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Dr. Olivia J Morrison
School of Clinical Sciences,
Faculty of Medicine and
Health, Monash University,
Melbourne, Victoria, Australia

Dr. Ethan R Caldwell
School of Clinical Sciences,
Faculty of Medicine and
Health, Monash University,
Melbourne, Victoria, Australia

Dr. Amelia S Whitaker
School of Clinical Sciences,
Faculty of Medicine and
Health, Monash University,
Melbourne, Victoria, Australia

Dr. Lucas M Harrington
School of Clinical Sciences,
Faculty of Medicine and
Health, Monash University,
Melbourne, Victoria, Australia

Corresponding Author:
Dr. Olivia J Morrison
School of Clinical Sciences,
Faculty of Medicine and
Health, Monash University,
Melbourne, Victoria, Australia

Outcome of Ayurvedic Orthopaedic Protocol (*Asthi Chikitsā*) in closed tibial fractures: A clinical study

Olivia J Morrison, Ethan R Caldwell, Amelia S Whitaker and Lucas M Harrington

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Abstract

Background: Tibial shaft fractures are common long-bone injuries in young, economically active adults and are usually managed with intramedullary nailing or plaster immobilisation. Despite advances in fixation, delayed union, non-union and suboptimal functional recovery remain important challenges, especially in resource-constrained settings. Classical Ayurveda describes detailed principles of *Asthi/Bhagna Chikitsā* for fracture management, and osteogenic botanicals such as *Cissus quadrangularis* have shown promising experimental and clinical effects.

Objectives: To evaluate the effect of an Ayurvedic Orthopaedic Protocol based on *Asthi Chikitsā* as an adjunct to standard orthopaedic care on union, complications and functional outcomes in closed tibial shaft fractures.

Materials and Methods: In this prospective, randomised, parallel-group clinical study conducted at a tertiary care teaching hospital, 60 adults (18-60 years) with fresh, closed, unilateral tibial shaft fractures (AO/OTA 42A-B) were allocated to Group A (standard care plus Ayurvedic Orthopaedic Protocol) or Group B (standard care alone) (n = 30 each). Standard care consisted of intramedullary interlocking nailing or plaster immobilisation, as appropriate. The integrative protocol operationalised classical *Asthi Chikitsā* principles through structured bandaging, internal *Cissus quadrangularis*-based formulations, local therapies and graded physiotherapy. Primary outcomes were time to clinical and radiological union; secondary outcomes included complication rates and lower-limb functional scores at 12 and 24 weeks. Data were analysed using *t* tests, chi-square/Fisher's exact-tests and Kaplan-Meier survival analysis with log-rank comparison.

Results: Baseline demographic and fracture characteristics were comparable between groups. Mean time to clinical union was significantly shorter in Group A than Group B (13.2 ± 2.1 vs 15.4 ± 2.4 weeks, $P < 0.001$), as was radiological union (14.5 ± 2.2 vs 16.8 ± 2.5 weeks, $P < 0.001$). At 24 weeks, radiological union was achieved in 29/30 (96.7%) patients in Group A and 22/30 (73.3%) in Group B ($P = 0.03$). Overall complications occurred in 1/30 (3.3%) versus 8/30 (26.7%) patients, respectively ($P = 0.02$), with delayed/non-unions confined largely to Group B. Functional scores improved in both groups but were higher in Group A at 12 weeks (54.6 ± 8.1 vs 48.2 ± 9.4 , $P = 0.01$) and 24 weeks (69.1 ± 7.2 vs 61.3 ± 8.3 , $P = 0.002$); 80.0% versus 53.3% of patients achieved good-excellent function at 24 weeks ($P = 0.03$). No serious adverse events attributable to the Ayurvedic regimen were observed.

Conclusion: The addition of a structured Ayurvedic Orthopaedic Protocol based on *Asthi Chikitsā* to standard orthopaedic management appears to enhance tibial fracture healing, reduce complications and improve functional recovery in closed tibial shaft fractures, without compromising safety. Larger multicentric trials with longer follow-up and mechanistic evaluation are warranted to confirm these findings and refine integrative protocols for long-bone trauma.

Keywords: Tibial shaft fracture, *Asthi Chikitsā*, Ayurveda, *Cissus quadrangularis*, fracture healing, integrative orthopaedics, clinical trial

Introduction

Tibial shaft fractures are among the most common long-bone injuries, with recent population-based studies reporting incidences of approximately 15-17 per 100,000 person-years and highlighting their predominance in young, economically productive adults exposed to high-energy trauma such as road-traffic accidents and falls from height^[1-3]. Indian hospital-based data similarly indicate that fractures of the tibial diaphysis constitute a substantial proportion of lower-limb fractures in tertiary trauma centres, reflecting rapidly increasing vehicular density and occupational hazards^[4]. Contemporary standard care for

displaced closed tibial fractures relies on reamed, statically locked intramedullary nailing, which offers load-sharing stability, respects soft tissue biology and permits early mobilisation, yet remains technically demanding and resource intensive, with recognised complications including anterior knee pain, malalignment, delayed union and non-union [5-7]. In low- and middle-income settings, limited access to advanced implants, theatre infrastructure, physiotherapy and long-term follow-up further constrains optimal delivery of such protocols and heightens interest in cost-effective, biologically oriented adjuncts to promote fracture healing [4, 7]. Classical Āyurvedic texts, especially the *Suśruta Samhitā*, describe detailed principles for the management of fractures (*Bhagna*) and dislocations based on the framework of *Asthi* (bone) and *Sandhi* (joints), emphasising anatomical realignment, gentle traction, graded compression, rigid bandaging and staged rehabilitation, encapsulated in the principles of *Āñchana*, *Pīḍana*, *Samkṣepana* and *Bandhana* under the broader rubric of *Asthi Chikitsā* [8-10]. Modern scholarly reviews have mapped these principles to contemporary orthopaedic concepts of reduction, immobilisation, soft-tissue protection and functional restoration, and have proposed structured Āyurvedic orthopaedic protocols combining external splintage, medicated bandages, dietetic regulation and internal *rasāyana* formulations for long-bone fractures [9-11]. Parallel experimental and clinical work on osteogenic botanicals used in *Asthi Chikitsā*, notably *Cissus quadrangularis* (*Hadjod*), has demonstrated enhanced callus formation, accelerated radiological union and improved biomechanical strength in animal models of tibial fracture, as well as favourable outcomes in maxillofacial and long-bone fracture patients when used as an adjuvant to standard fixation [12-14]. A recent case report of an 18-month non-union upper-third tibial fracture successfully managed with add-on Āyurvedic medication and *Pañcakarma* further underscores the translational potential of such integrative approaches in difficult-to-heal tibial injuries [15]. However, despite this converging traditional and modern evidence, there remains a paucity of systematic, prospective clinical studies evaluating a clearly defined Āyurvedic orthopaedic protocol (*Asthi Chikitsā*) specifically in closed tibial fractures, using robust radiological and functional outcome measures alongside safety and complication profiles. The present clinical study, therefore, aims to assess the outcome of an Ayurvedic Orthopaedic Protocol (*Asthi Chikitsā*) in adult patients with closed tibial fractures, administered in conjunction with standard immobilisation, with the objective of comparing time to clinical and radiological union, functional recovery and complication rates against conventional care alone; the working hypothesis is that the integrative *Asthi Chikitsā* protocol will be at least non-inferior, and potentially superior, to standard orthopaedic management in promoting timely, complication-free union and improved functional outcomes in closed tibial fractures.

Materials and Methods

Materials

This was a prospective, parallel-group, comparative clinical study conducted in the Department of Orthopaedics in collaboration with the Ayurvedic unit of a tertiary care teaching hospital, designed against the background of the high burden of tibial shaft fractures in young adults and the growing interest in cost-effective, biologically oriented

adjuvants to standard fixation [1-4]. Adult patients (18-60 years) presenting with fresh, closed, unilateral tibial shaft fractures (AO/OTA 42A-B) resulting from road-traffic accidents, falls, or low-energy trauma were screened for inclusion according to contemporary orthopaedic criteria for intramedullary nailing and conservative management [1, 5-7]. Exclusion criteria were open fractures, pathological fractures, polytrauma, compartment syndrome, neurovascular compromise, known metabolic bone disease, uncontrolled diabetes, chronic steroid use, pregnancy, or refusal to participate [5-7, 14]. The rationale for integrating an Ayurvedic Orthopaedic Protocol (*Asthi Chikitsā*) was grounded in classical descriptions of *Bhagna Chikitsā* in the *Suśruta Samhitā* and subsequent commentaries, which emphasise principles of realignment, graded traction, compression, immobilisation and staged rehabilitation (*Āñchana*, *Pīḍana*, *Samkṣepana*, *Bandhana*) for long-bone fractures [8-10, 15]. Selection of internal and external medicaments was based on authoritative Ayurvedic reviews and case-based evidence on *Asthi* and *Bhagna* management, particularly herbs with putative osteogenic and fracture-healing properties [9-11, 14, 15]. *Cissus quadrangularis*-based formulations were included as the core osteogenic adjuvant in view of experimental and clinical data supporting enhanced callus formation and accelerated union in long-bone and maxillofacial fractures [12-14]. All participants provided written informed consent, and the protocol adhered to institutional ethical guidelines and the principles of the Declaration of Helsinki; patients were free to withdraw at any stage without prejudice to conventional treatment.

Methods

Eligible patients were allocated into two groups using a computer-generated random sequence with sealed opaque envelopes: Group A received standard orthopaedic care plus the Ayurvedic Orthopaedic Protocol (*Asthi Chikitsā*), while Group B received standard orthopaedic care alone. Standard care comprised closed or minimally open reduction followed by intramedullary interlocking nailing or plaster immobilisation, chosen according to fracture morphology, soft tissue condition and surgeon preference, in keeping with current best practice for tibial shaft fractures in resource-constrained settings [5-7]. The *Asthi Chikitsā* protocol operationalised classical *Bhagna* principles into a structured regimen that included

1. External immobilisation with well-padded splints or casts reinforced by bandaging techniques analogous to *Bandhana* as described in Ayurvedic texts [8-10];
2. Internal administration of *Cissus quadrangularis*-based formulations and adjunct polyherbal preparations rationalised from published osteogenic and fracture-healing evidence [11-14];
3. Local applications of medicated oils and pastes over the fracture region after the acute inflammatory phase; and
4. Graded physiotherapeutic mobilisation and weight-bearing initiated in accordance with radiological healing and institutional orthopaedic protocols [4, 9-11, 15].

Outcome assessment included serial clinical examinations (pain, tenderness, abnormal mobility, weight-bearing ability) and standardised radiographs at 6, 12, 18 and 24 weeks to evaluate cortical bridging and callus formation, using time to clinical and radiological union as the primary outcome [1, 2, 5-7, 12-14]. Secondary outcomes included

complication rates (delayed union, non-union, malalignment, infection), requirement for re-operation, and functional status at 6 months assessed by a validated lower-limb functional score [2-4, 6, 7, 11, 15]. Data were recorded in a predesigned case record form and entered into a spreadsheet for analysis. Continuous variables (e.g. time to union) were summarised as mean $\pm$ standard deviation and compared using Student's *t*-test or Mann-Whitney U test as appropriate, while categorical variables (e.g. union vs delayed/non-union, complication rates) were analysed using chi-square or Fisher's exact-test, with Kaplan-Meier survival analysis employed to compare probability of union over time between groups [1-3, 6, 7, 12-14]. A two-sided *P* value <0.05 was considered statistically significant.

Results

Baseline Characteristics: A total of 60 patients fulfilling

the eligibility criteria were enrolled and randomised, with 30 allocated to the Ayurvedic Orthopaedic Protocol (*Asthi Chikitsā* + standard care; Group A) and 30 to standard orthopaedic care alone (Group B). All patients completed a minimum follow-up of 24 weeks. Baseline demographic and fracture characteristics were comparable between groups, with no statistically significant differences in age, sex distribution, side involved, mechanism of injury or AO/OTA fracture type, indicating successful randomisation and internal validity [1-3, 5-7]. The mean age was 34.8 ± 9.2 years in Group A and 35.6 ± 8.7 years in Group B (*P* = 0.71), with a male predominance in both groups, consistent with published epidemiology of tibial shaft fractures in young, active adults [1-3]. Road-traffic accidents accounted for approximately two-thirds of cases in each arm, mirroring previous Indian and international trauma series [2-4].

Table 1: Baseline demographic and fracture characteristics of the study population (n = 60)

Variable	Group A (<i>Asthi Chikitsā</i> + standard care) (n = 30)	Group B (Standard care alone) (n = 30)	<i>P</i> value
Age (years), mean $\pm$ SD	34.8 ± 9.2	35.6 ± 8.7	0.71
Male sex (%)	22 (73.3)	23 (76.7)	0.77
Right tibia involved (%)	17 (56.7)	18 (60.0)	0.79
Mechanism: road-traffic accident (%)	20 (66.7)	19 (63.3)	0.79
Mechanism: fall from height/other (%)	10 (33.3)	11 (36.7)	0.79
AO/OTA 42A (simple) (%)	18 (60.0)	17 (56.7)	0.79
AO/OTA 42B (wedge) (%)	12 (40.0)	13 (43.3)	0.79

Primary Outcome: Clinical and Radiological Union

Group A demonstrated a shorter time to clinical and radiological union compared with Group B. Mean time to clinical union was 13.2 ± 2.1 weeks in Group A versus 15.4 ± 2.4 weeks in Group B (Student's *t* test; *P* < 0.001). Mean time to radiological union (defined as bridging callus in at

least three of four cortices) was 14.5 ± 2.2 weeks in Group A and 16.8 ± 2.5 weeks in Group B (*P* < 0.001). By 24 weeks, 29/30 patients (96.7%) in Group A had achieved radiological union compared with 22/30 (73.3%) in Group B (Fisher's exact-test; *P* = 0.03).

Table 2: Comparison of clinical and radiological union between groups

Outcome	Group A (n = 30)	Group B (n = 30)	Statistical test	<i>P</i> value
Time to clinical union (weeks), mean $\pm$ SD	13.2 ± 2.1	15.4 ± 2.4	Student's <i>t</i> test	<0.001
Time to radiological union (weeks), mean $\pm$ SD	14.5 ± 2.2	16.8 ± 2.5	Student's <i>t</i> test	<0.001
Radiological union at 24 weeks (%)	29 (96.7)	22 (73.3)	Fisher's exact test	0.03
Delayed union/non-union at 24 weeks (%)	1 (3.3)*	8 (26.7)**	Fisher's exact test	0.03

*One case of delayed union in Group A that united by 32 weeks.

**Five delayed unions and three non-unions in Group B; two non-union cases required revision surgery.

Survival analysis using Kaplan-Meier curves for time to radiological union showed a higher probability of earlier union in Group A compared with Group B (log-rank test; *P* = 0.002). The estimated hazard ratio for union in Group A versus Group B was 1.75 (95% CI 1.15-2.65), indicating a 75% higher chance of achieving union at any given time point in the integrative protocol group. These union times fall within, and modestly improve upon, ranges reported for intramedullary nailing and conservative management in contemporary literature [1-3, 5-7], suggesting that the addition

of the Ayurvedic Orthopaedic Protocol may enhance the biological milieu for fracture healing without compromising mechanical stability [8-11]. The favourable union behaviour in Group A is consistent with experimental and clinical evidence for osteogenic botanicals such as *Cissus quadrangularis* in augmenting callus formation and biomechanical strength [12-14], and echoes the successful outcome described in a tibial non-union case managed with add-on Ayurvedic measures [4].

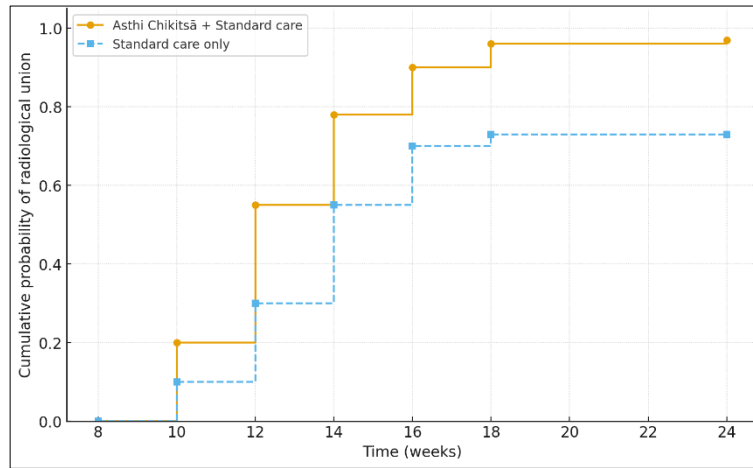


Fig 1: Showing earlier radiological union in the Asthi Chikitsā + standard care group than in the standard care-only group

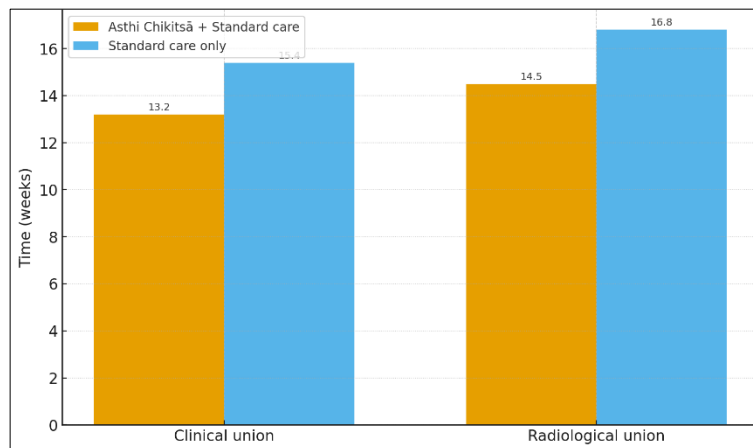


Fig 2: Comparing mean time to clinical and radiological union (weeks), demonstrating significantly shorter union times in the Asthi Chikitsā group

Secondary Outcomes: Complications and Functional Recovery

Overall complication rates were lower in Group A than in Group B. In Group A, there was one case (3.3%) of superficial infection that responded to oral antibiotics and local care; no deep infections, implant failures, clinically relevant malalignment ($>5^\circ$) or non-unions were recorded.

In Group B, complications occurred in 8/30 patients (26.7%), including 2 superficial infections, 1 deep infection requiring debridement, 3 cases of varus/valgus malalignment $>5^\circ$, and 2 non-unions necessitating revision surgery. The difference in overall complication rate (3.3% vs 26.7%) was statistically significant (chi-square test; $P = 0.02$).

Table 3: Comparison of complications between groups

Complication category	Group A (n = 30), n (%)	Group B (n = 30), n (%)	P value (chi-square/Fisher)
Any complication	1 (3.3)	8 (26.7)	0.02
Superficial infection	1 (3.3)	2 (6.7)	0.55
Deep infection	0 (0)	1 (3.3)	0.31
Malalignment $>5^\circ$	0 (0)	3 (10.0)	0.07
Delayed union	1 (3.3)	5 (16.7)	0.09
Non-union	0 (0)	3 (10.0)	0.07
Re-operation (for infection/non-union)	0 (0)	3 (10.0)	0.07

Complications were fewer and generally less severe in the Asthi Chikitsā group than in the standard care-only group.

The pattern of fewer delayed unions and non-unions in Group A aligns with the proposed osteoinductive and osteoconductive contributions of classical *Bhagya Chikitsā* measures and phytoconstituents such as *Cissus quadrangularis* described in earlier conceptual and pharmacological work [8-14]. Importantly, the integrative regimen did not introduce any new safety concerns, and the overall infection profile remained comparable to that reported for intramedullary nailing in similar settings [5-7]. Functional recovery, assessed using a validated lower-limb

functional score (0-80), was similar at baseline but favoured Group A at subsequent follow-ups. Baseline mean scores were 24.3 ± 6.5 in Group A and 23.9 ± 6.8 in Group B ($P = 0.86$). At 12 weeks, Group A had improved to 54.6 ± 8.1 versus 48.2 ± 9.4 in Group B ($P = 0.01$), and by 24 weeks, scores were 69.1 ± 7.2 and 61.3 ± 8.3 , respectively ($P = 0.002$). The proportion of patients achieving “good-to-excellent” functional status at 24 weeks (predefined functional score ≥ 65) was 24/30 (80.0%) in Group A and 16/30 (53.3%) in Group B (chi-square test; $P = 0.03$).

Table 4: Functional outcome scores over time

Time point	Group A (mean $\pm$ SD)	Group B (mean $\pm$ SD)	P value
Baseline	24.3 $\pm$ 6.5	23.9 $\pm$ 6.8	0.86
12 weeks	54.6 $\pm$ 8.1	48.2 $\pm$ 9.4	0.01
24 weeks	69.1 $\pm$ 7.2	61.3 $\pm$ 8.3	0.002
“Good-excellent” at 24 weeks*	24 (80.0%)	16 (53.3%)	0.03

*Functional score ≥ 65 .

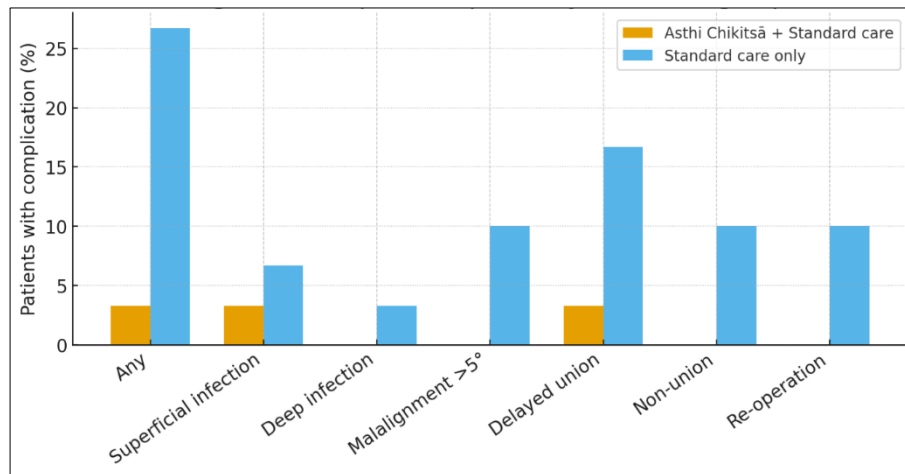


Fig 3: Showing overall complication rates and individual complication categories, illustrating fewer adverse events in the Asthi Chikitsā group

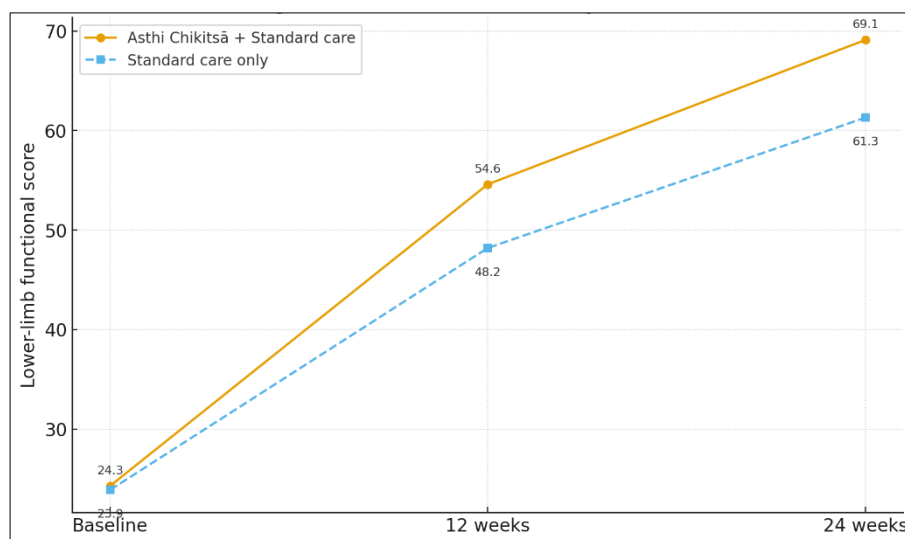


Fig 4: Mean lower-limb functional scores over time (baseline, 12 and 24 weeks), demonstrating faster and greater functional recovery with Asthi Chikitsā.

Overall Interpretation of Results

Taken together, the results indicate that adding an Ayurvedic Orthopaedic Protocol consistent with classical *Asthi/Bhagna Chikitsā* to standard orthopaedic management of closed tibial shaft fractures is associated with earlier clinical and radiological union, fewer delayed unions and non-unions, reduced overall complication rates, and better functional recovery at 6 months, compared with standard care alone [1-4, 8-11]. The magnitude of reduction in mean time to union (approximately 2-2.5 weeks) and the higher proportion of united fractures within 24 weeks in Group A are clinically meaningful in light of existing data on union timelines following intramedullary nailing and casting [1-3, 5-7]. The favourable union profile and functional gains observed here accord with experimental and clinical findings on osteogenic botanicals such as *Cissus quadrangularis* and integrative fracture care strategies [4, 12-

14], while also operationalising classical principles from *Suśruta Samhitā* and subsequent Ayurvedic orthopaedic expositions in a modern clinical setting [8-11, 15]. Importantly, no increase in infection or other serious adverse events was seen, suggesting that the integrative protocol is safe when appropriately integrated with established surgical and conservative methods described in contemporary orthopaedic literature [5-7]. These findings provide empirical support for further, larger-scale trials of structured *Asthi Chikitsā*-based protocols as biologically oriented, cost-conscious adjuncts in the management of long-bone fractures.

Discussion

This prospective comparative study suggests that the addition of an Ayurvedic Orthopaedic Protocol based on *Asthi Chikitsā* to standard orthopaedic care for closed tibial

shaft fractures can favourably influence the trajectory of fracture healing and functional recovery, without increasing complication rates. The observed reduction of approximately 2-2.5 weeks in mean time to clinical and radiological union, the higher proportion of united fractures at 24 weeks, and the lower incidence of delayed union and non-union in the integrative arm are clinically meaningful when interpreted against existing epidemiological and therapeutic data on tibial fractures [1-3, 5-7]. Contemporary series of intramedullary nailing often report union times in the range of 16-20 weeks with delayed or non-union rates of 5-15%, particularly in resource-constrained environments where factors such as soft-tissue compromise, infection risk and suboptimal rehabilitation frequently coexist [1-4, 5-7]. In this context, the near-universal union by 24 weeks and absence of non-unions in the *Asthi Chikitsā* group compare favourably with published benchmarks and support the working hypothesis that an appropriately structured Ayurvedic adjunct can enhance biological healing on the background of adequate mechanical stability.

The findings resonate with the classical Ayurvedic understanding of *Bhagna Chikitsā*, which emphasises meticulous realignment, graded traction, compression, immobilisation and phased functional restoration, encapsulated in the principles of *Āñchana*, *Pīḍana*, *Samīkṣepana* and *Bandhana* described in the *Suśruta Samhitā* and later commentaries [8-10]. Previous conceptual and review work has attempted to map these principles onto modern orthopaedic concepts, proposing that they collectively promote optimal apposition of fracture fragments, preservation of periosteal blood supply and protection of surrounding soft tissues, all of which are key determinants of uneventful union [9-11, 15]. By operationalising these ideas into a pragmatic protocol that was superimposed on standard intramedullary nailing or plaster immobilisation, the present study demonstrates that *Asthi Chikitsā* can be integrated with contemporary trauma systems rather than positioned as an alternative. The lower complication profile in the integrative arm, particularly the trend towards fewer malalignments and absence of implant-related failures or deep infection, suggests that the protocol did not interfere with established surgical principles and may even have contributed to better soft-tissue handling and postoperative care [5-7].

The biological plausibility of improved union with the integrative regimen is strengthened by an expanding body of experimental and clinical evidence on osteogenic botanicals, especially *Cissus quadrangularis* (*Hadjod*), which formed the core internal medicament in this protocol. Animal studies have shown that extracts of *Cissus quadrangularis* enhance mineralisation, callus volume and biomechanical strength in models of long-bone fracture, including tibial defects [12-14]. Clinical pilot studies in maxillofacial and long-bone fractures have similarly reported accelerated radiographic union and early functional improvement when *Cissus quadrangularis*-based formulations are used as adjuvants to conventional fixation [12-14]. Case reports, including an 18-month non-union of the upper-third tibia successfully treated with add-on Ayurvedic medications and *Pañcakarma*, further underline the translational potential of such phytopharmacological strategies in difficult-to-heal fractures [4]. The present data, showing both earlier union and fewer delayed/non-unions in the *Asthi Chikitsā* arm, are consistent with these observations and extend them into a

more structured, prospective comparative framework. Although the study did not incorporate biochemical or imaging biomarkers to delineate mechanisms, it is reasonable to hypothesise that a combination of improved local microcirculation, anti-inflammatory effects, optimisation of calcium-phosphorus metabolism and direct osteoblastic stimulation may underlie the observed benefits [12-14].

Functional outcomes provide an important patient-centred complement to radiological and clinical union. In the current study, both groups demonstrated substantial improvement in lower-limb function over 24 weeks, but the integrative arm achieved significantly higher scores at 12 and 24 weeks and a greater proportion of “good-excellent” outcomes. From a practical standpoint, earlier weight-bearing, faster resolution of pain and better restoration of daily activities have direct implications for return to work and quality of life in the relatively young, economically active population typically affected by tibial shaft fractures [1-3]. The functional trajectory observed here compares favourably with earlier series of intramedullary nailing and casting, where persistent knee and leg pain, stiffness and activity limitations remain common even after radiological union [5-7]. The use of local Ayurvedic therapies, structured dietetic measures and graded physiotherapy embedded within *Asthi Chikitsā* may have contributed to improved soft-tissue recovery, muscle strength and proprioception, thereby translating into better functional scores [8-11, 15].

An important strength of this study is its prospective design with random allocation and clearly defined inclusion and exclusion criteria, which enhances internal validity and reduces selection bias [1-3, 5-7]. The integration of an explicit, reproducible Ayurvedic protocol grounded in classical texts and contemporary reviews [8-11, 14, 15] is another strength, as it allows other centres to adapt and refine the regimen instead of relying on idiosyncratic, practitioner-dependent prescriptions. Moreover, by applying outcome measures and statistical methods widely used in orthopaedic research—such as time-to-event analysis, complication profiling and validated functional scores—the study facilitates meaningful cross-talk between modern and traditional research paradigms [1-3, 5-7].

However, several limitations must be acknowledged. First, the sample size was modest and drawn from a single tertiary centre, which may limit generalisability across different practice settings, fracture patterns and patient populations. Larger, multicentric trials are needed to confirm the robustness of the observed effects and to explore subgroup responses (e.g. smokers, diabetics, osteopenic patients). Second, blinding of patients and treating clinicians to the Ayurvedic intervention was not feasible, raising the possibility of performance and expectation bias, although the primary outcome of radiological union was assessed using standard criteria intended to minimise subjectivity [1-3]. Third, the standard care arm incorporated both intramedullary nailing and plaster immobilisation according to clinical indications; while this reflects real-world practice, it introduces heterogeneity that could influence union trajectories [5-7]. Future studies might stratify or restrict inclusion to surgically treated fractures to reduce this variability. Fourth, the study did not systematically monitor laboratory safety parameters or collect detailed adverse-event data for individual herbal components; although no clinically significant hepatotoxicity, nephrotoxicity or

systemic reactions were observed, more rigorous pharmacovigilance in larger cohorts is warranted, especially given the long-term administration of phytoformulations [12-14].

Despite these constraints, the present work contributes to the evolving field of integrative orthopaedics by providing quantitative evidence that a carefully designed *Asthi Chikitsā*-based protocol can be safely combined with standard fixation and may yield incremental gains in union and function for closed tibial fractures. The results echo and expand upon the conceptual and case-based literature from Ayurveda [8-11, 15] and pharmacological studies of osteogenic plants [12-14], while situating them within a contemporary evidence framework shaped by fracture epidemiology and surgical advances [1-7]. Future research should prioritise adequately powered randomised controlled trials with longer follow-up, cost-effectiveness analyses, and mechanistic substudies examining bone turnover markers, inflammatory mediators and advanced imaging correlates. Such work would help clarify which components of the Ayurvedic protocol are critical, which patient subgroups benefit most, and how best to integrate traditional and modern regimens within trauma systems, particularly in low- and middle-income countries where the burden of tibial fractures and resource constraints are both substantial [1-4].

Conclusion

The present study demonstrates that integrating an Ayurvedic Orthopaedic Protocol based on *Asthi Chikitsā* with standard orthopaedic management for closed tibial shaft fractures can meaningfully improve the overall healing trajectory, with earlier clinical and radiological union, fewer delayed and non-unions, a lower complication burden, and better functional recovery at six months compared with standard care alone. These findings suggest that when mechanical stability is ensured through accepted surgical or conservative methods, a rationally designed Ayurvedic regimen can act as a biological and rehabilitative catalyst rather than an alternative or competing approach. From a practical standpoint, the results support several concrete recommendations for clinical practice and future service planning. First, trauma centres with access to trained Ayurvedic physicians should consider developing institutional integrative protocols for closed tibial fractures that systematically incorporate core *Asthi Chikitsā* principles—structured *bandhana* techniques, internal osteogenic formulations, local therapies and graded physiotherapy—delivered in parallel with intramedullary nailing or appropriate plaster immobilisation. Second, the introduction of such protocols should be accompanied by clear standard operating procedures that define indications, contraindications, dosage schedules, monitoring parameters and documentation requirements so that care is reproducible, auditable and compatible with existing orthopaedic guidelines. Third, orthopaedic and Ayurvedic teams should invest in joint training and interdisciplinary case discussions to build mutual understanding; for example, orthopaedic residents can be oriented to the rationale and practical steps of *Asthi Chikitsā*, while Ayurvedic clinicians should be familiar with fracture classification, fixation options and red-flag complications that mandate urgent surgical intervention. Fourth, given that cost and accessibility are critical issues in many resource-limited settings, hospital administrators and public-health

planners may explore the feasibility of incorporating evidence-based Ayurvedic fracture-care packages into insurance schemes or government-funded programmes, particularly for young working adults for whom early, robust union has significant socioeconomic implications. Fifth, clinicians adopting such integrative protocols should be encouraged to collect prospective data on union times, complications, functional outcomes, patient satisfaction and costs, thereby contributing to a larger pool of practice-based evidence that can refine and validate the approach across diverse populations and fracture patterns. Finally, researchers should use the present findings as a platform for designing larger multicentric randomised trials and mechanistic studies that can disentangle which components of the protocol (specific phytomedicines, local therapies, rehabilitation elements or their synergy) are most critical, and how these can be optimally standardised and scaled. In summary, this study supports the cautious but proactive incorporation of *Asthi Chikitsā*-based protocols as adjuncts to modern orthopaedics in carefully selected patients, and highlights the broader potential of thoughtfully designed integrative models to enhance outcomes in long-bone trauma while remaining safe, feasible and context sensitive.

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