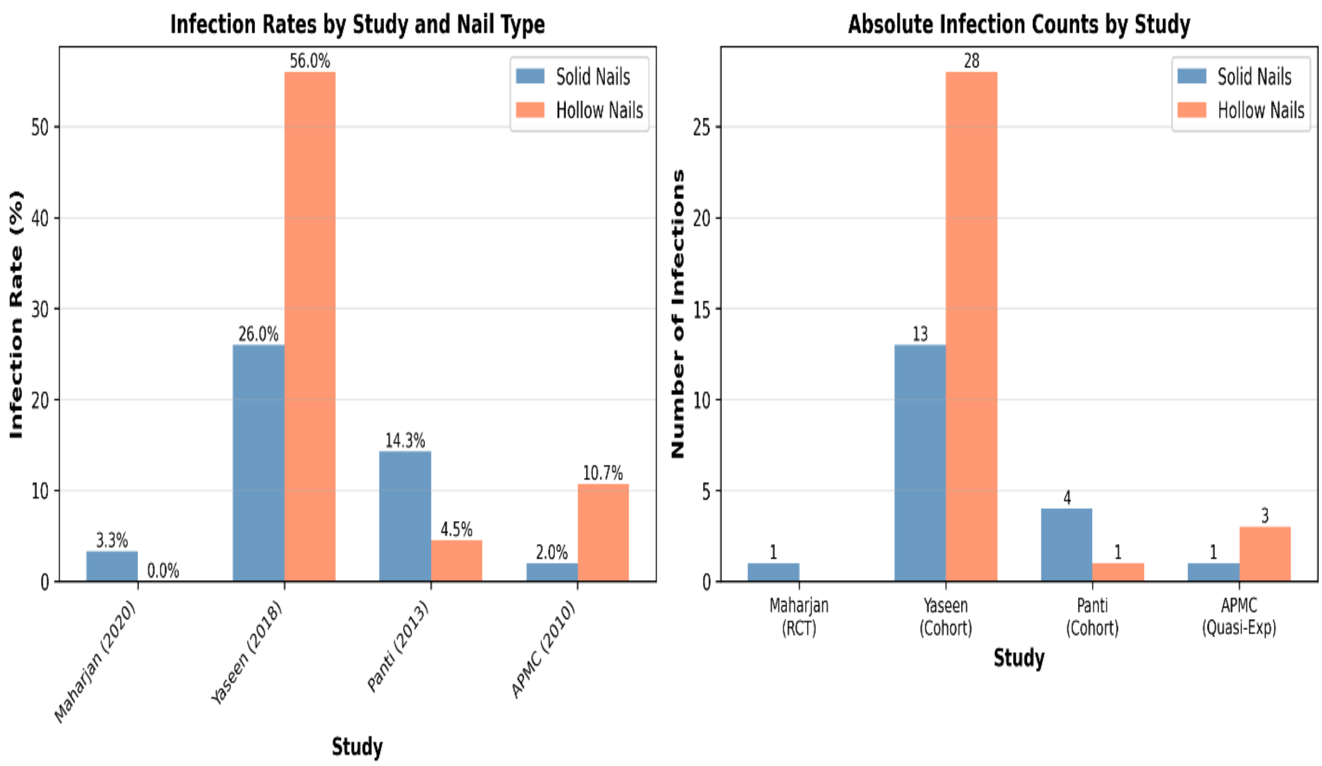

Figure 2: Infection rates and absolute infection count by study and nail type.

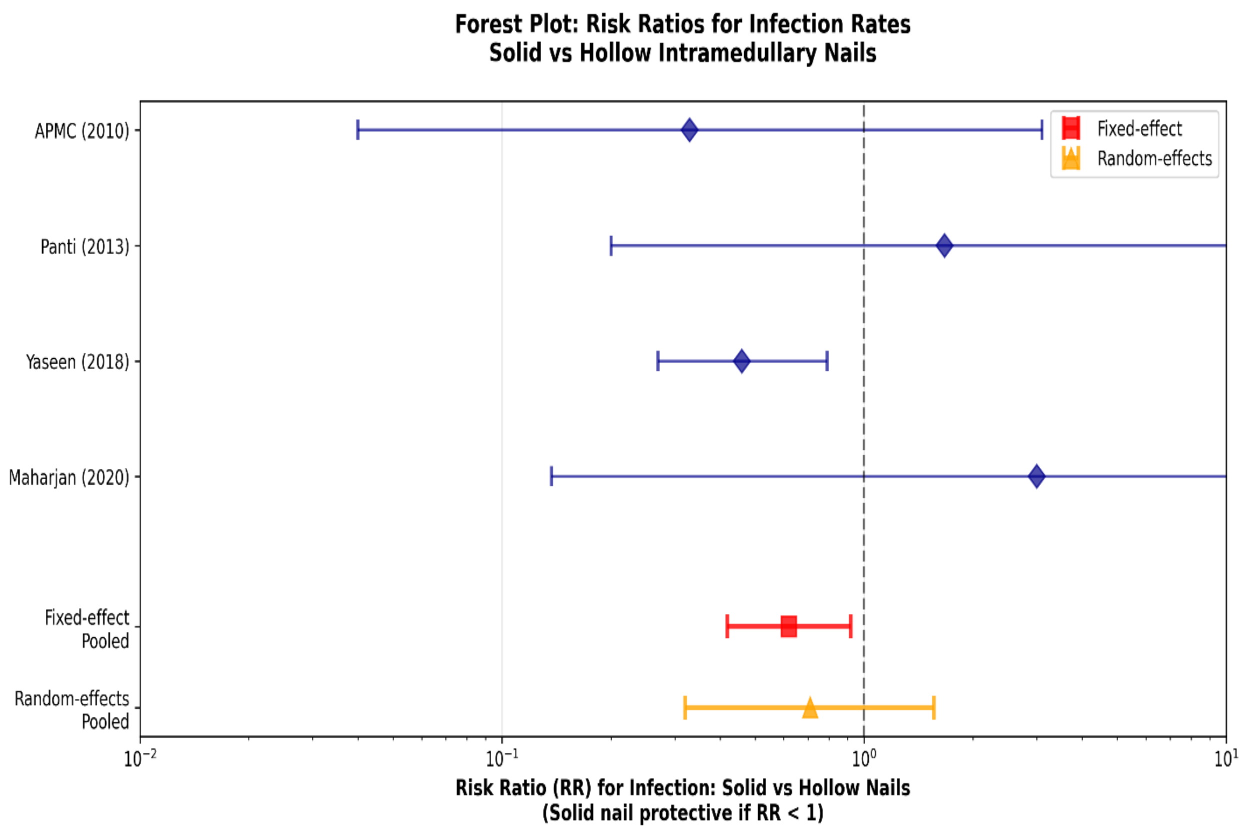

Figure 3: Forest plot comparing risk ratios for infection between solid and hollow intramedullary nails (fixed- and random-effects models).

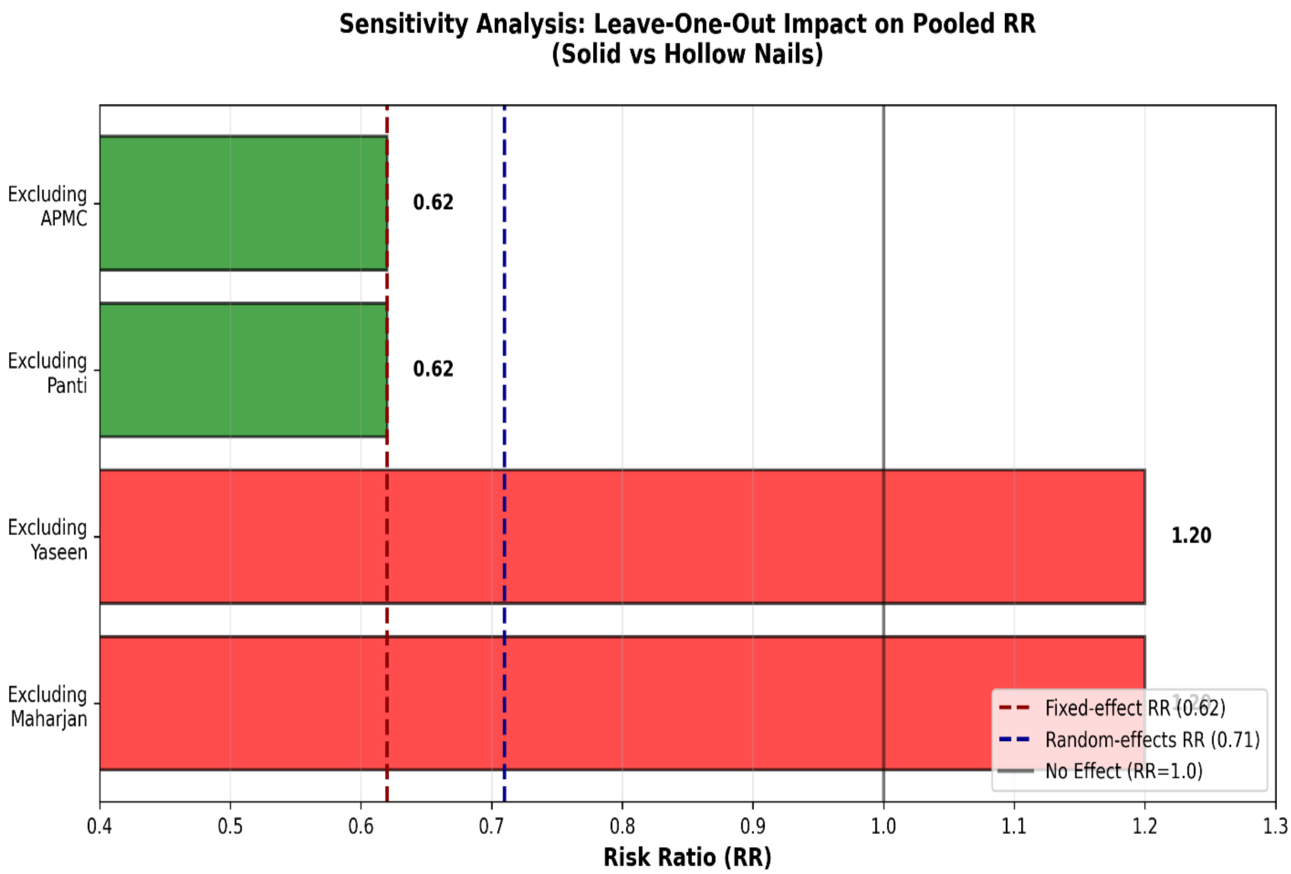

Figure 4: Leave-one-out sensitivity analysis showing impact of individual studies on pooled risk ratio.

DISCUSSION

Interpretation of pooled results and limitations

The pooled evidence from this meta-analysis is inconclusive regarding whether solid intramedullary nails reduce infection risk compared to hollow designs. While the fixed-effect model suggested a potential 38% risk reduction, these finding lacks robustness, as it is entirely contingent on a single large observational study with unusually high infection rates and short follow-up. The more conservative random-effects model, which appropriately weights heterogeneity, shows no significant difference between designs.[12-15,19] The stability analysis demonstrates that removing one key study shifts the combined estimate toward the null effect, raising serious concerns about the fragility of the current evidence base.

Biological plausibility and theoretical considerations

The theoretical mechanism supporting solid nail superiority is biologically plausible. The cannulated design in hollow nails could theoretically trap tissue fluids and create a protected microenvironment favorable for biofilm formation.[8,20] Studies of implant infection resistance demonstrate that biofilm bacteria exhibit high tolerance to antimicrobials, and the physical structure of an implant may influence adhesion and colonization patterns.[8,20]

However, this theoretical advantage has not been consistently demonstrated in clinical practice within the included studies, and the mechanism alone is insufficient to recommend changing established surgical practices.

Implant design versus patient and operative factors

The inconsistency of findings aligns with broader orthopedic evidence indicating that surgical technique, timing of antibiotics, soft tissue management, operative time, and fracture severity are often cited as more critical determinants of infection risk than specific implant design features.[9,21] The exceptional outlier infection rates in the Yaseen study (26–56%) suggest that unmeasured confounders- such as differences in fracture severity, operative environment quality, perioperative antibiotic availability, or postoperative care standards- play a far greater role than nail design itself.[9,21]

Clinical and technical advantages of cannulated nails

Cannulated IM nails offer significant technical and practical advantages that should not be abandoned based on inconclusive evidence of infection risk. These advantages include: (1) easier insertion over a guidewire, reducing operative time and blood loss; (2) reduced fluoroscopy exposure for patient and surgical team; (3) simplified technique, particularly beneficial in low-resource settings where technical expertise may be variable; (4) improved intraoperative control, potentially reducing malalignment.[7] In contexts where infection control measures are already suboptimal, the operational efficiency of cannulated nails may indirectly reduce infection risk by shortening operative time and reducing need for multiple attempts at reduction.

Geographic and population heterogeneity

All four included studies were conducted in South and Southeast Asia, limiting generalizability to high-income countries with lower baseline infection rates, more standardized operative protocols, and better antibiotic availability.[12-15] The applicability of findings from the Yaseen study- with infection rates of 26-56% to populations with expected baseline rates of 2-5% is highly questionable. Subgroup analyses by geographic region or baseline infection risk would have been informative but were not possible given the small number and similar origins of included studies.

Definition and timing of infection outcomes

Infection definitions and ascertainment methods varied across studies. The Yaseen study's unusually short follow-up (4 weeks) compared to standard surveillance periods (typically ≥12 weeks for postoperative infection) may have affected case capture. Different thresholds for defining superficial versus deep infection, and different approaches to diagnosing versus suspecting infection, could introduce bias. Standardized definitions would strengthen future comparisons.

Overall certainty of evidence

Using the GRADE framework, the overall certainty of evidence is very low due to: (1) limited number of studies (only 4); (2) methodological limitations (only 1 RCT; 2 retrospective cohorts with potential selection bias); (3) substantial heterogeneity in effect estimates across studies; (4) imprecision of effect estimates (wide confidence intervals including both benefit and harm); (5) risk of publication bias and selective outcome reporting.[16,19] These factors collectively support a very low certainty rating, indicating that confidence in the estimated effect is limited and further high-quality research would likely change the conclusions.

CONCLUSION

The current evidence is insufficient to support the conclusion that solid intramedullary nails reduce infection rates compared to hollow/cannulated designs in the treatment of long bone fractures. The apparent pooled effect favoring solid nails is inconsistent across studies and highly dependent on a single observational study with substantial methodological limitations. The overall certainty of evidence is very low, reflecting the limited number of studies, their methodological constraints, and substantial heterogeneity.[12,15-19] In light of these findings, clinical decisions on IM nail design should not be based solely on infection risk. The technical advantages of cannulated nails- including easier insertion, reduced operative time and radiation exposure, and simplified technique- represent meaningful clinical benefits that should be weighed against an unproven infection disadvantage. Surgeons should prioritize proven infection prevention strategies, including meticulous surgical technique, appropriate timing and dosing of antibiotic prophylaxis, and optimization of soft tissue management.[9,21] Future research should prioritize: (1) well-designed randomized controlled trials with adequate sample sizes and power for infection outcomes, conducted in diverse geographic and healthcare settings; (2) standardized definitions of infection, consistent follow-up periods, and comprehensive outcome ascertainment; (3) investigation of potential effect modification by patient factors (age, comorbidities), fracture characteristics (type, severity, open versus closed), and operative factors (timing, technique, antibiotic prophylaxis); (4) cost-effectiveness analyses comparing implant types and infection prevention strategies in resource-constrained versus well-resourced settings. Until higher-quality evidence becomes available, implant choice should be individualized, based on fracture characteristics, local expertise, equipment availability, and patient factors rather than on unproven associations with infection risk. Given the absence of clear evidence favoring solid over hollow designs, and the recognized technical advantages of cannulated nails, current practice patterns should be maintained while advocating for rigorous, prospective comparative studies to definitively resolve this question.

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