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ORIGINAL RESEARCH

Titanium versus Biodegradable Implants for Fracture Fixation: A Retrospective Comparative Study

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Background: Titanium alloy implants are widely used in fracture fixation due to their excellent mechanical stability, but they often require secondary surgeries for removal. In contrast, biodegradable implants eliminate the need for removal, yet concerns regarding their mechanical strength in load-bearing bones remain. This study evaluates the clinical trade-off between mechanical rigidity and the burden of secondary surgery by comparing titanium versus biodegradable implants in limb and pelvic fractures.

Methods: A retrospective cohort study was conducted on 73 patients treated between November 2021 and August 2024. Patients were divided into the titanium group (n = 40, primarily diaphyseal fractures) and the biodegradable group (n = 33, primarily metaphyseal/peri-articular fractures). Outcomes including implant palpability and reoperation rates were assessed. A stratified analysis compared outcomes in weight-bearing versus non-weight-bearing fractures.

Results: The mean age of patients was 42.6 ± 16.03 years. Titanium implants were associated with significantly higher rates of plate palpability (18/40, 45.0% vs 3/33, 9.1%; OR 8.18, 95% CI 2.14–31.3; $P = 0.001$) and secondary surgery (14/40, 35.0% vs 3/33, 9.1%; OR 5.38, 95% CI 1.39–20.8; $P = 0.012$) compared to biodegradable implants. Elective removal due to discomfort occurred in 17.5% (7/40) of titanium patients but was eliminated (0%) in the biodegradable group ($P = 0.014$). In the weight-bearing subgroup, biodegradable implants significantly reduced palpability (11.1% vs 53.3%, OR 9.14) without increasing complication-driven reoperations. However, three cases (9.1%) of refracture occurred in the biodegradable group compared to zero in the titanium group ($P = 0.088$).

Conclusion: In this cohort, biodegradable implants were associated with a reduction in implant palpability and elective removal surgery for metaphyseal and peri-articular fractures. However, due to lower mechanical strength, titanium remains the preferred choice for diaphyseal fractures requiring high mechanical stability. These findings are limited by the retrospective design and heterogeneity of fracture sites.

Keywords: titanium implants, biodegradable implants, fracture fixation, plate palpability, secondary surgery

Introduction

Bone fractures are among the most common musculoskeletal injuries mainly result from pathological weakness and mechanical trauma.[1] The global incidence of fractures is about 1% ~ 2%, of which limb fractures account for about 60% to 70%. For fractures accompanied by severe displacement that cannot achieve functional or anatomical alignment through manual reduction, surgical intervention is required. Open reduction and internal fixation (ORIF) using plates, screws or intramedullary nails remains the standard of care.[2,3] Most upper and lower limb fractures take approximately 3 to 6 months or more to complete healing.[4]

Commonly used internal fixation implants include stainless steel implants, carbon fiber implants, titanium alloy, and biodegradable alloy.[5] Titanium alloy implants are widely favored for their superior mechanical strength, biocompatibility and corrosion resistance. Compared with stainless steel implants, the flexibility of titanium alloy implants allows control

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of strain between debris and promotes bone healing.[6] Titanium alloys demonstrated superior mechanical properties compared with carbon fiber implants.[7] However, a significant clinical limitation of metallic fixation is hardware prominence, particularly in anatomical regions with thin soft tissue coverage (eg, the ankle or distal tibia). This frequently results in symptomatic palpability and discomfort, necessitating a secondary surgical procedure for implant removal.[8] This second trauma increases the economic burden on the healthcare system and exposes patients to additional surgical risks.

These drawbacks of metallic implants have driven the introduction of biodegradable fixation systems, which are designed to provide temporary stability during the healing phase before being gradually absorbed by the body, thus eliminating the need for removal.[9] Degradable implants are mainly composed of polyglycolic acid (PGA) and polylactic acid (PLA) often reinforced with magnesium alloys to enhance mechanical properties.[10] Due to their excellent biocompatibility and reduced infection risks, they have been used for fracture fixation in non-weight-bearing areas such as the craniomaxillofacial skeleton.[11,12] However, the application of degradable implants in load-bearing limb fractures remains controversial. Critics argue that biodegradable materials may possess insufficient mechanical strength to withstand weight-bearing forces, or exhibit unpredictable degradation rates that could compromise fracture stability.[13]

Therefore, the choice of titanium alloys and degradable implants involves a clinical trade-off between mechanical rigidity and the avoidance of secondary surgery. This study aims to evaluate this trade-off by comparing the clinical efficacy, complication rates, and reoperation burdens of titanium versus biodegradable implants. Furthermore, it seeks to address the controversy in long bone fixation by performing a subgroup analysis to compare outcomes in both weight-bearing and non-weight bearing fractures.

Methods

Study Design

This retrospective cohort study evaluates the outcomes of titanium (Group A) and biodegradable (Group B) plates and screws in patients with fractures of the upper limbs (metacarpal, phalangeal), lower limbs, or pelvis. Patients data were collected from Hospital HMIS system at the First Affiliated Hospital of Xinjiang Medical University from November 2021 to August 2024. Ethical approval was obtained from the Medical Ethical Committee of the First Affiliated Hospital of Xinjiang Medical University (Approval No. K202506-16). Due to the retrospective nature of the study, the requirement for informed consent for general data collection was waived by the ethics committee; however, specific written informed consent was obtained from all patients whose detailed case studies and radiographic images are presented in this manuscript. The biodegradable materials used in the study are composed of PLA/PGA with magnesium alloys.

Inclusion and Exclusion Criteria

Patients aged 18 years or older with closed fractures of the upper limb (metacarpal, phalangeal), lower limb, or pelvis requiring internal fixation were included in the study. Fractures were classified as simple (2 pieces), comminuted (3 pieces), or complex fractures (more than 3 pieces). Patients with open fractures, pathological fractures due to osteoporosis or malignancy, or those with systemic conditions such as chronic infections or uncontrolled diabetes that could affect bone healing were excluded. Additionally, patients who lost to follow-up before completing postoperative assessments were excluded from the study.

Surgical Procedure

All surgical procedures were performed by experienced orthopedic surgeons under either local intravenous anesthesia or general anesthesia, depending on the complexity of the fracture and patient condition. Preoperative planning involved detailed imaging, including anteroposterior and lateral radiographs, as well as 3D-CT reconstruction, to assess fracture displacement and guide the fixation strategy. A standard surgical approach was employed to expose the fracture site, ensuring careful preservation of the periosteal blood supply. Anatomical reduction of the fracture was achieved prior to fixation.

In the titanium group, fractures were stabilized using standard non-locking or locking titanium plates, which were carefully contoured to the bone surface. In the biodegradable group, fractures were fixed with biodegradable materials composed of PLA/PGA with magnesium alloys. To achieve anatomical contouring, the biodegradable plate was softened in a sterile saline bath (55–60°C) for approximately 10–20 seconds until malleable, molded to the patient-specific bony contour using a bending template and gentle broad-surface benders, and then allowed to cool to restore rigidity before definitive screw fixation. Repeated re-heating and excessive back-and-forth bending were avoided. Postoperatively, antibiotic prophylaxis and rehabilitation protocols were followed according to standard hospital guidelines, ensuring both groups received appropriate care to manage pain, prevent infection, and promote healing.

Postoperative Follow-Up and Assessment

For this retrospective study data regarding postoperative follow-up were collected for patients who had clinically followed up for minimum 6 months after surgery. Clinical data, including pain assessment, range of motion evaluation, and the detection of any signs of infection, implant failure, or other complications, were obtained through patient records. Pain scores (VAS/NRS) were recorded at each follow-up point to track pain severity over time. Radiographic healing was assessed at each time point, and secondary surgery was recorded based on implant failure or complications, including plate palpability, infection, and extrusion. The degradation process of biodegradable implants was monitored closely, particularly for signs of premature degradation that could affect implant stability. Data on adverse events related to biodegradable implants, such as inflammatory responses and premature loss of strength, were also tracked during the follow-up period. In cases where titanium implants caused discomfort or complications, implant removal was planned. For biodegradable implants, patients were monitored for the natural degradation process over time.

Statistical Analysis

All data were analyzed using SPSS 22.0 (IBM Corp, Armonk, NY). Continuous variables are presented as mean ± standard deviation (SD) and were compared using the Student's *t*-test or Mann–Whitney *U*-test depending on normality. Categorical variables are presented as frequencies and percentages and were analyzed using the Chi-square test or Fisher's exact test. To account for potential confounding due to fracture site heterogeneity, a stratified analysis was conducted based on weight-bearing status (weight-bearing vs non-weight-bearing) and fracture level. For key binary outcomes, Odds Ratios (OR) with 95% Confidence Intervals (CI) were calculated to estimate the magnitude of effects. A *P*-value of < 0.05 was considered statistically significant.

Results

Between November 2021 and August 2024, a total of 113 patients were initially screened for eligibility. Of these, 40 patients were excluded from the study. The reasons for exclusion included age under 18 years (n = 6), open fractures (n = 4), pathological fractures due to osteoporosis (n = 11), chronic active infection (n = 3), and uncontrolled diabetes (n = 4). Additionally, 12 patients were excluded due to loss of follow-up or incomplete medical records. The remaining 73 patients met all inclusion criteria and were included in the final analysis, divided into the titanium group (n = 40) and the biodegradable group (n = 33) (Figure 1).

A total of 73 patients were included in the study, with a mean age of 42.6 ± 16.03 years. The majority were male 46 (63.9%) and 27 (37%) were female. The titanium group consisted of 40 patients (60% male and 40% female), while the biodegradable group consist of 33 patients with a gender distribution (66.6% male, 33.4% female). The mean ages were comparable between the two groups (42.9 ± 15.9 years vs 43.1 ± 15.7 years, respectively) with no significant difference (*P* = 0.53). In terms of comorbidities, 9.6% of patients in the overall cohort had hypertension and 2.7% were diabetic. In titanium group, 12.5% of patients had hypertension and 5% were diabetic while in the biodegradable group 6.06% had hypertension with no diabetic patient. Neither of these differences was statistically significant (*P* = 0.59 and *P* = 0.56, respectively). Alcohol consumption was reported by 41.1% of patients overall, with 37.5% in the titanium group and 45.45% in the biodegradable group. Similarly, 53.4% of the cohort were classified as smokers, with 37.5% in the titanium group and 57.6% in the biodegradable group. Regarding BMI, the overall cohort had an average BMI of 26.23 ± 3.91 kg/m^2, with 39.7% classified as overweight and 26.0% as obese. In the titanium group 37.5% were overweight and 20.0%

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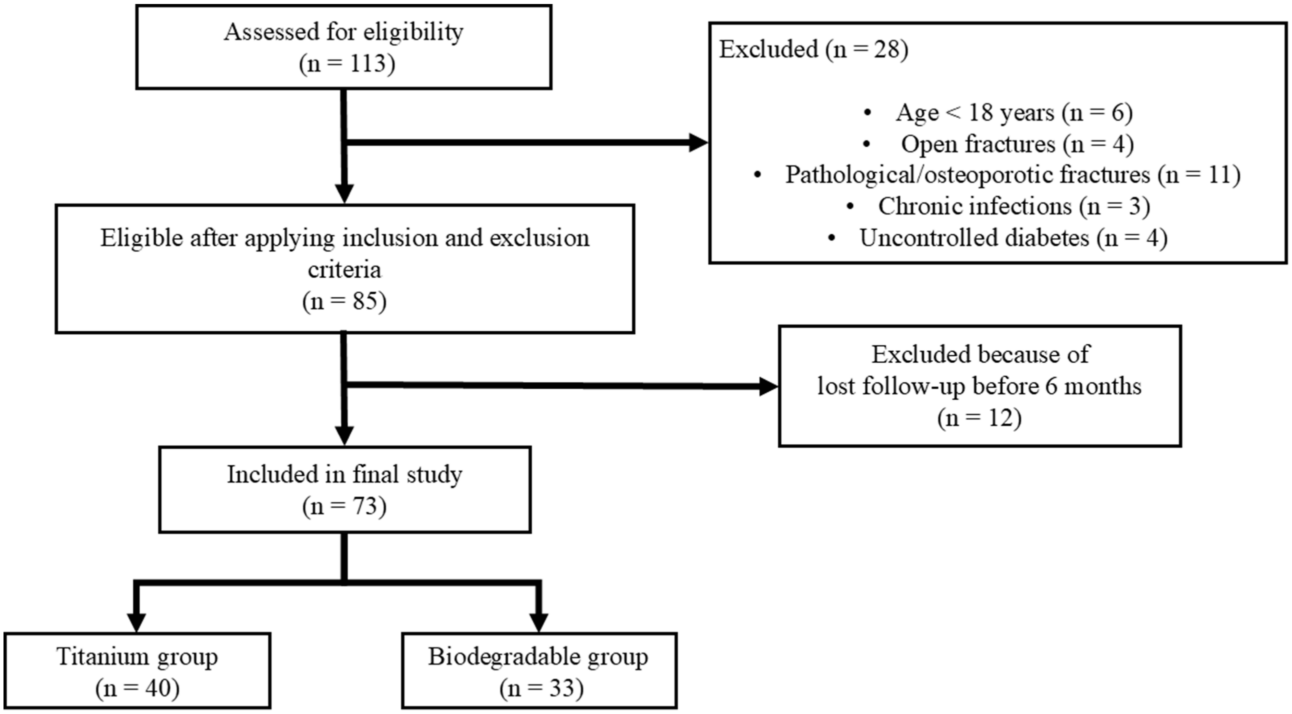

Figure 1 Schematic flow diagram illustratining patient selection process.

were obese, while in the biodegradable group, 42.4% were overweight and 33.3% were obese. In terms of pain severity, 57.5% of titanium patients reported severe pain compared with 39.4% in the biodegradable group while moderate pain was reported by 37.5% and 39.4%, respectively. Mild pain was more common in the biodegradable group (21.2%) compared to the titanium group (15.0%, P = 0.30) (Table 1).

Table 1 Characteristics of Study Participants by Implant Type

Variables	Category	Titanium (n = 40)	Biodegradable (n = 33)	*P*-value
Age (mean ± SD)		42.9 ± 15.9	43.1 ± 15.7	
Gender	Male	24 (60.0%)	22 (66.7%)	0.731
	Female	16 (40.0%)	11 (33.3%)	
Fracture Type	Comminuted	19 (47.5%)	12 (36.3%)	0.681
	Complex	14 (35%)	12 (36.3%)	
	Simple	7 (17.5%)	9 (27.3%)	
BMI	Normal	17 (42.5%)	8 (24.3%)	0.214
	Overweight	15 (37.5%)	14 (42.4%)	
	Obese	8 (20.0%)	11 (33.3%)	
Load Bearing	Weight Bearing	30 (75.0%)	27 (73.0%)	1.00
	Non-Weight Bearing	10 (25.0%)	6 (27.0%)	

(*Continued*)

Table 1 (Continued).

Variables	Category	Titanium (n = 40)	Biodegradable (n = 33)	*P*-value
Smoking Status	Yes	15 (37.5%)	19 (57.6%)	0.142
	No	25 (62.5%)	14 (42.5%)	
Hypertensive	Yes	5 (12.5%)	2 (6.06%)	0.592
	No	35 (87.5%)	31 (93.9%)	
Diabetic	Yes	2 (5.0%)	0 (0.00%)	0.563
	No	38 (95%)	33 (100%)	
Alcoholic status	Yes	15 (37.5%)	15 (45.4%)	0.651
	No	25 (62.5%)	18 (54.5%)	
Pain Severity (VAS/NRS)	Mild Pain	6 (15.0%)	7 (21.2%)	0.342
	Moderate Pain	15 (37.5%)	13 (39.4%)	
	Severe Pain	19 (47.5%)	13 (39.4%)	

The mechanism of injury differed significantly between the two groups ($P = 0.012$). Falls were the leading cause of fracture in the titanium group (70.0%), whereas the biodegradable group showed a more diverse injury profile, with a significantly higher proportion of trauma-related injuries (27.3% vs 5.0%) and sports injuries (9.1% vs 0.0%). Car accidents accounted for a similar proportion of cases in both the titanium (22.5%) and biodegradable (21.2%) groups. Regarding anatomical distribution, detailed analysis revealed distinct patterns in fracture location and level. In the upper limb, clavicle fractures were predominantly treated with titanium implants (n = 8) compared to biodegradable implants (n = 1), while biodegradable implants were more frequently utilized for fractures of the radius, ulna, and hand (n = 6 vs n = 0 in the titanium group). In the lower limb, the titanium group was characterized by a high prevalence of tibial shaft fractures (n = 27), whereas the biodegradable group showed a strong predilection for ankle and malleolar fractures (n = 12). Primary pelvic fractures were treated exclusively in the biodegradable group (n = 2, 6.1%). A statistically significant difference was observed in the fracture level ($P = 0.003$), reflecting the distinct biomechanical indications for each implant type. Titanium implants were primarily used for diaphyseal (shaft) fractures (57.5%), particularly in the tibia. In contrast, biodegradable implants were significantly more likely to be selected for metaphyseal, epiphyseal, or peri-articular fractures (84.8%), such as those involving the ankle, distal radius, or pelvis, where avoiding secondary removal is clinically advantageous. Table 2 represents characteristics of the fractures.

Table 2 Characteristics of Fractures

Variables	Category	Titanium(n = 40)	Biodegradable(n = 33)	*P*-value
Mechanism of Injury	Fall Down	28 (70.0%)	14 (42.4%)	0.012
	Car Accident	9 (22.5%)	7 (21.2%)	
	Trauma	2 (5.0%)	9 (27.3%)	
	Sports Injury	0 (0.0%)	3 (9.1%)	
	Hitting	1 (2.5%)	0 (0.0%)	

(*Continued*)

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Table 2 (Continued).

Variables	Category	Titanium(n = 40)	Biodegradable(n = 33)	*P*-value
Anatomical Site	Upper Limb	10 (25.0%)	11 (33.3%)	0.428
	— *Clavicle*	8	1	
	— *Humerus/Elbow*	2	4	
	— *Radius/Ulna/Hand*	0	6	
	Lower Limb	30 (75.0%)	20 (60.6%)	0.188
	— *Femur*	0	1	
	— *Tibia (Shaft/Plateau)*	27	1	
	— *Ankle/Malleolu*	1	12	
	— *Foot (Calcaneus/Talus)*	2	6	
	Pelvis	0 (0.0%)	2 (6.1%)	0.201
Fracture Level	Shaft (Diaphyseal)	23 (57.5%)	4 (12.1%)	0.003
	Metaphyseal/Epiphyseal	16 (40.0%)	28 (84.8%)	
	Unspecified	1 (2.5%)	1 (3.0%)	

Operative and hospitalization parameters are detailed in Table 3. There were no statistically significant differences between the two groups regarding surgical trauma or complexity. The mean operative time was comparable between the titanium (138.9 ± 58.0 min) and biodegradable (131.4 ± 54.7 min) groups (P = 0.571). Similarly, intraoperative physiological stress appeared consistent, with no significant differences observed in intraoperative blood loss (83.8 ±

Table 3 Operative Characteristics and Hospitalization Data

Variables		Titanium (n = 40)	Biodegradable (n = 33)	*P*-value
Plates & Screw Types	Titanium Plates and Screws	40 (100%)	0	<0.05
	Biodegradable Plates and Screws	0	33 (100%)	
Operative Time (min)	Mean ± SD	138.9 ± 58.0	131.4 ± 54.7	0.571
	Range	60–280	55–245	
Intraoperative Blood Loss (mL)	Mean ± SD	83.8 ± 98.5	94.2 ± 115.5	0.676
	Range	10–400	10–500	
Intraoperative Infusion (mL)	Mean ± SD	1087.5 ± 451.3	1242.4 ± 532.1	0.183
	Range	500–2000	500–2500	
Number of Screws Used	Mean ± SD	10.6 ± 4.3	6.3 ± 1.8	<0.001
	Range	4–22	4–10	
Hospital Length of Stay (days)	Mean ± SD	12.4 ± 7.8	10.1 ± 4.2	0.136
	Range	3–38	4–22	

98.5 mL vs 94.2 ± 115.5 mL, *P* = 0.676) or the volume of intraoperative fluid infusion (1087.5 ± 451.3 mL vs 1242.4 ± 532.1 mL, *P* = 0.183). However, a highly significant difference was observed in the implant hardware burden (*P* < 0.001). Patients in the titanium group required a significantly higher number of screws for fixation (mean 10.6 ± 4.3; range 4–22) compared to the biodegradable group (mean 6.3 ± 1.8; range 4–10). Regarding postoperative recovery, the mean length of hospital stay was shorter in the biodegradable group (10.1 ± 4.2 days) compared to the titanium group (12.4 ± 7.8 days), though this difference did not reach statistical significance (*P* = 0.136).

Clinical outcomes are summarized in Table 4. Regarding bone healing, satisfactory clinical and radiographic consolidation was observed in all patients across both groups. While specific time-to-union intervals were not standardized due to the retrospective nature of the study and varying fracture patterns (eg, tibial shaft vs ankle), union was confirmed in all patients during their follow-up visits. Although the mean follow-up duration was significantly shorter in the biodegradable group (7.9 ± 2.4 months) compared to the titanium group (18.6 ± 6.6 months), this observation period was sufficient to confirm union and the absence of early mechanical failure in the biodegradable cases. A significant difference was observed in implant palpability/discomfort, which was reported by 45.0% of patients in the titanium group compared to only 9.1% in the biodegradable group (Table 4; *P* = 0.001, OR 8.18). Consequently, the overall rate of secondary surgery was significantly higher in the titanium group (35.0% vs 9.1%, *P* = 0.012).

Crucially, Table 4 clarifies the indications for these reoperations. Elective removal due to implant discomfort accounted for half of the secondary surgeries in the titanium group (17.5%). When the analysis was restricted to complication-driven reoperations (eg, infection, fixation failure), there was no statistically significant difference between titanium (17.5%) and biodegradable (9.1%) implants (*P* = 0.496).

To address potential confounding by fracture type, a stratified analysis based on weight-bearing status was performed (Table 5). In the weight-bearing subgroup (lower limb and pelvis), titanium implants were associated with significantly higher odds of plate palpability compared to biodegradable implants (53.3% vs 11.1%, *P* = 0.001, OR 9.14). Furthermore, while the overall reoperation rate showed a trend toward being higher in the titanium group (30.0% vs 11.1%, *P* = 0.096), the difference was driven by elective procedures. Specifically, elective removal due to discomfort was significantly more frequent in the titanium group (20.0% vs 0.0%, *P* = 0.028). In contrast, there was no significant difference in complication-driven reoperations between the two groups in the weight-bearing cohort (10.0% vs 11.1%, *P* = 1.000). Among non-weight-bearing fractures (upper limb), there were no statistically significant differences in palpability (20.0% vs 0.0%, *P* = 0.491) or secondary surgery (50.0% vs 0.0%, *P* = 0.052). However, it is notable that no patient in the biodegradable non-weight-bearing group required reoperation for any reason. Secondary analysis of intraoperative parameters revealed that implant type influenced the hardware burden regardless of fracture location.

Table 4 Clinical Outcomes and Complications

Outcomes	Titanium (n = 40)	Biodegradable (n = 33)	OR (95% CI)	*P*-value
Patient Complaints				
— *Hardware Prominence*	16 (40.0%)	9 (27.3%)	1.78 (0.66–4.80)	0.324
— *Palpability/Discomfort*	18 (45.0%)	3 (9.1%)	8.18 (2.14–31.3)	0.001
Secondary Surgery	14 (35.0%)	3 (9.1%)	5.38 (1.39–20.8)	0.012
— *Elective Removal*	7 (17.5%)	0 (0.0%)	— †	0.014
— *Complication Driven*	7 (17.5%)	3 (9.1%)	2.12 (0.50–8.95)	0.496
Specific Complications				
— *Infection*	3 (7.5%)	1 (3.0%)	2.59 (0.26–26.2)	0.622
— *Refracture*	0 (0.0%)	3 (9.1%)	— †	0.088

Notes: †Odds Ratios were not calculated due to zero events in one group. *P*-values derived from Fisher's Exact Test.

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Table 5 Stratified Analysis of Clinical Outcomes by Weight-Bearing Status

Stratum	Outcome	Titanium	Biodegradable	Odds Ratio (OR)	*P*-value
Weight-Bearing	**Plate Palpability**	16/30 (53.3%)	3/27 (11.1%)	9.14	0.001
(Lower Limb)	**Secondary Surgery (Total)**	9/30 (30.0%)	3/27 (11.1%)	3.43	0.096
	— *Elective Removal*	6/30 (20.0%)	0/27 (0.0%)	—	0.028
	— *Complication-Driven*	3/30 (10.0%)	3/27 (11.1%)	0.89	1.000
Non-Weight-Bearing	**Plate Palpability**	2/10 (20.0%)	0/6 (0.0%)	—	0.491
(Upper Limb)	**Secondary Surgery (Total)**	5/10 (50.0%)	0/6 (0.0%)	—	0.052
	— *Elective Removal*	1/10 (10.0%)	0/6 (0.0%)	—	1.000
	— *Complication-Driven*	4/10 (40.0%)	0/6 (0.0%)	—	0.109

Table 6 Perioperative Management and Follow-up

Parameter		Titanium (n = 40)	Biodegradable (n = 33)	*P*-value
Anesthesia Method	General Anesthesia	11 (27.5%)	16 (48.5%)	0.161
	Spinal/Epidural	24 (60.0%)	15 (45.5%)	
	Nerve Block / Other	5 (12.5%)	2 (6.1%)	
Postoperative Pain	Mild	6 (15.0%)	7 (21.2%)	0.305
	Moderate	11 (27.5%)	13 (39.4%)	
	Severe	23 (57.5%)	13 (39.4%)	
Follow-Up Duration (months)	Mean ± SD	18.6±6.6	7.9±2.4	<0.001

Titanium implants required a significantly higher number of screws in both the weight-bearing (11.0±4.2 vs 6.6±1.8, $P < 0.001$) and non-weight-bearing subgroups (9.2±4.6 vs 5.6±1.9, $P = 0.043$). However, other surgical parameters were comparable across subgroups. There were no significant differences in intraoperative blood loss ($P = 0.898$ for weight-bearing; $P = 0.178$ for non-weight-bearing) or surgical time ($P = 0.369$ for weight-bearing; $P = 0.519$ for non-weight-bearing). A trend toward shorter hospital stay was observed in the biodegradable weight-bearing group (10.2 vs 13.2 days), though this did not reach statistical significance ($P = 0.068$).

Perioperative management and follow-up data are summarized in Table 6. The majority of patients in both groups underwent surgery under spinal or epidural anesthesia (60.0% in the titanium group and 45.5% in the biodegradable group), with no statistically significant difference in the distribution of anesthesia methods ($P = 0.161$). Postoperative pain control was also comparable between the groups; there was no significant difference in the proportion of patients reporting mild, moderate, or severe pain grades ($P = 0.305$).

However, a significant difference was observed in the follow-up duration ($P < 0.001$). The titanium group had a significantly longer mean follow-up period (18.6±6.6 months) compared to the biodegradable group (7.9 ± 2.4 months). This difference reflects the earlier adoption of titanium implants in our practice, whereas biodegradable implants represent a more recent introduction.

Typical Case

Typical Case 1

A 49-year-old male patient presented with fractures of the right tibial shaft and fibula, treated with ORIF using a titanium alloy plate and screws. Postoperative X-rays confirmed correct anatomical alignment and stable fixation. At the 6-month

Figure 2 Preoperative and postoperative radiographs of a 49-year-old male patient. (**A** and **B**) Preoperative anteroposterior and lateral views showing a twisted spiralfracture of the right tibial shaft associated with a Maisonneuve ankle fracture and syndesmotic instability. (**C** and **D**) Postoperative radiographs following open reduction and internal fixation (ORIF) with a titanium plate and screws. The fixation restored anatomical alignment and stability. Plate osteosynthesis was selected in this instance to ensure stable anatomical reduction of the complex spiral pattern and to manage the rotational instability of the ankle syndesmosis.

follow-up examination, no signs of complications were observed at the surgical site. The patient's postoperative pain and swelling gradually subsided, with excellent recovery (Figure 2).

Typical Case 2

A 42-year-old female patient presented with multiple pelvic fractures, including a left iliac fracture and left superior/ inferior pubic rami fractures, treated with ORIF using biodegradable plate and screws. Postoperative X-rays confirmed correct anatomical alignment and stable fixation. At the 1-year follow-up examination, excellent fracture healing was observed at the surgical site, and the patient had started weight-bearing functional exercises (Figure 3).

Typical Case 3

A 26-year-old male patient presented with distal fractures of the left tibia and fibula, treated with ORIF using biodegradable plate and screws. At the 1-year follow-up examination, excellent fracture healing was observed at the surgical site, with visible screw tracts left by absorbable screws. The patient had started weight-bearing functional exercises, and no second surgery was required for plate removal (Figure 4).

Discussion

Titanium and biodegradable implants both provide effective fracture stabilization, but each has distinct advantages and limitations. In this retrospective cohort study, the most significant finding is that biodegradable PLA/PGA with magnesium alloys implants significantly reduced the burden of secondary interventions compared to conventional titanium fixation. Our analysis reveals a distinct clinical trade-off: while titanium implants provided rigid fixation, they were associated with a high rate of hardware prominence (45.0%), leading to a significantly higher frequency of elective implant removal (17.5%). In contrast, the biodegradable cohort experienced zero elective removals (P = 0.014). This is consistent with findings from prior studies, which have similarly reported higher rates of hardware removal in patients treated with metallic implants.[14] The clinical implication of this finding is substantial. Recent large-scale meta-analyses have highlighted that elective hardware removal is not a benign procedure; it is associated with significant healthcare costs, a risk of wound complications, and a prolonged recovery period for patients.[15] By eliminating the need

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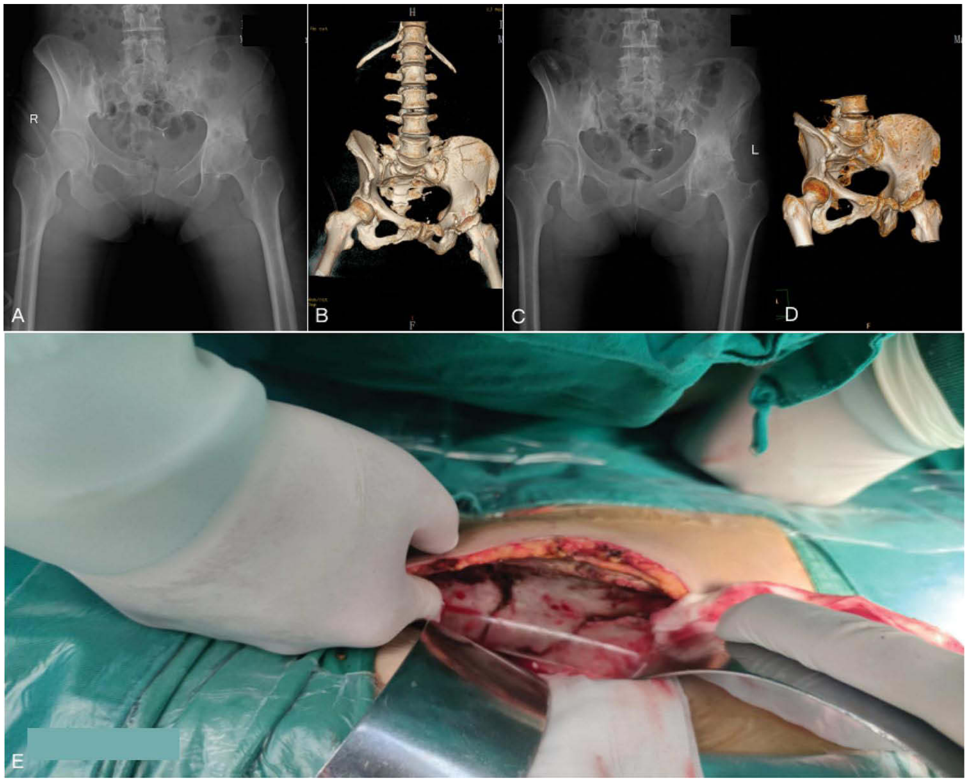

Figure 3 Preoperative and postoperative X-rays and CT scans of a 42-year-old female patient with a left iliac wing fracture of the pelvis. (**A**) shows the X-ray of the left iliac wing fracture, and (**B**) displays the three-dimensional-CT reconstruction. (**C**) is the postoperative follow-up X-ray, while (**D**) shows the three-dimensional-CT reconstruction at 1-year post-operation, demonstrating complete healing of the fracture line with visible screw tract holes left by absorbable screws. (**E**) shows intraoperative photograph showing exposure of the left iliac wing fracture site during fixation.

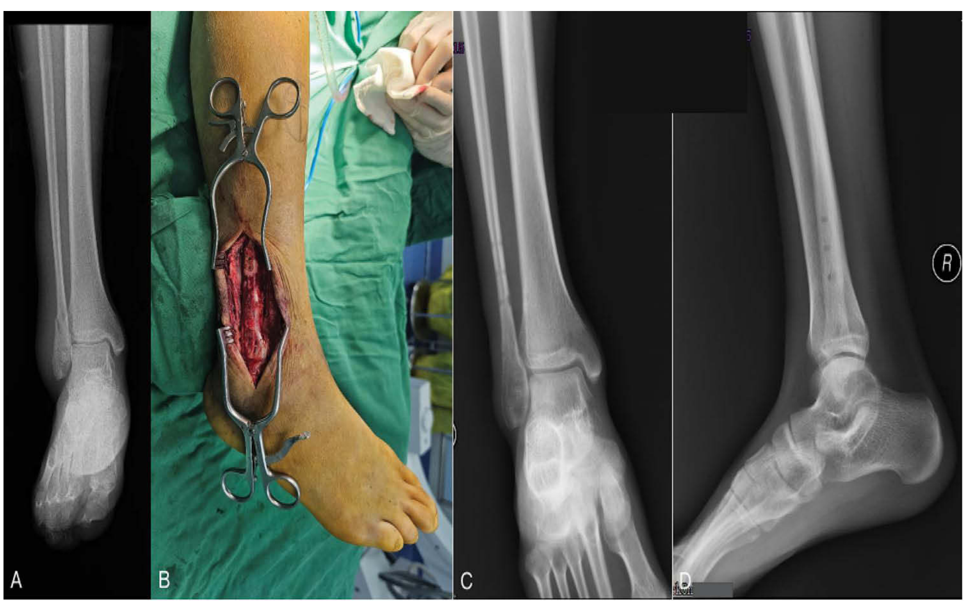

Figure 4 Preoperative and postoperative follow-up X-rays of a 26-year-old male patient with distal fractures of the left tibia and fibula. (**A**) show X-rays of the distal tibiofibular fractures on the left side. (**B**) shows exposure of the distal tibia and fabula fracture site through an anterolateral approach. (**C** and **D**) display X-rays at 1-year post-operation, demonstrating good fracture alignment and complete healing, with visible screw tract holes left by absorbable screws.

for this routine secondary surgery, biodegradable implants not only improve patient satisfaction but may also reduce the overall economic burden on the healthcare system, a benefit that is increasingly prioritized in modern orthopedics.

Patient demographics in this study align with findings from previous research. The mean patient age was 42.6 ± 16.03 years, with a male predominance (63.9%), most fractures affecting the lower limbs accounting for titanium group 75.6% while in the biodegradable it was recorded 60.6%. Weight-bearing fractures accounted for 75.0% in the titanium group and 73.0% in the biodegradable group, emphasizing the importance of implant durability in load-bearing bones. Comparable demographic patterns have been reported in other studies[16] and this similarity suggests our cohort is representative strengthening the generalizability of our findings.

A key criticism of biodegradable fixation in literature is its limited mechanical strength compared to titanium, particularly in weight-bearing bones. Biomechanical analyses have demonstrated higher stress concentrations in biodegradable implants, leading to increased failure risks in unstable fractures.[17] New biomechanical data has further elucidated this limitation. Studies comparing magnesium-based implants to titanium have shown that while magnesium offers superior load-sharing properties (reducing stress shielding), it possesses significantly lower torsional stiffness.[18] This makes biodegradable implants vulnerable to failure in fractures subject to rotational forces, such as spiral fractures of the tibial shaft. Our study addresses this by explicitly defining the clinical indications for each implant. As noted in our methodology, titanium was preferentially selected for diaphyseal (shaft) fractures where these bending and torsional forces are highest. Conversely, biodegradable implants were utilized primarily for metaphyseal and peri-articular fractures (eg, distal tibia, malleolus). In these anatomical regions, the soft tissue envelope is thin, and conventional metal plates frequently cause symptomatic prominence requiring removal. Our stratified analysis confirms this benefit: even among weight-bearing patients, those with biodegradable implants reported significantly lower palpability rates (11.1%) compared to the titanium group (53.3%, $P < 0.05$). This supports the clinical strategy of using biodegradable implants for articular fractures to avoid the second trauma of implant removal surgery.[19,20]

Moreover, biodegradable implants offered superior comfort, mechanical stability remains a valid concern. In our weight-bearing subgroup, we observed three cases (9.1%) of refracture or loss of reduction in the biodegradable group, compared to zero in the titanium group ($P = 0.193$). This finding aligns with concerns raised by other authors regarding the time-dependent loss of strength in degradable polymers and the potential for implant failure.[21] It is also important to consider the degradation behavior of magnesium. Recent radiographic analyses have identified that magnesium-based screws can exhibit transient radiolucent zones around the implant during the early degradation phase.[22] While typically benign, these zones may temporarily reduce screw pull-out strength before bone remodeling is complete. This underscores the need for strict patient compliance with protected weight-bearing protocols during the first 6–8 weeks. Despite these mechanical challenges, satisfactory clinical and radiographic consolidation was observed in the majority of patients. Previous clinical trials suggest that the magnesium component in these implants releases ions that promote angiogenesis and osteogenesis.[23,24] This biological advantage is supported by recent studies demonstrating that magnesium degradation products actively stimulate the CGRP/VEGF pathway, potentially offsetting the lower mechanical stiffness of the polymer by accelerating the biological cascade of healing.[25]

Critics of biodegradable systems often cite the complexity of intraoperative contouring as a disadvantage. However, our results showed no significant difference in operative time between the biodegradable and titanium groups in either weight-bearing (133.1 vs 147.7 min, $P = 0.369$) or non-weight-bearing (126.7 vs 112.5 min, $P = 0.519$) cohorts. This suggests that with the technique of hot-water contouring described in our methods, biodegradable plates can be applied with similar efficiency to standard metallic hardware, effectively removing "surgical difficulty" as a barrier to their adoption.

Overall, biodegradable implants reduce the need for hardware removal, improving patient outcomes and lowering surgical burden. However, fracture type and anatomical location clearly influence implant performance. High-load-bearing fractures may still require titanium implants due to their superior mechanical stability. However, our results show that biodegradable implants significantly reduce the need for secondary surgeries and plate palpability which is a major source of patient discomfort. Our findings provide a practical recommendation for clinicians: for patients with weight bearing fractures where implant palpability is primary concern, these modern biodegradable implants may present a clinically effective alternative to titanium.

This study has some limitations that must be acknowledged. First, as a retrospective, single center study the findings of the study are susceptible to selection bias as the choice of implant (titanium vs biodegradable) was based on surgeon preference and clinical judgment rather than randomization. Second, the relatively small sample size particularly within the weight-bearing and non-weight-bearing subgroups limits the study statistical power which may have prevented us from detecting more subtle differences in outcomes. Finally, the follow-up duration was not long enough to fully assess the long-term degradation behavior of the biodegradable implants meaning that late-onset complications which require multi-year observation may not have been captured.

Acknowledging these limitations, our study nonetheless provides important clinical evidence that biodegradable implants are a viable alternative to titanium, offering significant advantages in reducing implant palpability and the need for secondary surgeries. Future large-scale, randomized controlled trials with long-term follow-up are necessary to confirm these findings and more comprehensively evaluate the long-term performance of these materials.

Conclusion

In this cohort, biodegradable PLA/PGA magnesium-reinforced implants were associated with being a viable alternative to titanium implants for the fixation of metaphyseal and peri-articular fractures. They offer a clear advantage in reducing implant palpability and eliminating the need for elective hardware removal surgery. However, due to the lower mechanical strength compared to titanium implants, patient selection is critical. Biodegradable fixation is best reserved for fractures with good bony apposition in metaphysis, whereas titanium remains the preferred choice for diaphyseal fractures requiring high mechanical stability. These findings are limited by the retrospective design, inherent confounding by indication, and follow-up constraints; future large-scale research is required before drawing definitive practice recommendations.

Declaration of Generative AI and AI-Assisted Technologies in Writing Progress

During the preparation of this work author(s) used ChatGPT-5 in order to linguistic amendments. After using the tool/ service the author(s) reviewed and edited the content of the publication. This work has been reported in line with the TITAN criteria.

Data Sharing Statement

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1975 Helsinki Declaration and its later amendments or comparable ethical standards. In order to comply with the ethical considerations in this research, the information of the participants was kept confidential and other people were not able to access this information. The names and surnames of the participants were not used for data collection, and data collection was done after obtaining the code of ethics from Xinjiang Medical University. The study was approved by the Medical Ethical Committee of the First Affiliated Hospital of Xinjiang Medical University (K202506-16).

Consent for Publication

Written informed consent was signed from the three participants of the case studies before starting the study.

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Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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