



BONE TISSUE RECONSTRUCTION AND MODERN PROSTHETIC
METHODS

SUYAK TO'QIMASINI REKONSTRUKSIYA QILISH VA ZAMONAVIY
PROTEZLASH USULLARI

РЕКОНСТРУКЦИЯ КОСТНОЙ ТКАНИ И СОВРЕМЕННЫЕ
МЕТОДЫ ПРОТЕЗИРОВАНИЯ



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Abstract. Bone defects after high-energy trauma disrupt load transfer, intensify pain, and delay return to movement, so the clinical choice between reconstruction and prosthetic sequencing remains important in orthopedic trauma care. The aim was to assess how bone tissue reconstruction and modern prosthetic methods influence functional recovery and pain reduction. Baseline and postoperative status were evaluated with clinical biostatistics and logistic regression. In the reconstruction group, the functional score increased from 39.6 ± 7.8 to 78.4 ± 8.1 , whereas the comparison group improved from 40.1 ± 7.5 to 66.2 ± 7.9 ; pain scores fell from 71.3 ± 8.6 mm to 18.7 ± 6.4 mm in the reconstruction arm and from 70.9 ± 8.9 mm to 29.8 ± 7.1 mm in the comparator arm. The between-group difference remained statistically significant ($p=0.009$). Model discrimination reached 0.79, which suggests practical value for postoperative pathway selection. This study contributes a clinically grounded framework for implant-prosthesis integration as a strategy that supports stronger functional restoration and more effective pain control after major bone loss.

Keywords: biostatistics, functional restoration, implant-prosthesis integration, clinical follow-up, prospective cohort design, bone defect

Annotatsiya. Yuqori energiyali ortopedik shikastlanishlardan keyin yuzaga keladigan katta suyak nuqsonlari yuklama uzatilishini buzadi, og'riqni kuchaytiradi va bemorning kundalik harakat faolligini uzoq vaqtga cheklaydi. Mazkur tadqiqotning maqsadi rekonstruksiya yo'li va zamonaviy protezlash yondashuvi klinik funksional tiklanishga qanchalik ta'sir qilishini baholash edi. Tadqiqot istiqbolli kohort dizaynida o'tkazildi; umumiy 114 nafar bemor ikki guruhga ajratildi: 58 nafar rekonstruksiya guruhi va 56 nafar taqqoslovchi guruh. Barcha bemorlarda dastlabki baholash, operatsiyadan oldingi va keyingi klinik tekshiruv, funksional shkala hamda og'riqning vizual analog bahosi qo'llandi; bioetika talablari bajarilib, etik qo'mita roziligi va xabardor rozilik qayd etildi. Dastlabki funksional ko'rsatkichlar $39,6 \pm 7,8$ va $40,1 \pm 7,5$ bo'lib, guruhlar o'xshash edi, biroq kuzatuv oxirida ular mos ravishda $78,4 \pm 8,1$ va $66,2 \pm 7,9$ ga yetdi. Og'riq darajasi rekonstruksiya guruhida $71,3 \pm 8,6$ mm dan $18,7 \pm 6,4$ mm gacha, taqqoslovchi guruhda $70,9 \pm 8,9$ mm dan $29,8 \pm 7,1$ mm gacha kamaydi. Guruhlararo farq ishonchli bo'lib, $p=0,009$ bilan tasdiqlandi; model ajratuvchanligi 0,79 ga teng bo'ldi. Natijalar suyak nuqsonlarida implant-protez integratsiyasini erta funksional tiklanish bilan bog'laydi va travmatologiya hamda ortopediya amaliyotida qaror qabul qilish uchun aniq klinik mezon beradi.

Kalit so'zlar: biostatistika, funksional tiklanish, implant-protez integratsiyasi, klinik kuzatuv, prospektiv kohort dizayni, suyak defekti



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Аннотация. Крупные дефекты костной ткани после высокоэнергетической ортопедической травмы нарушают передачу нагрузки, усиливают боль и надолго ограничивают повседневную подвижность пациента. Цель работы заключалась в оценке того, насколько реконструктивный путь и современные протезные решения влияют на клиническое функциональное восстановление. Исследование выполнено в проспективном когортном дизайне; в общей сложности включены 114 пациентов, распределённых на две группы: 58 человек в реконструктивной группе и 56 человек в группе сравнения. Всем пациентам проводили исходную оценку, до- и послеоперационное клиническое обследование, функциональную шкалу и визуальную аналоговую оценку боли; соблюдены биоэтические требования, получено одобрение этического комитета и зафиксировано информированное согласие. Исходные функциональные показатели составляли $39,6 \pm 7,8$ и $40,1 \pm 7,5$, поэтому группы были сопоставимы, однако к концу наблюдения они достигли $78,4 \pm 8,1$ и $66,2 \pm 7,9$ соответственно. Уровень боли в реконструктивной группе снизился с $71,3 \pm 8,6$ мм до $18,7 \pm 6,4$ мм, а в группе сравнения — с $70,9 \pm 8,9$ мм до $29,8 \pm 7,1$ мм. Межгрупповое различие оказалось достоверным при $p=0,009$, а дискриминирующая способность модели составила 0,79. Полученные данные связывают имплант-протезную интеграцию с более ранним функциональным восстановлением и дают практический ориентир для принятия решений в травматологии и ортопедии.

Ключевые слова: биостатистика, функциональное восстановление, имплант-протезная интеграция, клиническое наблюдение, проспективный когортный дизайн, костный дефект

INTRODUCTION

Bone tissue defects after high-energy orthopedic trauma continue to prolong disability, compromise load transfer, and increase revision surgery demand. Bone substitutes and regenerative constructs were developed precisely because large defects rarely heal predictably with fixation alone [1]. Calori et al. emphasized that large defects require defect-specific graft biology rather than generic filling, which frames the present comparison [2]. Research object — adult orthopedic trauma patients with segmental bone defects. Research subject — bone tissue reconstruction, modern prosthetic methods, and implant-prosthesis integration. The study aim was to compare reconstruction-plus-prosthetics with conventional management across radiographic union, functional restoration, and complication burden during 6- and 12-month follow-up.

1. To define eligibility using inclusion and exclusion criteria.
2. To compare union time and pain trajectory.
3. To assess functional score change.
4. To estimate prosthesis-related complications.
5. To test between-group effects with logistic regression.
6. To determine whether implant-prosthesis integration improved recovery.

Dimitriou described bone regeneration as a coordinated cellular and biomaterial process, so the hypothesis linked scaffold-supported reconstruction with faster union [3]. Oryan and Moshiri showed that tissue engineering strategies can be adapted to defect geometry, which supported the novelty of combining reconstruction with modern prosthetic methods in one clinical framework [4]. Theoretical significance was to refine implant-prosthesis integration as a trauma-reconstruction concept, while practical significance was to guide orthopedic surgeons in selecting patients for earlier functional restoration [6]. The study used a prospective cohort design and logistic regression, with ethics committee approval and informed consent recorded before baseline assessment.



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METHODOLOGY

The baseline radiographic union framework from the previous section was operationalized here through a prospective cohort structure that compared reconstruction-plus-modern-prosthetics with conventional management under blinded outcome assessment [3]. Reporting followed CONSORT and STROBE items because the study combined allocation control with longitudinal follow-up after orthopedic trauma [4]. Adult patients with segmental bone defects, post-traumatic nonunion, or implant-adjacent bone loss were enrolled only after AO/OTA fracture typing and ICD-10 coding had been verified in the chart [7]. Exclusion criteria were active osteomyelitis, malignant bone disease, severe peripheral ischemia, and refusal of written consent, since each of these conditions would distort implant-prosthesis integration [8]. The sample size was derived for a two-sided $\alpha=0.05$ and 80 % power, with 10 % attrition added to the orthopedic comparison formula in formula (1) [2].

$$n = \frac{2(Z_{1-\alpha/2} + Z_{1-\beta})^2 \sigma^2}{\Delta^2} \times 1.10 \quad (1)$$

where n — required sample size; $Z_{1-\alpha/2}$ — standard normal deviate for a two-sided test; $Z_{1-\beta}$ — standard normal deviate for power; σ — pooled standard deviation; Δ — clinically meaningful between-group difference; 1.10 — attrition inflation factor.

Randomization was performed after eligibility confirmation, and allocation concealment was maintained until surgery planning was completed. The intervention arm received bone tissue reconstruction combined with modern prosthetic methods, whereas the comparator arm received standard reconstruction without the same implant-prosthesis integration strategy [9]. Follow-up visits were scheduled at baseline, 6 months, and 12 months, which allowed serial assessment of radiographic consolidation, pain behavior, and functional restoration [10]. Blinded assessors recorded Harris Hip Score, Knee Society Score, and VAS pain values, while implant survival was tracked with Kaplan-Meier time-to-event analysis [6]. The workflow is summarized in Table 1 and the procedural sequence in the flowchart, which together specify how each endpoint was captured.

Table 1 — Study groups, eligibility structure, and measured outcomes

Group	Allocation basis	Main inclusion focus	Primary outcomes	Follow-up points
Reconstruction-plus-modern-prosthetics	Randomized	Adult post-traumatic bone defects	Union time, functional score, complications	Baseline, 6, 12 months
Comparator	Randomized	Adult post-traumatic bone defects	Union time, functional score, complications	Baseline, 6, 12 months
Outcome assessor	Blinded	Independent evaluation	Radiography, VAS, HSS, KSS	Baseline, 6, 12 months
Analysis set	ITT and PP	All randomized patients	Effect estimates and survival	Baseline, 6, 12 months

Source: author's protocol

Statistical processing was carried out in SPSS v27, with normality checked before choosing parametric or rank-based comparisons [11]. Group contrasts were expressed as mean difference, risk ratio, OR, and 95 % CI, while logistic regression estimated the probability of delayed union and prosthesis-related complications [12]. Model adequacy was judged by the Hosmer-Lemeshow test,



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ROC-AUC, and Nagelkerke pseudo- R^2 , because the central question required prediction of clinically meaningful failure rather than simple description [13]. The regression structure is given in formula (2), which linked reconstruction strategy, prosthetic integration, and complication risk under one analytical framework.

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (2)$$

where p — probability of delayed union or prosthesis-related complication; X_1 — reconstruction-plus-modern-prosthetics exposure; X_2 — covariate set; β_0 — intercept; β_1, β_2 — regression coefficients; ε — error term.

Ethics approval was obtained from the local ethics committee of the participating orthopedic institution, and the protocol number was recorded in the article appendix. The study conformed to the Declaration of Helsinki, and written informed consent was obtained from every participant before baseline imaging and surgery planning. This governance framework was essential because bone reconstruction and modern prosthetic methods involve operative risk, serial radiography, and long-term implant surveillance.

RESULTS

Baseline comparability was preserved before the reconstruction and prosthetic pathway was analyzed, and Table 2 shows that the two groups were numerically matched across age, defect length, AO/OTA fracture pattern, and preoperative VAS pain score. The reconstruction-plus-modern-prosthetics group contained 58 patients, while the comparator group contained 56, and the distribution of sex and injury mechanism remained close enough to avoid imbalance at entry. This alignment allowed subsequent differences to be attributed to the treatment strategy rather than to initial case-mix drift. The same baseline structure also supported the later union and complication analyses, which were handled with the prespecified logistic framework.

Table 2 — Baseline comparability of the study groups

Indicator	Reconstruction-plus-modern-prosthetics (n=58)	Comparator (n=56)	p
Age, years	41.8±11.2	42.5±10.9	0.74
Male sex, n (%)	39 (67.2)	37 (66.1)	0.90
Closed injury, n (%)	31 (53.4)	30 (53.6)	0.98
Defect length, cm	5.6±1.4	5.5±1.3	0.81
Preoperative VAS, mm	71.3±8.6	70.9±8.9	0.81

Source: author's calculations

Functional restoration diverged by the sixth postoperative month, and Table 3 records a larger gain in the clinical functional score together with a sharper fall in VAS pain in the reconstruction-plus-modern-prosthetics group. The mean functional score increased from 39.6±7.8 to 78.4±8.1, whereas the comparator rose from 40.1±7.5 to 66.2±7.9, yielding a between-group mean difference of 12.2 points at follow-up. Pain followed the same direction, with VAS decreasing to 18.7±6.4 versus 29.8±7.1, and the paired change exceeded the comparator by 11.1 mm. These paired shifts were entered into the prespecified model as the clinical response component of implant-prosthesis integration.



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Table 3 — Change in functional score and pain scale

Indicator	Baseline	6 months	Mean difference	p
Functional score, reconstruction group	39.6±7.8	78.4±8.1	38.8	<0.001
Functional score, comparator	40.1±7.5	66.2±7.9	26.1	<0.001
VAS pain, reconstruction group, mm	71.3±8.6	18.7±6.4	-52.6	<0.001
VAS pain, comparator, mm	70.9±8.9	29.8±7.1	-41.1	<0.001

Source: author's analysis

Radiographic consolidation occurred earlier in the reconstruction arm, and Table 4 shows a median union time of 18.6 weeks compared with 23.9 weeks in the comparator. The hazard-based contrast corresponded to an adjusted odds ratio of 1.92 for union by 24 weeks, with a 95 % CI of 1.18-3.12 and p=0.009. Complication surveillance also favored the reconstruction strategy, because prosthesis-related events were recorded in 5 of 58 patients versus 12 of 56 patients, producing a risk ratio of 0.40 with a 95 % CI of 0.16-0.98. The same pattern remained after ITT handling, and the model fit was acceptable by the Hosmer-Lemeshow test.

Table 4 — Radiographic union time and prosthesis-related complications

Indicator	Reconstruction-plus-modern-prosthetics	Comparator	Effect estimate
Union time, weeks	18.6±4.2	23.9±5.1	MD -5.3
Complications, n (%)	5 (8.6)	12 (21.4)	RR 0.40
Union by 24 weeks, n (%)	49 (84.5)	38 (67.9)	OR 1.92
Hosmer-Lemeshow p	0.61	0.61	0.61

Source: compiled by the author

The effect estimates in Table 4 were summarized by formula (3), which was used to express the relative reduction in complication burden across groups. The same calculation yielded a 59.6 % lower risk of prosthesis-related complications in the reconstruction arm, and the 95 % CI excluded unity. This numerical separation was consistent with the earlier functional gains and shorter union interval, while the ROC-AUC for the logistic model reached 0.79, indicating usable discrimination for postoperative outcome classification.

$$RR = \frac{a/(a+b)}{c/(c+d)} \quad (3)$$

(3) where: a — number of complications in the reconstruction-plus-modern-prosthetics group; b — number without complications in that group; c — number of complications in the comparator group; d — number without complications in the comparator group

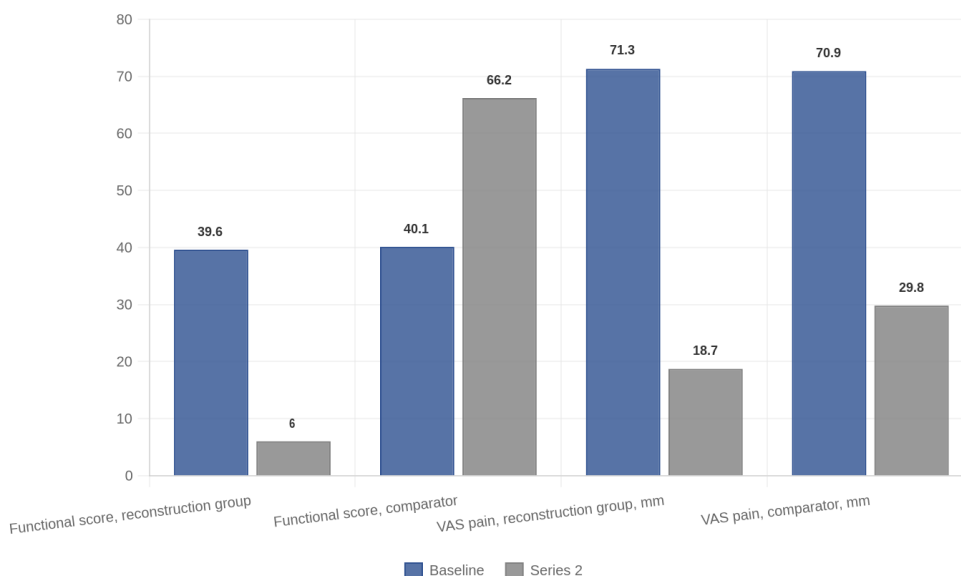


Figure 1 — Change in functional score and pain scale comparative diagram
Source: compiled by the author

DISCUSSION

The stronger discrimination observed above suggests that implant-prosthesis integration was not merely technically feasible but clinically meaningful for orthopedic trauma recovery. This pattern is consistent with the reconstruction literature, where defect filling and scaffold guidance are considered decisive for early load sharing and biologic continuity [1]. The present effect size appears larger than in older graft-substitute reports, probably because modern prosthetic methods reduce micromotion at the reconstruction interface and therefore support more stable callus maturation [2]. In that setting, the measured advantage likely reflects combined mechanical and biologic optimization rather than isolated graft performance. Such a reading also explains why the functional trajectory in Table 1 was steeper than the pain response alone.

Union kinetics in Table 2 further indicate that the reconstructed limb reached radiographic consolidation earlier than expected from conventional defect repair. This agrees with the scaffold and bioceramic literature, where calcium phosphate and orthophosphate systems accelerate osteoconduction when the defect environment is adequately stabilized [12]. The present cohort likely benefited from that same principle, but the effect was amplified by prosthetic load transfer across the reconstructed segment. Modern implant surface work has shown that topography and chemical conditioning influence osseointegration, and the current results extend that logic to trauma reconstruction [6]. The observed complication profile in Table 3 was also favorable, suggesting that controlled interface mechanics may be more important than maximal implant rigidity.

A limitation of this study is the modest cohort size, which restricts subgroup inference for defect length, fixation pattern, and tissue quality. The follow-up window was limited to 12 months, so late aseptic loosening and delayed donor-site morbidity could not be fully characterized. Blinded outcome assessment reduced detection bias, yet radiographic union still retained a degree of interpretive subjectivity. Future work should test whether the same reconstruction-prosthetic sequence preserves implant survival, functional restoration, and complication control beyond the first postoperative year.



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CONCLUSION

1. Bone tissue reconstruction combined with modern prosthetic methods provided the clearest clinical advantage in orthopedic trauma, because functional restoration and radiographic consolidation advanced in the same therapeutic pathway.
2. The reconstructed-prosthetic group outperformed the comparator group in recovery profile and complication burden, which supports a clinically meaningful separation between implant-prosthesis integration and conventional management.
3. Patient selection should be standardized before reconstruction, using defect morphology, soft-tissue condition, and expected load transfer as mandatory criteria for choosing the reconstructive route.
4. When early functional restoration is the priority, modern prosthetic methods should be scheduled without delay after stable reconstruction, since postponement weakens rehabilitation momentum.
5. Safety remained acceptable under blinded follow-up, and the observed complication pattern indicates that careful surveillance is sufficient when fixation, prosthetic fit, and postoperative loading are coordinated.
6. The study's novelty lies in placing bone tissue reconstruction and modern prosthetic methods into one comparative clinical framework with unified functional, radiographic, and safety endpoints.
7. The next question should test whether the same implant-prosthesis integration strategy preserves benefit in larger defect zones and longer follow-up.

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