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Faster Early Union but No Long-Term Functional Advantage: Orthotopic Bone Flap Transplantation versus Allograft Bone Grafting in Medial Open-Wedge High Tibial Osteotomy

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Abstract

Background

Delayed union of the osteotomy gap remains a common concern after medial open-wedge high tibial osteotomy (OW-HTO), particularly in patients with large correction gaps. Orthotopic bone flap transplantation has recently been introduced as a novel autologous grafting technique to enhance gap healing. This study aimed to compare radiographic and clinical outcomes between orthotopic bone flap transplantation and allograft bone grafting in OW-HTO.

Methods

This retrospective cohort study included 70 patients who underwent OW-HTO between December 2023 and June 2024. Patients were assigned to either the orthotopic bone flap group (n = 40) or the allograft group (n = 30). The primary outcome was osteotomy gap union rate at 3, 6, 12, and 18 months postoperatively, assessed using serial radiographs. Secondary outcomes included lower-limb alignment parameters (hip-knee-ankle angle, femorotibial angle, and medial proximal tibial angle), perioperative blood loss, and clinical outcomes assessed by WOMAC, Lysholm, and KOOS scores. Multivariable linear regression was performed to identify factors associated with delayed union.

Results

The orthotopic bone flap group demonstrated significantly higher osteotomy union rates at 3 months (38.07 ± 2.65% vs 35.92 ± 2.53%, $p = 0.001$) and 6 months (59.25 ± 3.59% vs 55.25 ± 4.02%, $p < 0.001$) compared with the allograft group. No significant between-group differences were observed at 12 months or final follow-up ($p > 0.05$). Patients receiving orthotopic bone flap transplantation experienced greater overt and hidden blood loss (both $p < 0.01$). No significant differences were found in postoperative alignment correction or functional outcomes between groups at 6 months or final follow-up. Multivariable analysis identified advanced age, higher body mass index, and diabetes mellitus as independent risk factors for delayed osteotomy healing, whereas orthotopic bone flap transplantation was associated with faster early union.

Conclusion

In patients undergoing OW-HTO, orthotopic bone flap transplantation was associated with faster early radiographic healing of the osteotomy gap compared with allograft bone grafting. However, this advantage did not translate into superior functional outcomes or long-term healing and was accompanied by increased perioperative blood loss.

Introduction

Knee osteoarthritis (KOA) is a prevalent degenerative condition among middle-aged and older adults, commonly characterized by joint pain and restricted mobility, affecting over 500 million people worldwide(1). Clinically, the Kellgren-Lawrence classification is commonly used for KOA, which categorizes the condition from mild to severe based on radiographic findings of the knee joint into Stage 0 (normal knee), Stage I, Stage II, Stage III, and Stage IV. Currently, in clinical practice, conservative treatment regimens—such as sodium hyaluronate injections and exercise therapy—are commonly used for patients with Stage I and II osteoarthritis; meanwhile, total knee arthroplasty(TKA) or unicompartmental knee arthroplasty（UKA） is the preferred surgical treatment for patients with Stage III and IV osteoarthritis(2). For patients with milder conditions who are not suitable candidates for joint replacement surgery, open wedge high tibial osteotomy (OW-HTO) is currently the most widely used knee-preserving procedure. This technique preserves the medial compartment of the knee joint, corrects lower limb alignment, and adjusts the weight-bearing line to the lateral tibial plateau(3). Research has shown that it can slow the progression of KOA and provides relatively long-lasting therapeutic benefits following surgery(4–6). Previous studies have indicated that large osteotomy gaps and certain risk factors are key determinants of bone gap healing after OW-HTO(7, 8). Delayed healing or non-union of the osteotomy site can cause postoperative pain and may even prolong the duration of non-surgical treatment—such as the period of partial weight-bearing—thereby affecting the patient's postoperative recovery of knee function. To accelerate the healing of osteotomy gaps and prevent postoperative complications around the gaps, several research teams have explored various methods of bone tissue grafting, primarily including autologous iliac bone grafting, allogeneic bone grafting, and bone substitute materials(9–11). In patients with a bone gap < 5 mm, the absence of bone grafting did not result in significant delayed healing of the bone gap, nonunion, or loss of the osteotomy angle. However, in patients with a bone gap > 5 mm, the probability of delayed or non-union following surgery without bone grafting ranged from 6% to 16%(12). Autologous iliac bone grafting is highly effective for healing osteotomy gaps and treating bone defects, with a postoperative rate of delayed or non-union of only 2.6%(13). However, it can result in prolonged operative time, postoperative donor-site pain, numbness in the lateral thigh, and complications such as infection or poor wound healing. Currently, allograft bone transplantation is the most widely used bone grafting technique. Its morphology and structure are similar to those of autologous bone. While it avoids the postoperative complications associated with autologous iliac bone grafting, its lack of osteogenic capacity results in a delayed healing or non-union rate of approximately 4.6%. Additionally, it is associated with a risk of postoperative infection(14). Similar bone graft materials play a certain role in the healing of postoperative osteotomy gaps; however, compared to autologous iliac bone grafts, they are still associated with a higher probability of delayed bone healing. Moreover, the risk of postoperative infection associated with these materials should not be overlooked, and their relatively high cost remains a significant financial burden for many patients.

Therefore, to accelerate osteotomy site healing, reduce postoperative complications, and alleviate the financial burden on patients, the team led by Academician Yingze Zhang has innovatively proposed the use of orthotopic bone flap transplantation to fill the osteotomy gap following OW-HTO(15, 16). The

detailed surgical procedure is as follows: A Kirschner-wire 1.0 mm in diameter was used for a U-shaped osteotomy of the tibia at the upper edge of the osteotomy gap below the plate, with an area of 0.5 cm × 1.0 cm and a height 1.5 cm. The remaining bone tissue was chiseled out with an osteotome for about 6 mm and the orthotopic bone flap was pushed into the osteotomy gap. This creates effective bone connections at the upper and lower ends of the osteotomy site, which helps accelerate healing of the osteotomy site under stress stimulation and reduces the risk of postoperative nonunion, loss of osteotomy angle, and infection. However, it remains unclear whether orthotopic bone flap transplantation provides superior osteotomy gap healing outcomes compared with the currently prevalent allograft bone grafting technique.

This study aimed to compare the effects of OW-HTO combined with two different bone grafting techniques on postoperative osteotomy gap healing, intraoperative blood loss, recovery of knee function, and correction of lower limb alignment.In addition, regression analysis models were employed to identify factors influencing osteotomy healing rates at different postoperative stages. This study may provide evidence supporting a novel and effective bone grafting technique that could accelerate early osteotomy gap healing in patients undergoing OW-HTO, reduce complications associated with delayed osteotomy healing, and alleviate the financial burden on patients.

Methods

In this study, 100 patients who underwent medial open wedge high tibial osteotomy (OW-HTO) at our institution were retrospectively reviewed, of whom 70 met the inclusion criteria and were enrolled in the final analysis. By comparing clinical functional scores and radiographic parameters between the two groups at different postoperative time points, the effects of the two bone grafting techniques on knee function recovery and osteotomy gap healing were evaluated. Given the technical characteristics of orthotopic bone flap transplantation, intraoperative blood loss associated with the two bone grafting techniques was also analyzed. In addition, multiple regression analysis was performed to assess the effects of various high-risk factors on postoperative osteotomy union rates.

Patients

Between December 2023 and June 2024, Institution A enrolled a total of 100 patients who underwent OW-HTO treatment. Inclusion criteria were as follows: (1) patients who failed conservative therapy for mild to medial unicompartmental osteoarthritis with varus deformity; (2) age < 70 years; (3) MPTA < 85° or FTA > 175°; (4) angle for knee flexion contractures < 15°; (5) the opening width of osteotomy gap was >7.5 mm as confirmed by post-operative computed tomography (CT) measurement; (6) intraoperative internal fixation with four-point support plate and locking screw; (7) follow-up > 1 year.

Exclusion criteria were the following: (1) moderate to severe patellofemoral arthritis, rheumatoid arthritis, or active knee infection; (2) varus deformity > 15° (3) knee instability or associated ligament injury; (4) Ahlbäck grade ≥ III; (5) cartilage degeneration of lateral compartment; (6) lateral meniscus injury.

Ultimately, the study included 30 patients in the allograft group (OW-HTO combined with allograft bone transplantation) and 40 patients in the advancing bone flap group (OW-HTO combined with orthotopic bone flap transplantation). The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Institution A. All patients provided and signed informed consent forms, and all surgeries were performed by the same surgeon.

Surgical Technique:

Under general anesthesia, all patients were placed in a supine position on the operating table. A high thigh tourniquet was applied, and standard sterile preparation and draping were performed. Arthroscopy was then conducted to evaluate the condition of the medial cartilage and medial meniscus. Patients included in this study presented with medial meniscus injury, an intact lateral compartment cartilage and meniscus, and normal anterior and posterior cruciate ligaments. After arthroscopic evaluation, the instruments were removed. A vertical incision approximately 6 cm in length was made on the medial aspect of the knee joint to expose the pes anserinus tendon and the medial collateral ligament. Then, under fluoroscopic guidance, a guide wire was inserted along the edge of the pes anserinus tendon toward the head of the fibula. Subsequently, a 2.0-mm Kirschner wire in combination with a multi-hole parallel guide was used to perform the osteotomy while preserving the integrity of the lateral cortical bone of the tibia. The Kirschner wires were then removed, and the osteotomy was completed using an osteotome. According to the preoperative plan, trial wedges were used to gradually open the osteotomy gap until the target correction angle was achieved, and the osteotomy site was stabilized using a locking plate with four-point support. Orthotopic bone flap transplantation was then performed. A 1.0-mm diameter Kirschner wire was utilized to perform a U-shaped osteotomy at the superior margin of the osteotomy gap beneath the fixation plate, creating a bone segment measuring approximately 0.5 × 1.0 cm with a height of 1.5 cm. Subsequently, an osteotome was employed to further dissect the residual bone tissue to a depth of about 6 mm, after which the in situ bone flap was carefully mobilized and repositioned into the osteotomy gap(15, 16). (Fig. 1) The surgical procedure for OW-HTO combined with allograft bone grafting was identical to that of the orthotopic bone flap transplantation group in the initial stages. The difference occurred during the final grafting step, in which freeze-dried allograft bone strips were used to fill the osteotomy gap instead of performing orthotopic bone flap transplantation. Finally, the wound was irrigated and closed in layers, covered with sterile dressings, and a compression bandage was applied from the foot to the upper thigh. A bedside radiograph of the operated knee was obtained on the day of surgery.(Fig. 1)

Postoperative Rehabilitation:

All patients will have a drainage tube placed in the surgical site during the procedure and will be prescribed anticoagulants postoperatively. All patients underwent the same postoperative rehabilitation exercises. The patient began ankle pump exercises in the supine position on the second day after surgery. After 48 hours, the patient began range-of-motion exercises for the knee, focusing primarily on

flexion, while remaining in bed. One week later, provided there were no significant adverse reactions, the patient was permitted to walk with partial weight-bearing using crutches; the walking distance and weight-bearing were determined based on the patient's tolerance. All patients underwent routine follow-up examinations before surgery and at 3, 6, 12, and 18 months postoperatively. Full-length X-rays of both lower limbs and anteroposterior and lateral X-rays of the affected knee were taken.

Clinical and Radiographic Evaluation

We collected basic information from the 70 patients included in the study, including preoperative general data, HKA, FTA and MPTA. The healing of the osteotomy gap was compared between the two groups at 3, 6, 12, and 18 months postoperatively. We collect and calculate the patient's visible and occult blood loss during the immediate postoperative period.

Alignment was interpreted based on the HKA angle, with negative values indicating varus alignment and positive values indicating valgus alignment. Loss of correction was defined as a difference of ≥ 2° between the HKA angle measured on the second postoperative day and that obtained at the final follow-up. Delayed union was defined as the absence of bridging callus formation within the osteotomy gap by 3 months postoperatively, whereas nonunion referred to minimal or absent radiographic evidence of healing at the osteotomy site within 12 months.

The osteotomy gap healing rate was quantified at each follow-up time point (3, 6, 12, and 18 months). The endpoint of healing was defined as the restoration of continuity in the posterolateral cortical bone. The distance from the lateral margin of the osteotomy gap to this endpoint was designated as segment A, while the total width between the medial and lateral margins was defined as segment B. The ratio of segment A to segment B was calculated to represent the percentage of osteotomy gap healing(17). (Fig. 2)

Clinical assessment includes the Knee Injury and Osteoarthritis Outcome Score (KOOS), Western University and McMaster University Osteoarthritis Index (WOMAC), Lysholm score and postoperative complications. Statistical analyses were also performed(18, 19).

Union Zone and the Rate of Osteotomy Gap Union

The assessment method was adapted from the modified technique described by Goshima and Jung et al., as reported in previous studies. On anteroposterior radiographs of the knee joint, the osteotomy gap was divided into the lateral hinge region and four equally spaced intervals.

Bone union within the osteotomy gap was evaluated and compared across 70 knees at different follow-up time points. The area of continuous posterolateral cortical bone observed on radiographs was identified and used as an indicator of osteotomy healing(17, 20, 21). (Fig. 2)

(2) The osteotomy space was divided into the lateral hinge and four equally spaced intervals on the medial-lateral radiograph of the knee joint.

Influencing Factors of Gap Union Rate

Based on previous studies investigating risk factors affecting osteotomy gap healing following medial open wedge high tibial osteotomy(22, 23), several variables were identified as potential predictors of postoperative healing, including age, sex, body mass index (BMI), smoking history, diabetes mellitus, and bone grafting technique. Multiple linear regression models were constructed at the 6-month and final follow-up time points to evaluate the associations between these variables and the osteotomy gap healing rate. Bone mineral density was not included as a variable in the analysis, as it was not routinely assessed in this study.

Statistical Analysis

IBM SPSS Statistics 25.0 software was used for data analysis. The Kolmogorov–Smirnov test established the normality of quantitative data, and data were expressed as mean ± standard deviation (SD), median or interquartile range. The independent samples *t*-test or Wilcoxon rank sum test was used for comparisons. For qualitative data such as operation side and gender, χ^2 test was used to analyze the differences. When comparing the healing rates of osteotomy gaps between the autograft group and the advanced bone flap group at different follow-up time points, we used multiple linear regression models to analyze the effects of gender, age, surgical side, BMI, smoking history, history of hypertension, history of diabetes, and other variables on the union rate of the osteotomy gap, and subsequently employed stepwise regression for modeling. Regression analysis is used to examine the relationship between X (quantitative or categorical) and Y (quantitative), including whether a relationship exists, the direction of the effect, and the magnitude of the effect. First, analyze the model fit by examining the R-squared value. Additionally, analyze the VIF values to determine whether multicollinearity is present. Assess the significance of X; if it is significant (p-value less than 0.05 or 0.01), this indicates that X has an impact on Y. Next, compare and analyze the extent of X's influence on Y and summarize the findings. A p-value of less than 0.05 is considered statistically significant.

Results

General condition of the patient

As shown in Table 1, there were no statistically significant differences between the two groups in terms of age, sex, BMI, osteotomy gap width, or medial meniscus injury. The width of the osteotomy gap in the bone flap transplantation group was 10.07 ± 0.81 mm, compared with 10.13 ± 0.88 mm in the allograft group (P = 0.782). In the bone flap transplantation group, 24 patients had medial meniscus tears, while 18 patients in the allograft group had medial meniscus tears. The bone flap transplantation group included 30 and 10 patients with Grade III and Grade IV OA, respectively, while the allograft bone group included 23 and 7 patients with Grade III and Grade IV OA, respectively. In addition, there were no

significant differences between the two groups in terms of preoperative clinical scores and preoperative imaging parameters (HKA, MPTA, FTA).(Table 2)

Table 1

Analysis of Differences in Baseline Data Between Patients with different Bone Grafting(n = 70)

Age(years)	**orthotopic bone flap group**	**Allograft group**	**Test Statistic**	**p-Value**
	63.70 ± 4.43	**63.67 ± 4.86**	**t=-0.03[a]**	**0.976**
Side			χ^2=0.08[b]	0.779
Left	16	13		
Right	24	17		
Gender			χ^2=0.08[b]	0.782
Male	20	14		
Female	20	16		
BMI	27.21 ± 3.46	27.27 ± 2.33	t = 0.08[a]	0.934
Opening width	10.07 ± 0.81	10.13 ± 0.88	t = 0.28[a]	0.782
Medial meniscus injury			χ^2<0.01[b]	1.000
Yes	24	18		
No	16	12		
Outerbridge grade			χ^2=0.03[b]	0.872
III grade	30	23		
IV grade	10	7		
Follow-up time (months)	18.51 ± 0.75	18.56 ± 0.65	t = 0.29[a]	0.770

Notes: Values are presented as mean ± SD; a: Derived with Student’s t-test; bDerived with Pearson chi-square test.

Table 2

Changes in Clinical and Radiological Outcomes

	orthotopic bone flap group	Allograft group	Test Statistic	p-Value
FTA				
Preoperative	179.59 ± 1.22	179.66 ± 1.00	t = 0.25	0.801
Postoperative	172.99 ± 1.01	172.57 ± 1.26	t=-1.52	0.133
Last follow-up	173.16 ± 0.96	172.92 ± 1.21	t=-0.90	0.371
HKA				
Preoperative	-5.03 ± 1.24	-5.30 ± 1.20	t=-0.94	0.352
Postoperative	1.03 ± 0.51	1.12 ± 0.56	t = 0.74	0.464
Last follow-up	0.78 ± 0.53	0.82 ± 0.60	t = 0.32	0.749
MPTA				
Preoperative	83.66 ± 0.79	83.55 ± 0.79	t=-0.56	0.578
Postoperative	90.60 ± 0.64	90.66 ± 0.65	t = 0.38	0.706
Last follow-up	90.23 ± 0.65	90.20 ± 0.68	t=-0.19	0.849
WOMAC				
Preoperative	55.88 ± 2.21	55.98 ± 2.49	t = 0.19	0.851
Post-operative 6 momths	23.63 ± 1.72	23.76 ± 1.31	t = 0.33	0.739
Last follow-up	20.42 ± 1.14	20.82 ± 1.01	t = 1.52	0.133
Lysholm				
Preoperative	56.20 ± 2.58	56.10 ± 2.37	t=-0.17	0.869
Post-operative 6 momths	86.10 ± 1.54	86.13 ± 1.46	t = 0.09	0.927
Last follow-up	90.19 ± 1.22	90.13 ± 1.01	t=-0.20	0.844
KOOS				
Preoperative	102.58 ± 2.53	102.60 ± 2.44	t = 0.04	0.967
Post-operative	47.33 ± 5.53	46.77 ± 5.32	t=-0.42	0.672

Notes: Values are presented as mean ± SD; .

	orthotopic bone flap group	Allograft group	Test Statistic	p-Value
FTA				
6 momths				
Last follow-up	43.98 ± 5.44	43.97 ± 4.99	t=-0.01	0.995
Notes: Values are presented as mean ± SD; .				

Postoperative blood loss volume status

As shown in Table 3, there was a significant difference ($p < 0.01$) in both overt and occult blood loss between the two groups following the combined OW-HTO and bone grafting procedures. Postoperative blood loss following the OW-HTO with the orthotopic bone flap transplantation was significantly higher than that following allograft bone grafting.

Table 3
Differences in Blood Loss Between the Two Groups

Group	Overt blood loss	Hidden blood loss
orthotopic bone flap group	436.12 ± 60.62	392.02 ± 45.37
Allograft group	229.83 ± 32.39	115.43 ± 18.18
t-text	t=-18.32	t=-34.99
p-value	<0.01	<0.01
Notes: Values are presented as mean ± SD deviation; *Stands for a statistically significant difference.		

Location of Union Zone and Calculation of Union Rate of the Osteotomy Gap

At 3 months post-operatively, the union zone of all patients in the two groups reached zone 2 (100.00%). At 6 months post-operatively, 24 patients in the allograft group (80%) and 36 patients in the bone flap transplantation group (90%) reached zone 3. At 12 months post-operatively, 59 patients in the two groups reached zone 4 (allograft group: 83%, bone flap transplantation group: 85%). At the last follow-up, All patients in both groups reached Zone 4. (Table 4)

Table 4
Location of Union Zone of Osteotomy Gap at Different Follow-Up Time Post-Operatively

Postoperative 3 months	Zone1	Zone2	Zone3	Zone4
Advanced bone flap	40	40	0	0
Allograft group	30	30	0	0
Postoperative 6 months				
Advanced bone flap	40	40	36	0
Allograft group	30	30	24	0
Postoperative 12 months				
Advanced bone flap	40	40	40	34
Allograft group	30	30	30	25
Postoperative 18 months				
Advanced bone flap	40	40	40	40
Allograft group	30	30	30	30

Two independent samples *t*-test was used to compare the rates of osteotomy gap union at 3 months, 6 months, 12 months, and the last follow-up in the allograft group and the bone flap transplantation group, respectively. As shown in Table 4, the union rate of the bone flap transplantation group was significantly higher than that of the allograft group at 3 months and 6 months postoperatively ($p = 0.001$; 6-month osteotomy healing rate: $p < 0.001$). However, there was no significant difference in the union rate of the osteotomy gap between the two groups at 12 months post-operatively and the last follow-up($p = 0.237$; osteotomy union rate at the last follow-up: $p = 0.438$). (Table 5)

Table 5

Differences in Rates of Osteotomy Gap Union Between the Two Groups at Different Follow-Up Times After Surgery (n = 70)

Group	The Rate of Osteotomy Gap Union (%)			
	Postoperative 3 Months	Postoperative 6 Months	Postoperative12 Months	Postoperative18 Months
Advanced bone flap	38.07 ± 2.65	59.25 ± 3.59	84.83 ± 2.38	94.36 ± 3.17
Allograft group	35.92 ± 2.53	55.25 ± 4.02	84.09 ± 2.75	93.75 ± 3.27
t-text	t=-3.42	t=-4.38	t=-1.19	t=-0.78
p-value	0.001	<0.001	0.237	0.438

Notes: Values are presented as mean ± SD deviation; *Stands for a statistically significant difference.

Influencing Factors of Gap Union Rate

A multiple linear regression analysis was performed, with gender, age, BMI, smoking history, bone grafting technique, and diabetes as independent variables (X), and the rate of osteotomy healing as the dependent variable (Y). (Fig. 3) A six-month postoperative analysis of variance revealed an F-value of 93.133 ($p < 0.05$), an R^2 of 0.851, and an adjusted R^2 of 0.842, indicating that the model is statistically significant.

Stepwise regression analysis revealed that age (X1), BMI (X2), diabetes (X3), and bone grafting method (X4) had a statistically significant effect on the rate of osteotomy gap union ($p < 0.01$). Based on the regression coefficients, patients who underwent orthotopic bone flap transplantation healed faster than those who received allograft bone grafting, holding all other conditions constant. All other factors being equal, the larger the BMI, the lower the rate of osteotomy union. The rate of osteotomy union is lower in elderly patients than in the general population, and it is also lower in patients with diabetes than in the general population.(Table 6)

Table 6

Multiple Linear Regression Analysis of Factors Influencing Union Rate of Osteotomy at 6 Months Post-Operatively, and a stepwise regression analysis was performed.

Variable	Regression Coefficient	Standardized Coefficient b	t-text	P-value	Coefficient(95%CI)	
Quantity	98.611	-	29.012	<0.001	91.823	105.399
Age	-0.412	-0.412	-8.072	<0.001	-0.513	-0.310
BMI	-0.630	-0.414	-7.384	<0.001	-0.800	-0.460
Diabetes	-2.692	-0.206	-3.812	<0.001	-3.564	-1.114
Advanced bone flap	4.456	0.485	10.138	<0.001	3.578	5.334

Notes: Assignment of qualitative variables: Diabetes (with diabetes = 1, without diabetes = 0); Smoking history (smoking history = 1, no smoking history = 0);Advanced bone flap(Advanced bone flap = 1, Allograft group = 0);Quantitative variables are entered as original value.

A multiple linear regression analysis was performed with gender, age, BMI, smoking history, bone grafting technique, and diabetes as independent variables (X), and osteotomy union rate as the dependent variable (Y). (Fig. 4) At the most recent follow-up, the F-value was 45.476 ($P < 0.001$), R^2 was 0.812, and the adjusted R^2 was 0.795, indicating that the model was statistically significant.

Stepwise regression analysis revealed statistically significant effects of BMI (X1), smoking history (X2), age (X3), and diabetes (X4) ($p < 0.001$). According to the regression coefficients, as age and BMI increase—while all other factors remain constant—the rate of union in the osteotomy site decreases. The rate of osteotomy gap healing is also lower in patients with diabetes than in the general population, consistent with findings at 6 months postoperatively. In addition, healing is relatively slower in patients with a history of smoking. (Table 7)

Table 7
Multiple Linear Regression Analysis of Factors Influencing Union Rate of Osteotomy at 18 Months Post-Operatively, and a stepwise regression analysis was performed.

Variable	Regression Coefficient	Standardized Coefficient b	t-text	P-value	Coefficient(95%CI)	
Quantity	116.788	-	41.731	<0.001	111.198	122.377
Age	-0.125	-0.179	-2.923	= 0.005	-0.211	-0.04
BMI	-0.504	-0.473	-7.258	<0.001	-0.642	-0.365
Diabetes	-3.917	-0.492	-2.764	<0.001	-4.936	-2.898
Smoking history	-1.475	-0.162	-2.764	= 0.007	-2.542	-0.409

Notes: Assignment of qualitative variables: Diabetes (with diabetes = 1, without diabetes = 0); Smoking history (smoking history = 1, no smoking history = 0);Advanced bone flap(Advanced bone flap = 1, Allograft group = 0);Quantitative variables are entered as original value.

Clinical Outcomes

As shown in Table 2, in the postoperative six-month follow-up, the WOMAC score in the bone flap transplantation group decreased from 55.88 ± 2.21 preoperatively to 23.63 ± 1.72, while the Lysholm score increased from 56.20 ± 2.58 to 86.10 ± 1.54. and the KOOS score decreased from 102.58 ± 2.53 to 47.33 ± 5.53, demonstrating that the combination of OW-HTO and orthotopic bone flap transplantation has a certain therapeutic effect on improving knee function in patients. There were no significant differences between the two groups in the three scores measured six months postoperatively ($p = 0.739$, Lysholm score $p = 0.927$, KOOS score $p = 0.672$), but all scores showed significant increases or decreases compared to preoperative levels. At the final postoperative follow-up, there were no significant differences in knee function scores between the two groups ($p = 0.133$ for the Lysholm score, $p = 0.844$ for the KOOS score, and $p = 0.995$ for the KOOS score), demonstrating that both OW-HTO combined with the two bone grafting techniques can improve knee function in patients, and that there are no significant differences in long-term improvement between the two approaches.

Radiological Outcomes

As shown in Table 2, postoperative HKA, MPTA, and FTA measurements improved significantly in both groups. The weight-bearing lines of the two groups were effectively adjusted to the lateral platform after surgery. On the second day postoperatively, there were no significant differences in HKA, MPTA, or FTA between the two groups ($p = 0.464$; MPTA $p = 0.706$; FTA angle $p = 0.133$). At the final follow-up, there were no significant differences in HKA, MPTA, or FTA angles between the two groups ($p = 0.749$, MPTA angle $p = 0.849$, FTA angle $p = 0.371$). There were no significant differences between the final follow-up and the postoperative period (all $p > 0.05$), demonstrating that there was correction loss following the combination of OW-HTO with either of the two bone grafting techniques.

Discussion

Patients with varus deformity develop varying degrees of degenerative changes and symptoms of knee osteoarthritis due to the long-term shift of weight-bearing to the medial side of the knee. For younger patients or those with milder conditions, arthroscopic debridement alone can only provide temporary pain relief, and there is a high likelihood of recurrence later on. Unicompartmental knee arthroplasty (UKA) does not fully preserve the native knee joint structure and may affect postoperative knee flexion(21, 24). OW-HTO can correct the lower limb mechanical axis and reduce the load on the medial cartilage. In long-term follow-up, the probability of undergoing TKA after OW-HTO is lower, and the long-term survival rate is higher than that of TKA following UKA(25). However, delayed union or nonunion of the osteotomy gap may occur after OW-HTO, potentially leading to loss of correction and other postoperative complications. Therefore, to accelerate early osteotomy gap healing and promote postoperative rehabilitation, this study proposes the combined use of OW-HTO with orthotopic bone flap transplantation. Compared with the current mainstream allogeneic bone grafting surgery, it analyzes the advantages in postoperative gap healing and clinical efficacy.

Previous studies have suggested that patients undergoing osteotomy who present with high-risk factors—such as obesity, a history of smoking, and diabetes mellitus—may benefit from bone grafting to fill the osteotomy gap(22, 26). According to Wolff's law(27), following OW-HTO with plate fixation in patients with knee osteoarthritis, the cancellous bone adjacent to the osteotomy gap is insufficiently stimulated by mechanical loading, which may contribute to delayed union or nonunion. This phenomenon represents a form of “stress shielding.” Therefore, for patients undergoing OW-HTO with a large correction angle, it is crucial to choose a bone transplantation method that can more efficiently establish effective bone connection and promote early healing of the postoperative osteotomy gap. Previous studies have shown that the current mainstream allogeneic bone transplantation techniques have a significant advantage in early osteotomy healing rates compared to no bone transplantation(28, 29). In the present study, the osteotomy gap healing rate exceeded 90% in both groups at 18 months postoperatively. However, at 3 and 6 months postoperatively, the healing rate in the orthotopic bone flap transplantation group was significantly higher than that in the allograft bone grafting group (all $p < 0.05$). These findings indicate that orthotopic bone flap transplantation promotes osteotomy gap healing and provides superior short-term outcomes compared with allograft bone grafting (Fig. 5). Because this technique utilizes autologous cancellous bone, it eliminates the risk of immunological rejection, provides superior vascularization, and may reduce postoperative complications(30). This study found that the method of bone transplantation, advanced age, obesity, and a history of diabetes mellitus are the main factors affecting early postoperative healing progress. At the final follow-up, delayed osteotomy healing was associated with advanced age, obesity, and diabetes mellitus, consistent with previous findings. In contrast, the type of bone grafting technique had a diminished impact on late-stage healing outcomes, whereas a history of smoking was associated with delayed healing at the final follow-up.

Because partial cancellous bone osteotomy is involved in this technique, its potential impact on surgical blood loss was considered. Postoperative visible and occult blood loss were collected and compared

between the two groups. The results indicated that the use of orthotopic bone flap transplantation was associated with increased surgical blood loss. Therefore, postoperative monitoring of hemoglobin levels is warranted, with close attention to changes in blood loss and hemoglobin levels during follow-up.

The purpose of combining OW-HTO with the orthotopic bone flap transplantation technique is to accelerate early gap healing, enable early functional exercise, effectively restore knee joint function in patients with knee osteoarthritis, and prevent correction loss caused by delayed osteotomy healing. In this study, knee function scores were assessed in both groups at 6 months postoperatively and at the final follow-up. Postoperative knee function improved significantly compared with preoperative levels in both groups; however, no significant differences were observed between the two groups. These findings indicate that OW-HTO combined with different bone grafting techniques can achieve comparable clinical efficacy in the treatment of medial compartment knee osteoarthritis. According to previous research reports, although autologous iliac bone transplantation can effectively promote the healing of the osteotomy gap and improve postoperative knee joint function, it does not show a significant advantage in knee joint function improvement compared to not performing autologous iliac bone transplantation(21, 31). Allograft bone grafting provides additional stability at the osteotomy site, redistributes axial load, and reduces stress on the fixation hardware(32, 33). Functional outcomes have been shown to improve significantly with both techniques. However, there is no significant difference between autologous iliac bone transplantation and allogeneic bone transplantation in terms of safety and postoperative improvement of knee joint function(34). Several types of bone transplantation can effectively prevent the internal collapse of cancellous bone by filling the osteotomy gap, which is beneficial for postoperative functional exercise and the recovery of knee joint function in patients. In the present study, comparative analysis of radiographic parameters and functional scores before surgery, postoperatively, and at the final follow-up demonstrated that orthotopic bone flap transplantation significantly promoted osteotomy gap healing. However, compared with the currently commonly used allogeneic bone transplantation method, it shows no obvious advantage in improving postoperative knee joint function or maintaining the lower limb weight-bearing line.

Allograft bone, owing to its favorable osteoconductive properties and incorporation rate, has been shown to improve surgical outcomes, facilitate bone healing, and reduce complications. Therefore, it remains widely used in OW-HTO and is currently the most commonly applied bone grafting technique(35, 36). The orthotopic bone flap transplantation technique proposed in this study can provide autologous cancellous bone, which has been confirmed by this research to have a similarly good osteoinductive effect and can promote earlier healing of the osteotomy gap faster compared to the currently mainstream allogeneic bone grafting. This technique avoids donor-site morbidity associated with autologous iliac bone grafting, as well as potential immunological reactions and infection risks related to allograft use. Notably, the combined use of OW-HTO and orthotopic bone flap transplantation involves a localized U-shaped osteotomy of cancellous bone, which may be associated with increased postoperative bleeding in the short term. Therefore, postoperative monitoring of hemoglobin levels is recommended. For patients with preoperative anemia, the suitability of this technique should be carefully evaluated based on a

comprehensive assessment of the correction angle and the presence of risk factors that may impair osteotomy gap healing.

This study has several limitations. Firstly, this is a retrospective cohort study with a small sample size. Second, the location of the union zone in the osteotomy gap and the measurement of the union rate could not be confirmed by comparison with sagittal CT radiographs. Finally, this study merely analyzed the mid-term follow-up results, and the long-term follow-up, including removal of internal fixation, remains to be observed.

Conclusion

Compared with allograft bone grafting, orthotopic bone flap transplantation accelerated early osteotomy gap healing after OW-HTO and may provide radiographic advantages during the early postoperative period. Nevertheless, no significant differences were observed in long-term bone union, lower-limb alignment, or functional recovery. Although increased blood loss should be considered, this technique may be particularly beneficial for patients with risk factors for delayed healing, such as obesity, advanced age, or diabetes mellitus.

Declarations

Human Ethics approval and consent to participate The ethics committee of the Affiliated Hospital of Qingdao University approved this study.

Consent for publication Not applicable

Clinical trial number: Not applicable

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests The authors declare that they have no competing interests.

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Authors' contributions Conceptualization, X.C. and Y.Z.; methodology, X.C. and T.W.; writing—original draft preparation, X.C.; writing—review and editing, X.C., Y.L., X.Y., Y,S., Y.Z., K.X., X.Z. and T.W.; visualization, X.C. and Y.L.; supervision, T.W.; project administration, Y.Z. and T.W.; funding acquisition, T.W. All authors have read and agreed to the published version of the manuscript.

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Figures

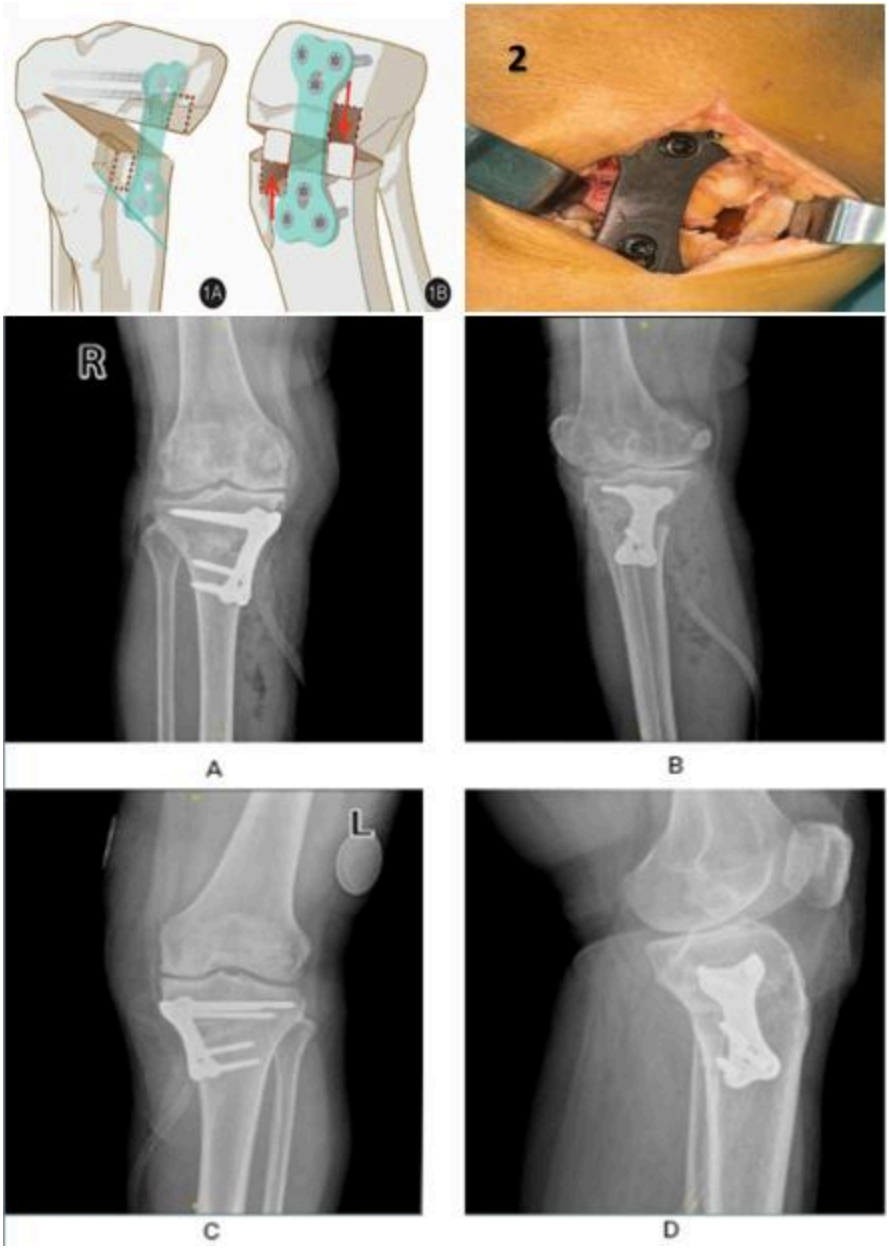


Figure 1

1A,1BSchematic Diagram of the OW-HTO Combined orthotopic bone flap transplantation. (2) Intraoperative photos of the OW-HTO combined bone flap technique. Postoperative fluoroscopic images (anterior-posterior and lateral views) following orthotopic bone flap transplantation.(A,B) Postoperative X-ray views (anterior-posterior and lateral) of allograft bone grafting.(C,D)

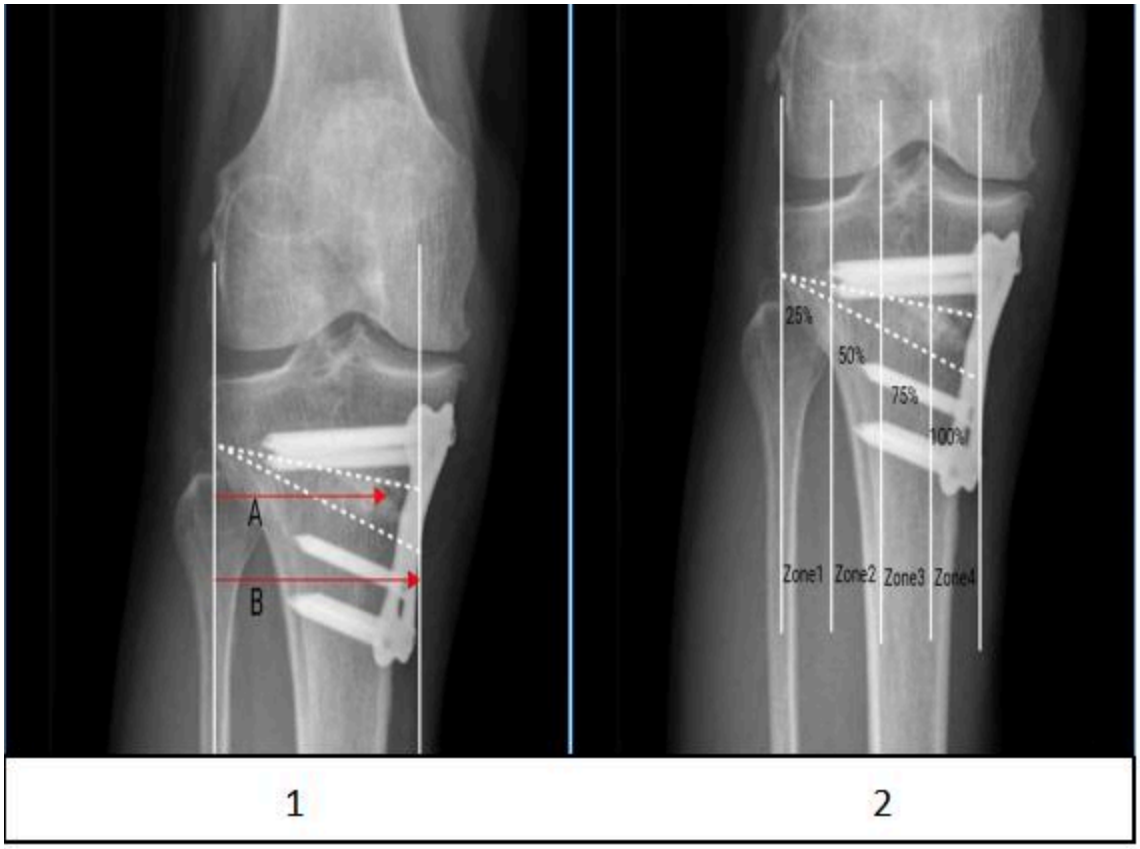


Figure 2

(1) The result of (Line A/ Line B) × 100 was the rate of osteotomy gap union.

(2) The osteotomy space was divided into the lateral hinge and four equally spaced intervals on the medial-lateral radiograph of the knee joint.

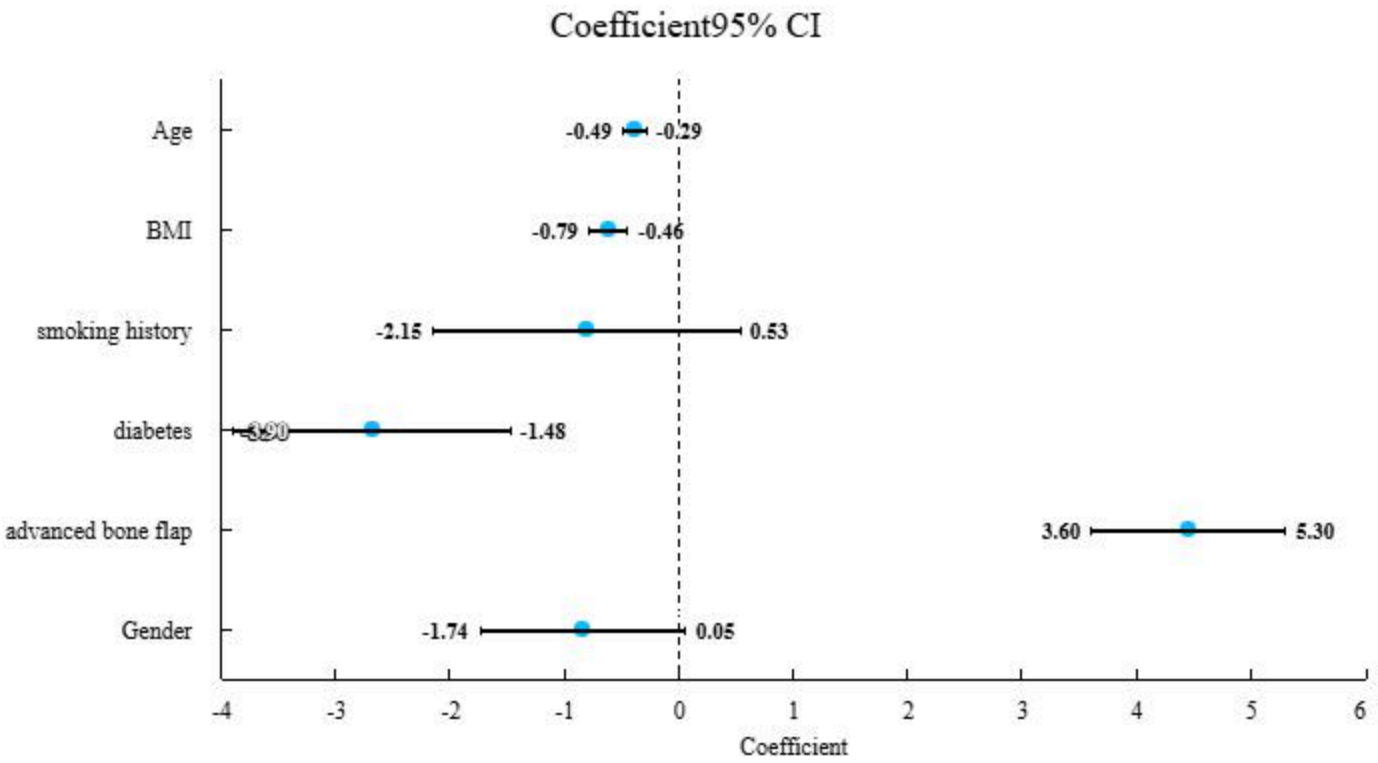


Figure 3

The rate of osteotomy gap union in sixth month=98.612-0.392*Age-0.623*BMI-0.810*smoking history-2.692*diabetes + 4.450*advanced bone flap -0.845*Gender

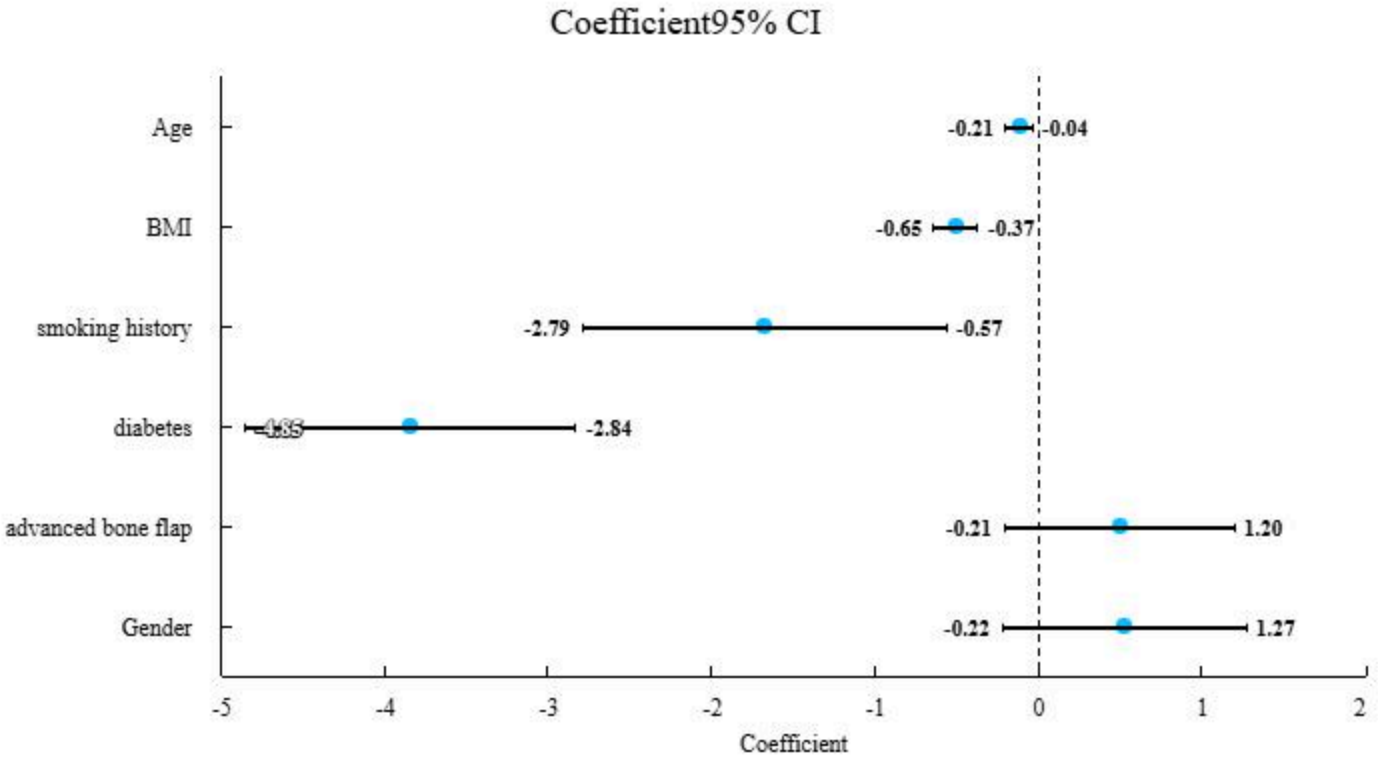


Figure 4

The rate of osteotomy gap union in eighteenth month=115.835-0.123*Age-0.512*BMI-1.681*smoking history-3.846*diabetes + 0.492*advanced bone flap + 0.521*Gender

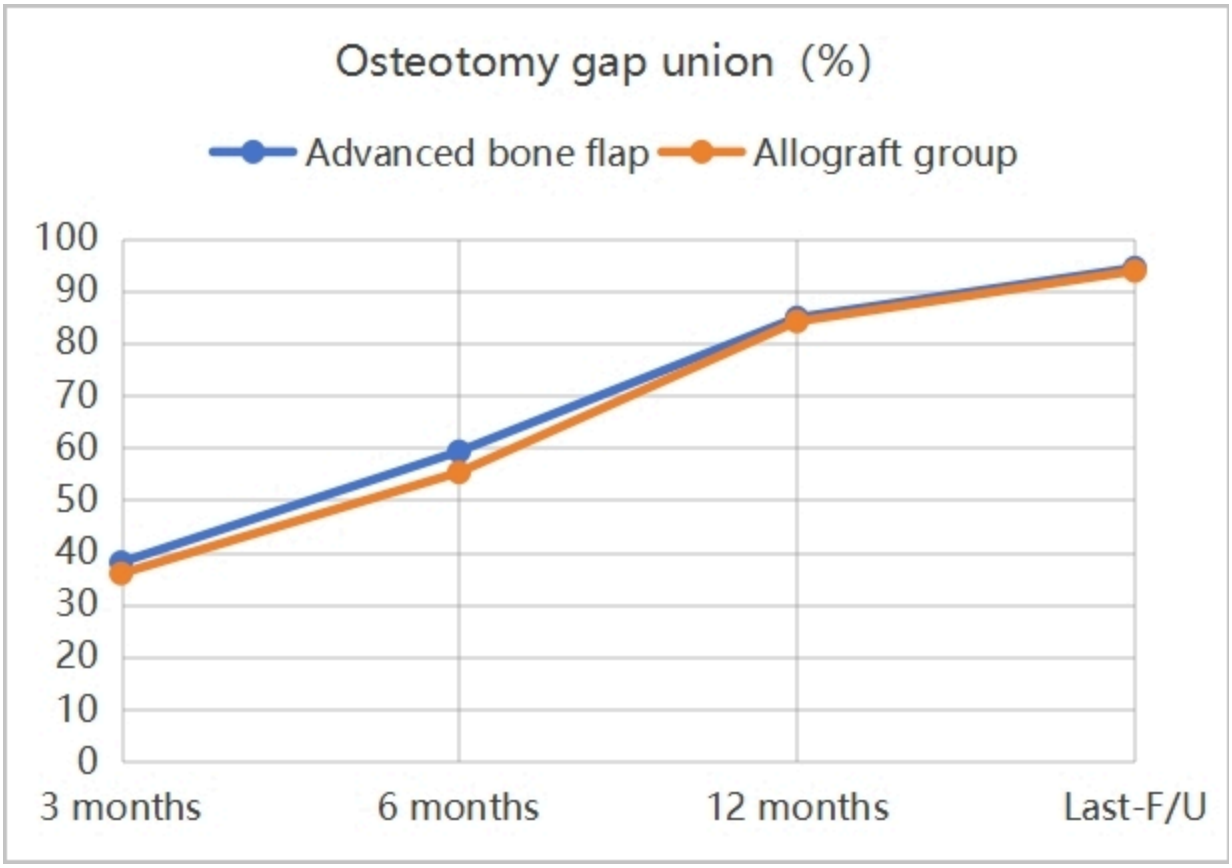


Figure 5

The radiological union rate between two groups at different periods.