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Management of Chronic Long-Bone Osteomyelitis Using Antibiotic Cement–Coated Nails in Libya: A Cross-Sectional Survey Across Public Hospitals in the Eastern, Central, and Western

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ABSTRACT

Chronic long-bone osteomyelitis remains a persistent challenge for orthopaedic services, particularly in settings where diagnostic capacity and surgical resources vary between hospitals. This cross-sectional survey was conducted across five Libyan public hospitals in the Eastern, Central, and Western regions to estimate chronic osteomyelitis caseload patterns and to examine how structural capacity and surgeon decision-making processes were associated with utilisation of antibiotic cement–coated intramedullary nails. A purposive–convenience sampling approach was used to recruit 500 orthopaedic clinicians, with questionnaire administration supervised on-site to support completeness and standardised procedures. Data were analysed using SPSS (Version 29) through descriptive statistics, bivariate tests aligned with the hypotheses, and multivariable regression modelling with $p < .05$ and 95% confidence intervals. The sample comprised 380 males (76.0%) and 120 females (24.0%), with 64.0% reporting prior use of coated nails and 72.0% reporting annual chronic osteomyelitis caseloads of ten or more cases. Hypothesis testing demonstrated significant regional differences in caseload (H1: $F(2, 497) = 6.84$, $p = .001$). Structural capacity showed a positive association with utilisation (H2: $r = .41$, $p < .001$; $\beta = 0.38$, 95% CI [0.29, 0.47], $p < .001$). Surgeon capability independently predicted utilisation (H3: $\beta = 0.31$, 95% CI [0.22, 0.40], $p < .001$). Diagnostic and microbiology capacity and stronger orientation towards local antibiotic delivery independently predicted higher utilisation (H4: $\beta = 0.24$, 95% CI [0.15, 0.33], $p < .001$; $\beta = 0.29$, 95% CI [0.20, 0.38], $p < .001$). Overall, utilisation patterns were shaped by regional context, service infrastructure, and surgeon-level processes rather than clinical preference alone, indicating that strengthening diagnostics, resource availability, and targeted training may support more consistent management across Libyan public hospitals.

Keywords: Chronic osteomyelitis, Antibiotic-coated nails, Orthopaedic infection, Structural capacity, Libya.

إدارة التهاب العظم والنقي المزمن في العظام الطويلة باستخدام المسامير المغطاة بإسمنت محمّل بالمضادات الحيوية في ليبيا: دراسة مقطعية عبر المستشفيات العامة في المناطق الشرقية والوسطى والغربية

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ملخـــــص البحـــــث

يظل التهاب العظم والنقي المزمن في العظام الطويلة تحدّياً مستمراً أمام خدمات جراحة العظام، ولا سيما في البيئات التي تختلف فيها القدرات التشخيصية والموارد الجراحية بين المستشفيات. أُجريت هذه الدراسة المقطعية عبر خمسة مستشفيات حكومية ليبية في بالمناطق الشرقية والوسطى والغربية، بهدف تقدير أنماط عبء حالات التهاب العظم والنقي المزمن، ودراسة كيفية ارتباط القدرة الهيكلية للمستشفيات وعمليات اتخاذ القرار لدى الجراحين باستخدام المسامير داخل النخاع المغلّفة بالإسمنت المحمّل بالمضادات الحيوية. استُخدم أسلوب المعاينة القصدية–الميسّرة لتجنيد 500 من أطباء جراحة العظام، مع الإشراف المباشر على توزيع الاستبيانات داخل مواقع الدراسة لضمان الاكتمال وتوحيد الإجراءات. جرى تحليل البيانات باستخدام SPSS الإصدار (29) من خلال الإحصاءات الوصفية، والاختبارات الثنائية المتوافقة مع الفرضيات، ونماذج الانحدار متعددة المتغيرات عند مستوى دلالة $p < .05$ وبمستوى ثقة 95%. تكوّنت العيّنة من 380 ذكراً (76.0%) و120 أنثى (24.0%)، مع إبلاغ 64.0% عن استخدام سابق للمسامير المغلّفة، و72.0% عن عبء سنوي لا يقل عن عشر حالات من التهاب العظم والنقي المزمن. أظهرت اختبارات الفرضيات فروقاً بين المناطق إقليمية ذات دلالة في عبء الحالات ($H1: F(2, 497) = 6.84, p = .001$). كما ارتبطت القدرة الهيكلية للمستشفى إيجابياً بالاستخدام ($H2: r = .41, p < .001; \beta = 0.38, 95\%\ CI\ [0.29, 0.47], p < .001$). وتنبأت كفاءة الجراح بشكل مستقل بالاستخدام ($H3: \beta = 0.31, 95\%\ CI\ [0.22, 0.40], p < .001$). كذلك تنبأت القدرة التشخيصية والمخبرية والتوجّه نحو الإعطاء الموضعي للمضادات الحيوية بزيادة الاستخدام بشكل مستقل ($H4: \beta = 0.24, 95\%\ CI\ [0.15, 0.33], p < .001; \beta = 0.29, 95\%\ CI\ [0.20, 0.38], p < .001$) بوجه عام، تبيّن أن أنماط الاستخدام قد تشكّلت بفعل السياق الإقليمي والبنية التحتية للخدمات وعوامل متعلقة بالجراحين، وليس التفضيل السريري وحده، مما يشير إلى أن تعزيز القدرات التشخيصية وتوافر الموارد والتدريب الموجّه قد يدعم إدارة أكثر اتساقاً لالتهاب العظم والنقي المزمن في المستشفيات الحكومية الليبية.

الكلمات المفتاحية: التهاب العظم والنقي المزمن، المسامير المغلّفة بالمضادات الحيوية، عدوى جراحة العظام، القدرة الهيكلية، ليبيا.

1. Introduction

Osteomyelitis has remained one of the most persistent challenges in orthopaedic surgery because infection within bone has frequently progressed alongside impaired vascularity, biofilm formation, and sequestrum-related chronicity, each of which can limit antibiotic penetration and compromise mechanical stability and long-term function [1,2]. Burden has continued to be reported internationally, with population-based evidence indicating osteomyelitis incidence in the range of tens per 100,000 person-years in some settings, while hospital-based patterns have also highlighted the ongoing clinical workload associated with site-specific disease, including vertebral and foot-related osteomyelitis [3,5]. Orthopaedic services have therefore faced sustained pressure to control infection while preserving limb integrity, particularly where trauma, fracture fixation, and revision procedures have interacted with contamination risk and prolonged follow-up needs.

Chronic osteomyelitis has been characterised by progressive inflammatory destruction of bone with sequestrum formation and recurrent episodes that can escalate morbidity and disability, while microbiological patterns have continued to shape surgical planning and

antimicrobial choice [1,6]. Staphylococcal species have remained dominant pathogens in many orthopaedic bone infections, with Gram-negative organisms also contributing in complex cases, which has heightened concern regarding antimicrobial resistance and the adequacy of empirical regimens [6]. Clinical experience has indicated that treatment pathways are often prolonged and complex, with repeated operations, soft-tissue compromise, nutritional vulnerability, and functional limitation affecting outcomes, particularly when services are constrained by resource limitations and delayed presentation [7]. However, the epidemiological picture has not been uniformly defined across regions, and national estimates have not always been available to support planning and surveillance.

Libyan literature has framed osteomyelitis as a clinically significant condition in developing settings, with recurrent emphasis on late diagnosis, delayed referral, interrupted follow-up, and co-morbidities that can predispose to chronicity [8]. Osteomyelitis has been described as affecting both jaw bones and long bones, with jaw disease frequently following odontogenic infection, while long-bone disease has been linked to trauma, fractures, and post-operative contamination, each of which relates directly to orthopaedic workload and surgical risk [8]. The Libyan review has indicated that frequency appears high within clinical experience, yet numerical prevalence has not been reported, leaving uncertainty about the magnitude of burden across health facilities and regions [8]. Clinical consequences such as sinus formation, sclerosis, sequestration, pathological fracture, and prolonged disability have been repeatedly associated with chronic disease, which has reinforced the likely ongoing relevance for orthopaedic units managing limb-threatening infection rather than isolated cases [8].

Orthopaedic infection control has classically relied on aggressive debridement of necrotic bone and infected tissue, combined with antibiotic therapy as an adjunct rather than a standalone cure, because biofilm and devitalised bone have limited the delivery and effect of systemic antimicrobials [2,7]. Local antibiotic delivery has therefore gained importance, with polymethylmethacrylate (PMMA) cement widely used as a carrier to deliver high local concentrations at the site of pathology [9,10]. Early approaches have included cement beads and blocks which can support dead-space management, although bead-based strategies have not reliably provided structural stability and have sometimes required difficult secondary removal when fibrosis and soft-tissue compromise have developed [10]. Reconstruction needs have remained substantial, because bone grafting, soft-tissue flaps, and stabilisation strategies have often been necessary to address defects created after debridement and to restore function, particularly in long-bone disease where instability has increased non-union risk and reinfection potential [7]. Ongoing concern has also been noted in relation to resistant organisms such as MRSA, with calls for improved surveillance programmes and locally harmonised, evidence-based practices suited to Libyan service realities [8].

Antibiotic cement–coated intramedullary nails have attracted interest because a single device can combine intramedullary dead-space management, sustained local antibiotic exposure, and stabilisation of the infected long bone. Evidence from clinical studies has suggested that remission can be achieved in many cases when debridement, canal preparation, and local antibiotic delivery have been integrated, with relapse monitoring requiring careful follow-up and consistent outcome definitions [11]. Libyan clinical reporting has also begun to describe local experience with antibiotic cement–coated nails, with a single-centre case series

from Sabratha Teaching Hospital reporting infection control in most treated cases, which has indicated feasibility but has not clarified national variation in adoption, access, or decision pathways [12].

The aim of the study is to quantitatively estimate the burden (prevalence/caseload) of chronic long-bone osteomyelitis across Libyan public hospitals and to model how hospital structural capacity and surgeon decision-making processes are associated with the utilisation of antibiotic cement–coated intramedullary nails, with attention to regional variation and system-level constraints. A clear gap has therefore emerged for Libya because osteomyelitis has been described as highly prevalent in clinical terms, yet the absence of quantified prevalence estimates and the lack of multi-centre evidence about orthopaedic practice patterns have limited the ability to standardise care. Practice-related evidence has remained especially limited regarding when antibiotic cement–coated nails are selected, which antibiotics are incorporated, how culture and susceptibility testing informs decisions, and what barriers including implant availability, cement supply, theatre capacity, microbiology turnaround, and follow-up continuity influence real-world use. Knowledge about radiographic features has been advancing internationally, with sclerosis and cortical thickening frequently reported as common findings in chronic osteomyelitis, while interpretative variability has persisted for soft-tissue swelling, which may affect diagnostic consistency across clinicians [13]. Within Libya, descriptive academic work has provided foundational pathology and management framing; nevertheless, orthopaedic surgery has lacked multi-region evidence capable of clarifying service variation and supporting locally tailored guidance [8]. Addressing this gap could support more consistent infection-control strategies, would inform context-appropriate orthopaedic guidelines, and may improve alignment between diagnostic practice, surgical stabilisation, and local antibiotic delivery in chronic long-bone osteomyelitis.

2. Theoretical framework

A health-service delivery perspective is appropriate for explaining variation in chronic long-bone osteomyelitis (COM) burden and the uneven uptake of antibiotic cement–coated intramedullary nails across Libyan public hospitals. The Donabedian Structure–Process–Outcome (SPO) framework provides a coherent theoretical basis, as it links health-system capacity (structure) to clinical behaviour and decision-making (process), and subsequently to observable service outputs or utilisation outcomes [14]. Within the Libyan context, substantial heterogeneity exists in hospital resources, infection management pathways, and specialist availability, which plausibly contributes to differences in how COM is treated and which surgical strategies are adopted. Structural elements such as theatre access, implant and cement supply chains, microbiology services, and multidisciplinary infection support are therefore expected to influence how surgeons manage complex, biofilm-associated bone infections. At the same time, clinical practice remains partly shaped by experiential and institutional norms, meaning that uptake of coated nail technology may vary even where the clinical rationale is accepted. Aligning the study aim with the SPO framework allows the investigation to move beyond clinical efficacy and focus instead on how system and behavioural factors shape real-world utilisation patterns.

2.1 Conceptual model and variables (SPO mapping)

The study applies an SPO model to explain variation in the utilisation of antibiotic cement–coated intramedullary nails across Libyan public hospitals. Structural capacity is conceptualised as the foundation upon which clinical processes operate, with both jointly determining utilisation outcomes.

2.3 Outcome (dependent variable)

The primary outcome is utilisation of antibiotic cement–coated intramedullary nails. This is operationalised either as a continuous measure reflecting frequency of use over a defined period or as a binary indicator capturing use versus non-use at surgeon or hospital level.

2.4 Predictors (independent variables)

Structural predictors include a composite resource availability index encompassing access to coated nails, PMMA cement, appropriate antibiotics, theatre capacity, and supporting infrastructure. Diagnostic and microbiology capability is also treated as a structural predictor, reflecting access to culture, susceptibility testing, and relevant imaging.

Process-level predictors capture surgeon capability and exposure, including years of practice, infection or non-union caseload, and prior experience with coated nail techniques, alongside decision-making orientation towards local antibiotic delivery compared with systemic-only approaches.

2.5 Contextual factor

Geographical region is included as a contextual covariate to reflect broader differences in healthcare organisation and infrastructure that may modify both structure and process.

2.6 Hypothesis development

Within the SPO logic, regional context is expected to shape structural capacity; structural capacity is expected to influence process-level decisions; and these decisions are expected to determine utilisation patterns. On this basis, four hypotheses are specified:

H1: Hospital-level COM prevalence or caseload differs significantly by region.

H2: Greater structural resource availability is positively associated with higher utilisation of antibiotic cement–coated intramedullary nails.

H3: Higher surgeon capability and exposure are positively associated with utilisation, independent of structural resources and region.

H4: Diagnostic and microbiology capability and a stronger orientation towards local antibiotic delivery independently predict higher utilisation in multivariable models.

3. Methods

3.1 Research Design

A cross-sectional survey design was employed to examine utilisation patterns of antibiotic cement–coated intramedullary nails (ACCINs) in the management of chronic long-bone osteomyelitis (COM) across public hospitals in Libya. This design was selected for its suitability in estimating prevalence, describing current clinical practices, and assessing associations between structural, process-related, and utilisation variables at a defined period in time [15,16]. Given the study aim of evaluating real-world practice rather than establishing causality, a cross-sectional approach provided an efficient and analytically appropriate

framework for testing the proposed hypotheses within the Structure Process Outcome (SPO) logic.

3.2 Participants

Participants were eligible if they were orthopaedic surgeons or senior orthopaedic clinicians practising in Libyan public hospitals with direct responsibility for managing chronic long-bone osteomyelitis, including decisions related to debridement, fixation, or infection control. Eligible respondents were required to work in public hospitals located in the Eastern, Central, or Western regions of Libya and to have completed at least one year of independent orthopaedic practice following specialist training, ensuring sufficient exposure to institutional workflows and case complexity. Willingness to provide informed consent and to complete the self-administered questionnaire was also required. Clinicians were excluded if they were trainees, interns, or residents without independent decision-making authority; if they practised exclusively in private healthcare facilities; or if their clinical work was confined to subspecialties not routinely involved in long-bone infection management, such as spine-only or sports orthopaedics. Non-surgical healthcare professionals and surveys that were incomplete or duplicated were also excluded to preserve analytical validity.

3.3 Study Setting

The study was conducted across five public hospitals providing orthopaedic trauma and infection services in Libya, representing the Eastern, Central, and Western regions. Ethical approval and administrative oversight were granted by Sabriate Hospital, which served as the coordinating centre. Data collection was supervised locally at each hospital to ensure consistency in questionnaire administration. The participating hospitals were selected based on service volume, availability of orthopaedic surgery units, and regional representation, enabling comparison of COM caseloads and resource capacity across different healthcare contexts.

3.4 Sampling Technique and Sample Size

A non-probability purposive–convenience sampling strategy was applied, targeting orthopaedic surgeons and senior clinicians directly involved in managing chronic bone infections. This approach was considered appropriate given the specialised nature of ACCIN use and the absence of a comprehensive national registry of orthopaedic infection specialists [14,15]. A total sample of 500 participants was targeted to provide adequate statistical power for regional comparisons, bivariate testing, and multivariable modelling. This sample size was judged sufficient for detecting moderate associations across multiple predictors while maintaining model stability in multivariable analyses [16].

3.5 Questionnaire Design

The questionnaire was structured to capture surgeon-level, hospital-level, and system-level factors influencing the management of chronic long-bone osteomyelitis in Libyan public hospitals. Initially, demographic and professional data were collected to characterise respondents by age, qualification, experience, hospital type, and regional distribution, allowing contextual interpretation of subsequent responses. Subsequently, utilisation of antibiotic cement–coated intramedullary nails was measured as the primary outcome, reflecting contemporary orthopaedic strategies for infection control and stabilisation. In parallel, structural capacity and decision-making domains were assessed to capture resource availability,

microbiology access, and institutional constraints, which are recognised determinants of infection management in low-resource settings [1,17]. Moreover, surgeon capability and clinical exposure were included to reflect practice-pattern influences reported in both historical and recent literature [6,18]. Finally, orientation towards local antibiotic delivery was examined, recognising the clinical rationale for local therapy in biofilm-associated infection and devitalised bone [10,9].

3.6 Measurement Validity and Reliability

Measurement reliability and construct validity were evaluated to ensure robustness of the survey instrument. The questionnaire comprised six scales, including demographic and professional characteristics, utilisation of antibiotic cement–coated intramedullary nails, structural capacity and decision-making, surgeon capability and exposure, orientation towards local antibiotic delivery, and clinical practice constraints. These constructs were informed by established orthopaedic infection literature spanning both classical pathophysiological frameworks and contemporary implant-based management strategies [1,19,18].

Internal consistency was assessed using Cronbach's alpha (α). As presented in Table 1, All Likert-based scales demonstrated acceptable to strong reliability, with α values ranging from 0.78 to 0.89, exceeding the recommended threshold of 0.70. Construct validity was examined using Average Variance Extracted (AVE), with values between 0.52 and 0.64 (Table 1), indicating satisfactory convergent validity. These findings support the instrument's suitability for modelling associations between structural capacity, surgeon decision-making, and utilisation patterns in chronic osteomyelitis management.

Table 1. Measurement Reliability and Validity Summary

Scale Name	Number of Items	Cronbach's Alpha (α)	AVE
Utilisation of Coated Nails	8	0.86	0.61
Structural Capacity & Decision-Making	9	0.83	0.57
Surgeon Capability & Exposure	9	0.89	0.64
Local Antibiotic Orientation	9	0.85	0.59
Clinical Practice Constraints	9	0.78	0.52
Demographic & Professional Profile	10	N/A	N/A

3.7 Recruitment Process

Recruitment was conducted between January 2025 and 31 October 2025. Eligible participants were identified through orthopaedic departments at each participating hospital. Following departmental briefings, clinicians were approached in person and provided with a printed information sheet detailing study objectives, procedures, and confidentiality safeguards. Participation was voluntary, and written informed consent was obtained prior to questionnaire completion. Data collection occurred under direct supervision to address queries and ensure completeness, without interfering with clinical duties.

3.8 Data Analysis Techniques

Data were analysed using IBM SPSS Statistics (Version 29). Analysis proceeded in three stages. Univariate analysis summarised participant characteristics and scale responses using means, standard deviations, frequencies, and percentages. Bivariate analyses examined associations aligned with the hypotheses: regional differences in COM caseloads (H1) were assessed using

comparative tests across regions; associations between structural capacity and ACCIN utilisation (H2), and between surgeon capability and utilisation (H3), were examined using correlation and comparative methods. Multivariable regression modelling was then applied to evaluate H4, assessing whether diagnostic capacity, microbiology support, and orientation toward local antibiotic delivery independently predicted utilisation while controlling for region and structural resources. Statistical significance was set at $p < 0.05$, with 95% confidence intervals reported to support interpretive precision.

3.9 Ethical Considerations

Ethical approval was formally obtained from Sabriate Hospital, with institutional permission secured from all participating public hospitals. The study adhered to established ethical principles for research involving human participants. All respondents received an information sheet and signed a written informed consent form. Anonymity was preserved by excluding identifiable data, and completed questionnaires were stored securely with restricted access. Given the professional nature of the survey, the study posed minimal risk to participants.

4. Findings

4.1 Participant Characteristics

Table 2 illustrates the demographic and professional characteristics of the participating orthopaedic clinicians (n = 500) drawn from public hospitals across Libya. Male respondents constituted the majority of the sample (380, 76.0%), while female clinicians accounted for 120 (24.0%). Age distribution demonstrated a predominance of mid- to late-career surgeons, with the largest proportions falling within the 35–44 years (34.0%) and 45–54 years (30.0%) categories, whereas younger (<35 years) and older (≥55 years) groups each represented 18.0% of the cohort. Regarding professional seniority, consultants (42.0%) and specialists (38.0%) comprised most respondents, compared with senior registrars (20.0%). Regional representation was balanced across the Eastern (34.0%), Central (33.0%), and Western (33.0%) regions. Teaching hospitals (38.0%) and tertiary referral centres (30.0%) accounted for a substantial proportion of participants, alongside general hospitals (32.0%). A majority reported moderate to high annual chronic osteomyelitis caseloads (10–25 cases: 42.0%; >25 cases: 30.0%) and previous experience using antibiotic cement–coated intramedullary nails (64.0%). Access to microbiology culture and sensitivity testing was reported as consistently available by 42.0%, with variable or limited access noted by the remainder.

Table 2. Section A: Demographic and Professional Characteristics of Participants (n = 500)

Variable	Category	Frequency n (%)
Gender	Male	380 (76.0)
	Female	120 (24.0)
Age group (years)	<35	90 (18.0)
	35–44	170 (34.0)
	45–54	150 (30.0)
	≥55	90 (18.0)
Highest qualification	Diploma/Master's	140 (28.0)
	Board certification	230 (46.0)
	Fellowship	130 (26.0)
Years of practice	<5	95 (19.0)

	5–10	165 (33.0)
	>10	240 (48.0)
Professional role	Consultant	210 (42.0)
	Specialist	190 (38.0)
	Senior registrar	100 (20.0)
Hospital region	Eastern	170 (34.0)
	Central	165 (33.0)
	Western	165 (33.0)
Hospital type	General	160 (32.0)
	Teaching	190 (38.0)
	Tertiary referral	150 (30.0)
Annual COM caseload	<10	140 (28.0)
	10–25	210 (42.0)
	>25	150 (30.0)
Prior use of coated nails	Yes	320 (64.0)
	No	180 (36.0)
Microbiology access	Always	210 (42.0)
	Sometimes	170 (34.0)
	Rarely/Not available	120 (24.0)

4.2 Participant Responses on Utilisation and Structural Capacity Scales

Table3 illustrates the responses to the utilisation and structural capacity scales indicated generally positive orientations towards antibiotic cement–coated intramedullary nail use and the supporting service environment. For the utilisation scale, routine hospital use of coated nails showed a moderate to high central tendency (M = 3.9, SD = 0.8), while personal experience with the technique scored slightly higher (M = 4.1, SD = 0.7). Perceptions of coated nails as a standard option for chronic infection or infected non-union were similarly strong (M = 4.0, SD = 0.8). Preference for local antibiotic delivery over systemic therapy alone demonstrated consistent agreement (M = 4.2, SD = 0.6), and use in recurrent or relapsed infection contexts remained prominent (M = 4.1, SD = 0.7). Within the structural capacity and decision-making scale, access to appropriate implants (M = 3.8, SD = 0.9) and PMMA cement with antibiotics (M = 3.7, SD = 0.9) showed moderate availability. Confidence linked to training and experience with coated nails yielded higher scores (M = 4.0, SD = 0.8), whereas resource constraints influencing utilisation were also reported (M = 3.9, SD = 0.8), indicating variability across institutional contexts.

Table 3. Summary of Participant Responses on Utilisation and Structural Capacity Scales (n = 500)

Scale	Item Description	Mean ± SD
Utilisation of Antibiotic Cement–Coated Nails	Routine use in hospital practice	3.9 ± 0.8
	Personal use in chronic osteomyelitis	4.1 ± 0.7
	Considered a standard treatment option	4.0 ± 0.8
	Preference for local over systemic antibiotics	4.2 ± 0.6
	Use in recurrent or relapsed infection	4.1 ± 0.7
	Reduction in staged procedures	3.8 ± 0.9

	Combined infection control and stability	4.3 ± 0.6
	Overall effective utilisation	4.0 ± 0.7
Structural Capacity and Decision-Making	Access to suitable intramedullary nails	3.8 ± 0.9
	Availability of PMMA cement and antibiotics	3.7 ± 0.9
	Adequate operating theatre time	3.6 ± 0.9
	Reliable microbiology services	3.5 ± 1.0
	Adequate imaging support	3.9 ± 0.8
	Training/exposure to coated nail use	4.0 ± 0.8
	Confidence in local antibiotic delivery	4.1 ± 0.7
	Resource limitations affecting use	3.9 ± 0.8
	Influence of institutional protocols	3.8 ± 0.9

4.3 Participant Responses on Surgeon Capability, Decision Orientation, and Practice Constraints

Table 4 show, the responses to the surgeon capability and clinical exposure scale indicated a high level of self-reported experience in managing chronic long-bone osteomyelitis. Extensive clinical experience scored strongly (M = 4.2, SD = 0.6), alongside frequent management of infected non-unions (M = 4.1, SD = 0.7). Formal training in antibiotic cement–coated nail techniques showed slightly lower dispersion but remained positive (M = 3.9, SD = 0.8), while confidence in patient selection and familiarity with cement preparation techniques were consistently rated (M = 4.0, SD = 0.7 and M = 3.8, SD = 0.8, respectively).

Decision-making orientation towards local antibiotic delivery demonstrated robust agreement across items. Recognition of the limitations of systemic antibiotics alone yielded high scores (M = 4.3, SD = 0.6), and consideration of biofilm-related pathology was similarly prominent (M = 4.2, SD = 0.6). Preference for combined mechanical stabilisation and local delivery remained strong (M = 4.4, SD = 0.5). In contrast, the clinical practice constraints scale reflected moderate agreement, with theatre time limitations (M = 3.8, SD = 0.9) and resource constraints (M = 3.9, SD = 0.8) emerging as salient influences, alongside cost considerations affecting implant choice (M = 3.7, SD = 0.9).

Table 4. Summary of Participant Responses on Process-Related Scales (n = 500)

Scale	Item Description	Mean ± SD
Surgeon Capability & Clinical Exposure (IV3)	Extensive experience managing chronic osteomyelitis	4.2 ± 0.6
	Frequent treatment of infected non-unions	4.1 ± 0.7
	Formal training in coated nail use	3.9 ± 0.8
	Confidence in candidate selection	4.0 ± 0.7
	Familiarity with cement preparation techniques	3.8 ± 0.8
	Management of complex bone infections	4.1 ± 0.6
	High trauma-related infection workload	3.9 ± 0.8
	Keeping updated with infection-related advances	4.2 ± 0.6
	Comfort managing implant-related complications	4.0 ± 0.7

Decision Orientation to Local Antibiotic Delivery (IV4)	Local delivery essential in chronic infection	4.4 ± 0.5
	Systemic antibiotics often insufficient	4.3 ± 0.6
	Influence of poor bone vascularity	4.1 ± 0.7
	Consideration of biofilm formation	4.2 ± 0.6
	Advantage of coated over standard nails	4.3 ± 0.6
	Preference for combined stabilisation and delivery	4.4 ± 0.5
	Reduced recurrence risk with local delivery	4.2 ± 0.6
	Importance of high local antibiotic concentration	4.3 ± 0.6
	Likelihood of use in long-standing infection	4.1 ± 0.7
Clinical Practice Constraints & Adoption Readiness	Theatre time limitations	3.8 ± 0.9
	Antibiotic availability influencing decisions	3.9 ± 0.8
	Influence of institutional protocols	3.7 ± 0.9
	Resource limitations restricting use	3.9 ± 0.8
	Lack of specialised infection teams	3.8 ± 0.9
	Microbiology support affecting confidence	4.0 ± 0.7
	Cost influencing implant selection	3.7 ± 0.9
	Institutional experience shaping willingness	3.9 ± 0.8
	System-level constraints on optimal care	4.0 ± 0.7

4.5 Hypotheses Testing Results

Table 5 demonstrates the bivariate and multivariable analyses were conducted to evaluate the four hypotheses.

H1: Regional variation in COM caseload

Comparative analyses demonstrated significant regional differences in reported hospital-level chronic osteomyelitis (COM) caseloads. Clinicians practising in Western-region hospitals reported higher mean annual caseloads compared with Eastern and Central regions, $F(2, 497) = 6.84$, $p = .001$. Post hoc comparisons indicated that the Western region differed significantly from both the Eastern ($p = .003$) and Central ($p = .011$) regions, supporting H1.

H2: Structural resource availability and utilisation

Structural resource availability showed a positive association with ACCIN utilisation. Correlation analysis indicated a moderate positive relationship ($r = .41$, $p < .001$). In regression analysis, higher structural capacity scores significantly predicted greater utilisation ($\beta = 0.38$, 95% CI [0.29, 0.47], $p < .001$), supporting H2.

H3: Surgeon capability and exposure

Surgeon capability and clinical exposure were also positively associated with utilisation. Clinicians with higher capability scores reported greater ACCIN use ($\beta = 0.31$, 95% CI [0.22, 0.40], $p < .001$), independent of region and structural resources, supporting H3.

H4: Diagnostic capacity and decision orientation

In multivariable modelling, diagnostic and microbiology capability ($\beta = 0.24$, 95% CI [0.15, 0.33], $p < .001$) and stronger orientation toward local antibiotic delivery ($\beta = 0.29$, 95% CI [0.20, 0.38], $p < .001$) independently predicted higher utilisation, supporting H4. See ta

These findings demonstrate consistent support for all four hypotheses, indicating that regional context, structural capacity, and surgeon-level processes are associated with utilisation patterns of antibiotic cement–coated intramedullary nails across Libyan public hospitals.

Table 5. Summary of Hypothesis Testing Results (n = 500)

Hypothesis	Key Predictor(s)	Statistical Test	Effect Estimate (95% CI)	*p* value	Outcome
H1: Regional differences in COM caseload	Region	ANOVA	$F(2, 497) = 6.84$	.001	Supported
H2: Structural capacity → utilisation	Structural resource index	Linear regression	β = 0.38 [0.29, 0.47]	< .001	Supported
H3: Surgeon capability → utilisation	Capability/exposure score	Linear regression	β = 0.31 [0.22, 0.40]	< .001	Supported
H4: Diagnostics & decision orientation → utilisation	Microbiology capacity; local-delivery orientation	Multiple regression	β = 0.24 [0.15, 0.33]; β = 0.29 [0.20, 0.38]	< .001	Supported

5. Discussion

The present cross-sectional survey investigated how orthopaedic clinicians in Libyan public hospitals use antibiotic cement–coated intramedullary nails to manage chronic long-bone osteomyelitis, drawing on responses collected across the Eastern, Central, and Western regions from key referral settings, including Sabratha Hospital (Western region), Ibn Sina Hospital (Central region), Benghazi Medical Centre, and Al-Butnan Medical Centre in Tobruk (Eastern region). The cross-sectional design was appropriate for describing current practice patterns and testing association pathways at a defined time point, particularly where system variation is expected across sites and regions [14,15]. Strong alignment between the study aims and the Structure–Process–Outcome framework suggests that hospital structures and surgeon processes can be examined together without requiring longitudinal follow-up. This framing offers a useful basis for locally relevant benchmarking of infection-management practice.

The findings of the study show that the participating clinicians were predominantly experienced decision-makers managing moderate-to-high chronic osteomyelitis caseloads, with substantial prior exposure to coated nail use. Chronic osteomyelitis is widely characterised as a persistent inflammatory infection involving sequestrum formation, recurrent episodes, and progressive bone destruction, often requiring repeated procedures and long-term planning rather than a single-stage intervention [1,16]. Clinical complexity linked to scarring, compromised soft tissues, and comorbid conditions may plausibly concentrate management in senior hands, particularly in public referral centres. Such workforce patterns suggest that service planning should priorities specialist-led pathways for complex infection care.

The findings of the study demonstrate broadly favourable attitudes towards coated nails as a standard option that combines stability with local antimicrobial delivery. Evidence indicates that local antibiotic strategies were developed partly because systemic antibiotics may fail to achieve adequate concentrations in chronically infected bone, especially where vascularity is poor and biofilm is established [2,6]. Technique evolution from PMMA beads and spacers towards antibiotic-loaded devices is frequently framed as an attempt to retain high local

antibiotic exposure while addressing mechanical needs [10,9]. Strong clinician agreement with this rationale may suggest that guideline development in Libya could build on existing conceptual acceptance rather than starting from basic justification.

The findings of the study illustrate that hospital structural capacity was rated as moderately available for implants, cement, theatre time, imaging, and microbiology support, while institutional constraints remained clearly evident. PMMA remains a common carrier because it is accessible and capable of delivering high local antibiotic concentrations; however, bead-based approaches can require staged removal and may become difficult to manage in fibrotic or compromised tissue environments [10,9]. Reliance on coated nails may therefore reflect an effort to reduce staged procedures in settings where theatre access is constrained. Such structural variability suggests that procurement systems and theatre scheduling policies may influence utilisation as strongly as surgeon preference.

The findings of the study show significant regional variation in chronic osteomyelitis caseloads, supporting the premise that context shapes burden and service demand. Libyan work on osteomyelitis has emphasised persistence of disease in developing settings, with late presentation, trauma-related infection, interrupted follow-up, and limited early specialist access contributing to progression towards chronicity [8]. Broader evidence similarly indicates that chronic osteomyelitis imposes substantial health-system costs and complex diagnostic pathways, even where resources are stronger, suggesting that under-resourced contexts may experience amplified constraints [17,3]. Regional heterogeneity may therefore indicate the need for targeted, site-specific resource allocation rather than uniform planning.

The findings of the study demonstrate that structural resource availability was positively associated with utilisation of antibiotic cement–coated nails, consistent with the SPO assumption that "structure" influences "process." International reviews describe coated nails as an approach shaped by availability, indications, and outcome reporting, with ongoing variation in implementation across settings [18]. Meta-analytic evidence has also suggested that antibiotic-coated intramedullary nailing is used as a strategy for infected non-unions and long-bone infection management, while outcomes may depend on case selection and system support [19]. Although surgeon acceptance appears high, the observed structure–utilisation link may imply that improving supply reliability and diagnostics could translate into more consistent adoption.

The findings of the study show that surgeon capability and clinical exposure independently predicted utilisation, indicating that clinician-level processes may operate beyond structural capacity alone. Chronic bone infection management frequently requires integration of debridement, stabilisation, and antimicrobial strategy selection, and surgeon judgement is often central when evidence is heterogeneous or protocols are limited [7,16]. Training and accumulated experience could plausibly reduce uncertainty around cement preparation, candidate selection, and complication management, thereby increasing appropriate use. This pattern may imply that structured training and mentorship, potentially anchored in referral centres, could strengthen safe and standardised uptake.

The findings of the study demonstrate that diagnostic and microbiology capability, alongside stronger orientation towards local antibiotic delivery, independently predicted utilisation in multivariable models. Microbiology patterns in chronic osteomyelitis commonly involve Staphylococcus species, with implant-related infection frequently linked to coagulase-

negative staphylococci, and these patterns have practical implications for antibiotic selection and confidence in treatment planning [6,1]. Despite conceptual support for local delivery, limited culture and sensitivity access may constrain targeted therapy and reinforce reliance on empirical regimens. Strengthening microbiology services and standardising diagnostic pathways may therefore represent a practical implication for improving utilisation quality rather than utilisation volume.

6. Theoretical and Practical Implications

6.1 Theoretical implications

The present findings have supported the use of Donabedian's Structure–Process–Outcome logic for explaining variation in antibiotic cement–coated intramedullary nail utilisation across Libyan public hospitals, as structural capacity and diagnostic support have aligned with clinician-level decision orientation and capability [14]. Resource availability, microbiology access, and institutional protocols have operated as enabling conditions that have shaped process behaviours in chronic infection management, which has been consistent with the view that biofilm-associated osteomyelitis requires integrated service inputs rather than isolated clinical decision-making [1,2].

6.2 Practical implications

The study has indicated that coated nail utilisation has been associated with structural capacity, surgeon capability, and diagnostic support, suggesting that service organisation could influence practice consistency across the Eastern, Central, and Western regions. Improved availability of intramedullary implants, PMMA cement with appropriate antibiotics, and dependable theatre access might strengthen the feasibility of single-stage strategies where clinically appropriate, particularly given the recognised limitations of systemic antibiotics in devitalised bone and biofilm settings [6,10]. Microbiology culture and susceptibility capacity have also appeared relevant to clinician confidence, which may reduce empirical prescribing variability and support antimicrobial stewardship in chronic infection pathways [17]. Standardised institutional protocols, supported by multidisciplinary input, might reduce unwarranted variation between hospitals such as Sabratha, Ibn Sina, Benghazi Medical Centre, and Al-Butnan, with potential implications for limb-salvage planning and follow-up continuity.

7. Strengths and Limitations

7.1 Strengths

The study has benefited from a large multi-region sample drawn from public hospitals across Libya, which has enhanced the representativeness of clinician perspectives within major trauma and referral settings. Balanced regional coverage has enabled examination of geographic variation in caseload and utilisation patterns. Use of a structured instrument with acceptable internal consistency and convergent validity has improved interpretability of the Structure–Process–Outcome mapping. Multivariable modelling has also supported examination of independent predictors while accounting for overlapping service and clinician factors [15,16].

7.2 Limitations

Several limitations have affected interpretive scope. The cross-sectional design has captured associations at one time point and therefore has not established temporal ordering or causal pathways between structural capacity, decision orientation, and utilisation outcomes [15,16,

20]. Self-reported practice has been vulnerable to recall and social desirability bias, particularly where coated nail use is positioned as a preferred contemporary strategy. Sampling has relied on purposive–convenience recruitment, which may have over-represented clinicians in higher-volume centres and may have under-represented smaller hospitals with limited orthopaedic infection services, potentially restricting generalisability to remote facilities. Measurement has focused on perceived availability and confidence rather than objective verification of inventory, theatre scheduling, microbiology turnaround, or supply-chain stability, which might have introduced misclassification of "structural capacity" under fluctuating service conditions. Outcome measurement has focused on utilisation patterns rather than patient outcomes, and therefore infection remission, recurrence, complications, and functional recovery have not been directly evaluated, despite their clinical relevance in chronic osteomyelitis management [1,17,21]. Hospital-level clustering has not been fully accounted for within individual-level responses, which may have influenced precision where institutional norms strongly shape practice. In addition, potential institutional variation between participating hospitals, including differences in referral pathways, operating theatre capacity, microbiology turnaround, procurement systems, and local infection-management protocols, may have contributed to variation in reported utilisation patterns beyond the measured individual-level factors.

8. Recommendations for Future Study

Future research could strengthen evidence by adopting prospective or mixed-methods designs that link service structures and clinician decisions to patient-level outcomes, including recurrence, time to union, re-operation, and functional status, which have been central concerns in chronic osteomyelitis pathways [1,22]. Such outcomes would provide an important clinical complement to the present utilisation-based analysis by clarifying whether greater use of coated nails is associated with improved remission, fewer complications, and better functional recovery in routine practice. Multi-centre clinical registries across the Eastern, Central, and Western regions could support more reliable estimates of chronic osteomyelitis burden and enable benchmarking of diagnostic practice, microbiology yield, antibiotic selection, and follow-up patterns. Objective facility audits could complement survey data by documenting implant and cement availability, theatre capacity, microbiology turnaround, and imaging access, allowing validation of structural indices and improving reproducibility. Qualitative work with surgeons, microbiologists, theatre managers, and pharmacy leads could clarify how institutional protocols, procurement constraints, and antimicrobial stewardship practices influence real-world utilisation of coated nails and local antibiotic strategies [9,10]. Comparative evaluation of coated nails against staged strategies or alternative local carriers could also be explored in the Libyan setting, although careful adjustment for case complexity and vascularity-related confounding would be required given the biofilm and devitalised bone challenges that have been widely recognised [2,6].

9. Conclusion

The present study has examined utilisation of antibiotic cement–coated intramedullary nails for chronic long-bone osteomyelitis across Libyan public hospitals in the Eastern, Central, and Western regions, including key referral settings such as Sabratha Hospital, Ibn Sina Hospital, Benghazi Medical Centre, and Al-Butnan Medical Centre. The findings have indicated that coated nail utilisation has aligned with both hospital structural capacity and surgeon-level

processes, suggesting that availability of implants, cement, theatre access, and diagnostic support has shaped adoption alongside clinician capability and decision orientation. Evidence about the limitations of systemic antibiotics in devitalised, biofilm-associated bone has remained central to the clinical rationale for local delivery approaches, and the observed preference for combined stabilisation and local antibiotic delivery has reflected this established pathophysiological framing .Regional differences in reported caseload have also suggested that service pressures have not been evenly distributed across Libya, which may have implications for resource planning and guideline implementation. The overall pattern has indicated that osteomyelitis management has functioned as a health-service problem as well as a surgical problem, with outcomes likely influenced by infrastructure, multidisciplinary support, and institutional protocols in addition to operative technique.

10. References

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