

Is Bone Grafting Necessary in Opening Wedge High Tibial Osteotomy? A Meta-Analysis of Radiological Outcomes

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Purpose: Bone grafting in opening wedge high tibial osteotomy (OWHTO) is still controversial. The purpose of this study is to compare the radiological outcomes of OWHTO with bone graft (autogenous, allogeneous, and synthetic bone graft) and those without bone graft.

Materials and Methods: PubMed, MEDLINE, EMBASE and Cochrane Register of Studies databases were searched using specific inclusion and exclusion criteria for radiological studies involving OWHTO with bone graft and without bone graft groups. All reported delayed union, nonunion and correction loss were analyzed. Data were searched from the time period of January 2000 through July 2014. In addition, a modified Coleman methodology score (CMS) system was used to assess the methodological quality of the included studies.

Results: Twenty-five studies with a mean CMS value of 77 (range, 61 to 85 score) were included. In total, 1,841 patients underwent OWHTO using 4 different procedures for bone graft: autobone graft (n=352), allobone graft (n=547), synthetic bone graft (n=541) and no bone graft (n=401). There was a similar tendency for delayed union, nonunion and correction loss rate among the osteotomy space filling methods.

Conclusions: The meta-analysis showed there was a similar tendency for radiological union and correction maintenance among patients undergoing OWHTO regardless of the type of bone in all of the studies. However, the currently available evidence is not sufficient to strongly support the superiority of OWHTO with bone graft to OWHTO without bone graft.

Keywords: Knee, Osteoarthritis, Osteotomy, Bone graft, Meta-analysis

Introduction

Opening wedge high tibial osteotomy (OWHTO) with medial plate fixation is a proven adequate and safe method for treatment of medial compartment osteoarthritis of the knee and varus deformity, particularly in young and/or active individuals^{1,2}.

Advantages of OWHTO, compared to closed wedge osteotomy, include preservation of bone stock, predictable and adjustable correction, relatively easy exposure with avoidance of proximal tibio-fibular joint disruption, fibular nerve palsy, and compartment syndrome³.

However, OWHTO creates a gap in the metaphysis of the tibia. To enhance bone healing and increase initial mechanical stability, a high degree OWHTO may require the application of bone graft/substitute to fill the osteotomy gap. Moreover, OWHTO has been associated with risk of nonunion, collapse and loss of correction⁴. Autologous bone graft is the “gold standard” to fill the bone defect, but iliac crest graft harvest has risks. The associated complications include pain, thigh hypoesthesia, infection, pelvic bone fracture and discomfort wearing clothes^{5,6}. Allograft to avoid donor side morbidity was successfully applied in HTO⁷. However, the use of allograft increases additional risks such as disease transmission, immunologic reactions and slow remodeling.

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Due to the limited autologous bone availability and the problem of donor-site morbidity, many efforts have been made to find adequate supporting material for augmentation after osteotomy. Hydroxyapatite, β -tricalcium phosphate or the combination of both are the most commonly used synthetic augments in OWHTO. In the meantime, some recent studies presented good short-term results of OWHTO without additional bone substitutes for filling the osteotomy gap^{8,9}. Still, the most suitable material for filling the opening space in OWHTO has not been identified.

Over the past decade, there has been only one randomized controlled study on the comparison of autologous bone grafting and

no filling method, which reported similar outcomes between the two methods¹⁰. Although randomized controlled trials (RCTs) are considered to offer the ideal and highest level of evidence for patient care, numerous “good” surgical practices have evolved into the “standard of care” without being randomized against placebo or ineffective treatment options¹¹, which probably explains why only one RCT has been published. Considering that observational studies constitute the best available evidence¹², we attempted to conduct a meta-analysis of observational studies for the purpose of providing surgeons with informed data for better decision-making in OWHTO.

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Studies on patients who received OWHTO	Studies on patients who received closing wedge HTO
Studies reporting minimum 1-year follow-up data on radiological outcomes and complications of OWHTO	Studies reporting less than 1-year follow-up data on radiological outcomes and complications of OWHTO
Level I, II, III, or IV evidence	Level V evidence (case report, technical note, letter to editor), biomechanical reports, and review articles
Articles written in English	Articles written in languages other than English
Human subjects	Non-human subjects
Study published or in press online between January 1, 2000 and May 1, 2014	Study published or in press online on or before January 1, 2000
Medial plate fixation for OWHTO	Other devices (external fixator, staple) for OWHTO

OWHTO: opening wedge high tibial osteotomy.

Table 2. Search Protocol

No.	Search terms	Results
1	osteoarthritis [tiab]	35,633
2	"osteoarthritis" [MeSH:NoExp]	28,000
3	1 OR 2	49,340
4	"knee joints" [tiab] OR knee [tiab] OR tibia [tiab] OR tibial [tiab]	106,972
5	("knee" [MeSH]) OR "knee joint" [MeSH] OR "tibia" [MeSH]	72,058
6	4 OR 5	134,573
7	3 AND 6	16,821
8	"osteoarthritis, knee" [MeSH] OR "genu varum" [MeSH] OR "tibia/radiography" [MeSH] OR "tibia/surgery" [MeSH] OR "tibia/therapy" [MeSH] OR "genu valgum" [MeSH]	20,120
9	"knee osteoarthritis" [tiab] OR "osteoarthritis of knees" [tiab] OR "osteoarthritis of knee" [tiab] OR "genu varum" [tiab] OR "medial gonarthrosis" [tiab] OR "valgus knee" [tiab] OR "varus knee" [tiab] OR "varus deformity" [tiab] OR "valgus deformity" [tiab] OR "genu valgum" [tiab]	7,381
10	8 OR 9	23,707
11	7 OR 10	31,784
12	"osteotomy" [MeSH:NoExp] OR osteotomy [tiab] OR osteotomies [tiab]	31,896
13	11 AND 12	3,664
14	13 AND publication date from 2000/01/01 to 2014/05/02	2,057

The purpose of this study was to compare the radiological outcomes of OWHTO with bone graft (autogenous graft, allogeneous graft, and synthetic bone) and those without bone graft. The hypotheses were that the use of bone graft would produce superior radiological outcomes.

Materials and Methods

1. Eligibility Criteria

Published studies were included in this meta-analysis if they met the eligibility criteria described in Table 1. Patients included in this study were limited to osteoarthritis patients. There was no limitation in the age of patients. Fixation method was limited to plate fixation using either a locking or a non-locking plate.

2. Data Sources and Search Strategy

A literature search of online databases (MEDLINE, EMBASE and Cochrane Register of Studies) was performed. The search strategy used in the case of MEDLINE is presented in Table 2, which was modified for each of the other databases (Table 2).

Next, the references from the included studies were screened, and experts in the field were contacted for help in identifying additional studies. Two independent review authors (Han and Song) selected citations each based on the titles and abstracts. The eligibility of the full papers of those citations initially thought to fulfill the inclusion criteria was then assessed. In cases where a consensus could not be reached, a third review author (Nha) was consulted.

Table 3. Criteria of the Coleman Methodology Score for Studies

Criteria	Score	Criteria	Score
Part A—only one score to be given for each of the seven sections			
1. Study size—number of osteotomies		6. Description of surgical procedure	
>60	10	Adequate (technique stated with necessary details of the type of procedure)	5
41–60	7	Fair (technique only stated without elaboration)	3
20–40	4	Inadequate, not stated or unclear	0
2. Mean follow-up (mo)		7. Description of postoperative rehabilitation	
>24	5	Well described with >80% of patients complying	10
12–24	2	Well described with 60%–80% of patients complying	5
>12, not stated or unclear	0	Protocol not reported or <60%–80% of patients complying	0
3. Number of different surgical procedures included in each reported outcome		Part B—scores may be given for each option in each of the three sections if applicable	
One surgical procedure only	10	1. Outcome criteria	
More than one surgical procedure, but >90% of subjects undergoing one procedure	7	Outcome measures clearly defined	2
Not stated, unclear or <90% of subjects undergoing one procedure	0	Timing of outcomes assessment clearly stated	2
4. Type of study		Use of outcome criteria with good reliability	3
Randomised control trial	15	Use of outcome with good sensitivity	3
Prospective cohort study	10	2. Procedure for assessing outcomes	
Retrospective cohort study	0	Subjects recruited	5
5. Diagnostic certainty		Investigator independent of surgeon	4
In all	5	Written assessment	3
In >80%	3	Completion of assessment by subjects themselves with minimal investigator assistance	3
In <80%, no, unclear	0	3. Description of subject selection process	
		Selection criteria reported and unbiased	5
		Recruitment rate reported: >80% or <80%	5 or 3
		Eligible subjects not included in the study satisfactorily accounted for or 100% recruitment	5

3. Data Abstraction

A standardized form was used to extract data from the included papers on study characteristics, patient characteristics, surgical intervention, duration of follow-up, osteotomy size, postoperative rehabilitation protocol, radiological bone union period, nonunion rate, delayed union rate, correction loss rate and graft-related problems. The extracted data were then cross-checked for accuracy. Disagreements were settled by the Nha.

4. Statistical Analysis

Statistical analysis was performed using STATA/MP ver. 13.0 (Stata Corp., College Station, TX, USA). Effect sizes for dichotomous data (incidence of nonunion, delayed union, and loss of correction) were calculated using random-effect models and expressed as event rates. The mean values of the continuous data (the mean bone union period; the mean difference in bone union period) were compared using a t-test. For each effect size, a 95% confidence interval was given. Heterogeneity was calculated according to the method of Higgins et al.¹³⁾ and expressed as I_2 (range, 0% [complete consistency] to 100% [complete inconsistency]). Analysis of comparative studies and level IV case series analysis were performed separately. Case series analysis was performed to investigate whether the case series support the results of the one RCT and four comparative studies.

5. Quality Assessment

The methodological quality of the included studies was assessed by the two review authors (Han and Song) using the 10 critical appraisal criteria of the Coleman methodology score (CMS) (Table 3). The final scores ranged from 0 to 100, with a perfect score (100) indicating a study design that completely avoids the influences of chances, various biases, and confounding factors.

6. Included Studies

Based on the full-text review, the final meta-analysis included 25 studies on OWHTO. A flowchart illustrating the study selection process is depicted in Fig. 1¹⁴⁾. The included studies are listed in Table 4. Twenty case series, one RCT and four comparative studies were included in the meta-analysis.

Results

1. Quality Assessment

The modified CMS value for individual study is presented in Table 3. The mean modified CMS value for all included studies was 77 (range, 61 to 85 score). The mean CMS value for each criterion is shown in Table 5.

2. Radiological Outcomes

The overall results are shown in Table 6.

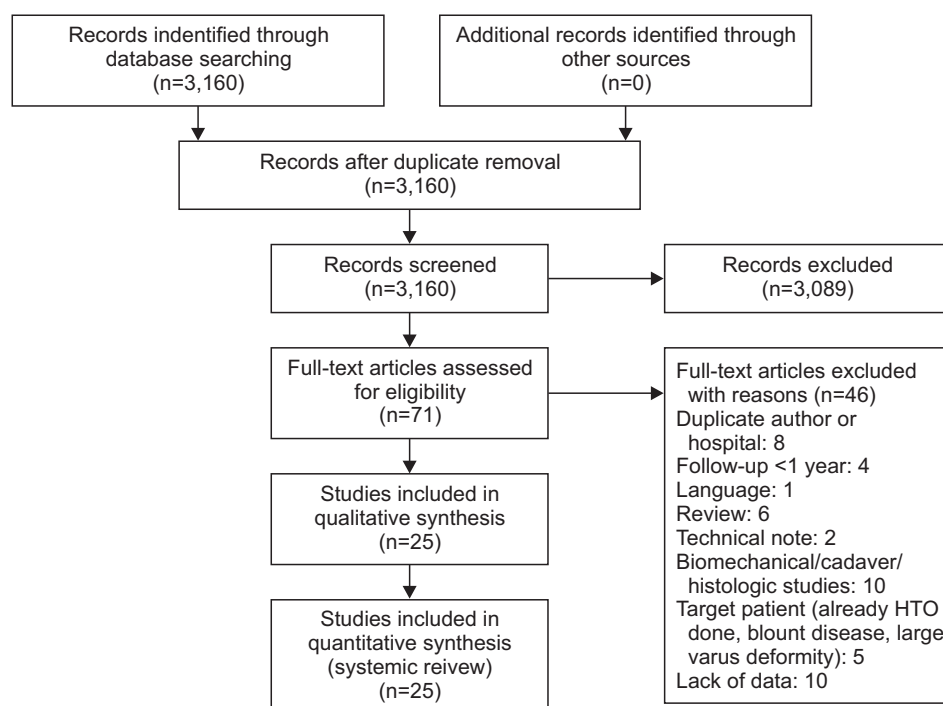


Fig. 1. Flowchart of identification of opening wedge high tibial osteotomy studies. HTO: high tibial osteotomy. Reprint from Moher et al.¹⁴⁾

Table 4. Studies Included in the Meta-Analysis

Author	Year	No. of patients	Filler type	Follow-up (mo)	Design/level of evidence	Fixation type	CMS
Chae et al. ⁵⁾	2011	138	Auto	37	Case/4	T plate	75
Yacobucci and Cocking ⁷⁾	2008	50	Allo	25	Case/4	Puddu plate	79
Zorzi et al. ¹⁰⁾	2011	23	Auto	24	RCT/1	Puddu plate	84
	2011	23	No	24		Puddu plate	
Bode et al. ¹⁵⁾	2013	52	No	60	Case/4	TomoFix	73
Schroter et al. ¹⁶⁾	2011	35	No	12	Case/4	Aescula plate	76
El-Azab et al. ¹⁷⁾	2011	50	No	36	Case/4	TomoFix	82
Brosset et al. ¹⁸⁾	2011	51	No	24	Case/4	TomoFix	72
El-Assal et al. ¹⁹⁾	2010	59	No	38	Case/4	4 holes toothed plate	85
Kolb et al. ²⁰⁾	2009	51	No	52	Case/4	TomoFix	85
Zaki and Rae ²¹⁾	2009	50	No	60	Case/4	TomoFix	75
Shim et al. ²²⁾	2013	37	Auto	36	Case/4	Arthrex plate	61
Schroter et al. ²³⁾	2013	32	Auto	77	Case/4	LC-DCP	82
Noyes et al. ²⁴⁾	2006	55	Auto	20	Case/4	Arthrex plate	83
Haviv et al. ²⁵⁾	2012	22	Allo	75	Case/4	Puddu plate	79
Santic et al. ²⁶⁾	2010	310	Allo	71	Case/4	T plate (AO)	83
DeMeo et al. ²⁷⁾	2010	20	Allo	100	Case/4	Puddu plate	82
Saito et al. ²⁸⁾	2014	64	Synthetic	78	Case/4	TomoFix	70
Saragaglia et al. ²⁹⁾	2011	124	Synthetic	125	Case/4	T plate (AO)	70
Ozalay et al. ³⁰⁾	2009	15	Synthetic	27	Case/4	Medial rigid angle plate	80
Koshino et al. ³¹⁾	2003	21	Synthetic	79	Case/4	T shaped, straight double plate	79
Hernigou and Ma ³²⁾	2001	203	Synthetic	120	Case/4	Osteotomy plate	85
Pornrattanamaneewong et al. ³³⁾	2012	30	Auto	>24	Comparative/3	T buttress plate	67
	2012	30	No	>24		TomoFix	
Jung et al. ³⁴⁾	2013	94	Allo	24	Comparative/4	Aescula plate	67
	2013	92	Synthetic	24		TomoFix	
Kuremsky et al. ³⁵⁾	2010	19	Auto	15	Comparative/3	Arthrex osteotomy plate	72
	2010	51	Allo	15		Arthrex osteotomy plate	
Gouin et al. ³⁶⁾	2010	18	Auto	45	Comparative/2	Surfix plate	79
	2010	22	Synthetic	45		Surfix plate	

CMS: Coleman methodology score, Auto: autogenous bone graft, Case: case series, Allo: allogeneous bone graft, No: no filling, Synthetic: synthetic material filling, Comparative: comparative study, RCT: randomized controlled study.

1) Radiological bone union period

Only three studies with no-filling method, one study with allogeneous graft and one study with synthetic graft presented mean radiological bone union periods and statistical deviations, rendering any statistical analysis meaningless. The radiological outcomes and radiological bone union periods are described in Table 7 and plotted in Fig. 2. Note that allogeneous graft groups required a longer period for union.

2) Nonunion and delayed union.

Table 6 lists all papers that were included in this meta-analysis. Kolb et al.²⁰⁾ defined delayed union as prolonged osteotomy healing of more than four months, and defined nonunion as no evidence of healing six months after osteotomy. Shim et al.²²⁾ defined delayed union as the lack of bridging callus and the presence of radiolucent areas within the opening wedge defect more than three months after surgery, and nonunion as no evidence of

Table 5. Overall Coleman Methodology Score for Each Criterion

Criteria (maximum score)	Mean	Standard deviation	Range
Part A			
Study size (10)	6.84	2.76	4–10
Mean follow-up (5)	4.4	1.22	2–5
No. of procedures (10)	10	0	10
Type of study (15)	7.8	4.58	0–15
Diagnostic certainty (5)	5	0	5
Surgery description (5)	4.4	1.22	3–5
Rehabilitation description (10)	7.6	4.35	0–10
Part B			
Outcome criteria (10)	7.96	1.67	4–10
Procedure for outcomes (15)	8	2.41	3–12
Selection process (15)	15	0	15
Total score (100)	77	6.58	61–85

healing within six months. Hernigou and Ma³²⁾ defined delayed union as the presence of pain at the osteotomy site after 45 days with evidence of loss of correction. Yacobucci and Cocking⁷⁾, defining nonunion as the absence of radiological union requiring iliac crest bone grafting, reported two cases of nonunion in corrections of 15 degrees and an unrecognized fracture of the lateral hinge in one of those cases.

Nonunion and delayed union rates assessed according to the filler type are presented in Table 8. There was a similar tendency for nonunion and delayed union rates among studies classified according to the filler type. The nonunion and delayed union rates were also analyzed according to the type of fixation. Table 9 shows nonunion and delayed union rates assessed according to the fixation type. There was also a similar tendency for nonunion and delayed union rates among studies classified according to the fixation type. No series were reported on OWHTO using an

Table 6. Overall Results of Studies

Author	Filling method	Radiological union (day), mean (SD)	Osteotomy size (mm or °), mean (SD)	Loss of correction	Nonunion	Delayed union	FWB (wk)	PWB (wk)
Chae et al. ⁵⁾	Tricortical iliac crest	N/A	N/A	6/138	0	N/A	6	2
Yacobucci and Cocking ⁷⁾	Proximal tibial cortico-cancellous wedge allograft	120 (28)	10.1°	1/50	2/50	N/A	N/A	8
Zorzi et al. ¹⁰⁾	Cancellous iliac crest autologous bone	87	9.9	1/23	0	N/A	N/A	8
	No	96	10.2	2/23	0	N/A	N/A	8
Bode et al. ¹⁵⁾	No	N/A	N/A	0	2/52	2/52	4	2–3
Schroter et al. ¹⁶⁾	No	N/A	8.0 (2.0)	2/35	N/A	N/A	6–8	N/A
El-Azab et al. ¹⁷⁾	No	N/A	7.1° (2.4°)	N/A	0	3/50	6	POD 1 day
Brosset et al. ¹⁸⁾	No	135 (49)	N/A	0	0	2/51	N/A	N/A
El-Assal et al. ¹⁹⁾	No	90 (15)	10.5 (1.5)	1/59	0	0	N/A	N/A
Kolb et al. ²⁰⁾	No	90 (14)	10.9 (1.5)	0	1/51	0	6	N/A
Zaki and Rae ²¹⁾	No	N/A	N/A	0	0	N/A	N/A	N/A
Shim et al. ²²⁾	Tricortical iliac crest	90	6.42	N/A	0	1/37	N/A	N/A
Schroter et al. ²³⁾	Iliac crest bone wedge	N/A	8.2 (4.9)	N/A	N/A	N/A	6–8	N/A
Noyes et al. ²⁴⁾	Tricortical iliac crest	90	9.7 (3.1)	1/55	0	3/55	8	4
Haviv et al. ²⁵⁾	Tricortical iliac crest	180	5.0–17.5	0	0	0	13	6
Santic et al. ²⁶⁾	Femoral head	168	8.6 (2.0)	0	0	0	12	6
DeMeo et al. ²⁷⁾	Tricortical iliac crest+cancellous bone chips	N/A	N/A	0	0	1/20	11.4	6–8
Saito et al. ²⁸⁾	Hydroxyapatite Or β tricalcium phosphate wedge	N/A	12	0	0	1/64	N/A	N/A

Table 6. Continued

Author	Filling method	Radiological union (day), mean (SD)	Osteotomy size (mm or °), mean (SD)	Loss of correction	Nonunion	Delayed union	FWB (wk)	PWB (wk)
Saragaglia et al. ²⁹⁾	β tricalcium phosphate wedge	N/A	N/A	1/124	0	7/124	N/A	N/A
Ozalay et al. ³⁰⁾	Biphasic calcium phosphate	N/A	12.6	0	0	N/A	N/A	N/A
Koshino et al. ³¹⁾	Porous hydroxyapatite wedge	96 (7)	N/A	0	0	N/A	8	3–4
Hernigou and Ma ³²⁾	Synthetic material	90	N/A	N/A	1/203	2/203	N/A	N/A
Pornrattananeewong et al. ³³⁾	Tricortical iliac crest autologous bone	N/A	N/A	N/A	0	0	4	2
	No	N/A	N/A	N/A	0	0	4	2
Jung et al. ³⁴⁾	Allogenic cancellous bone chip graft	N/A	N/A	12/94	1/94	0	10	6
	Porous β-tricalcium phosphate wedge	N/A	N/A	6/92	0	0	6	POD 1 day
Kuremsky et al. ³⁵⁾	Tricortical iliac crest autologous bone	N/A	12.9	N/A	0	N/A	N/A	6
	Freeze-dried cortico-cancellous allogenic structural graft	N/A	11.8	N/A	0	N/A	N/A	6
Gouin et al. ³⁶⁾	Iliac crest tricortical autologous bone	78	10.0	6/22	0	N/A	N/A	N/A
	Calcium-phosphate ceramic spacer	154	10.0	1/18	0	N/A	N/A	N/A

SD: standard deviation, FWB: full weight-bearing, PWB: partial weight-bearing, N/A: not available, POD: postoperative day.

Table 7. Bone Union Period

Filler type	Author	Bone union period (day), mean (SD)
No	Brosset et al. ¹⁸⁾	135 (49)
	El-Assal et al. ¹⁹⁾	90 (15)
	Kolb et al. ²⁰⁾	90 (14)
Auto	Shim et al. ²²⁾	90
	Noyes et al. ²⁴⁾	90
Allo	Yacobucci and Cocking ⁷⁾	120 (28)
	Haviv et al. ²⁵⁾	180
	Santic et al. ²⁶⁾	168
Synthetic	Koshino et al. ³¹⁾	96 (7)
	Hernigou and Ma ³²⁾	90

SD: standard deviation, No: no filling, Auto: autogenous bone graft, Allo: allogeneous bone graft, Synthetic: synthetic material filling.

autologous bone graft with a locking plate.

3) Loss of correction

Yacobucci and Cocking⁷⁾ reported one case of correction loss with lateral cortex fracture, wherein the correction angle was 15 degrees. Saragaglia et al.²⁹⁾ also reported one case of correction loss associated with screw breakage. Tables 9 and 10 list the incidence and rate of loss of correction. There was a similar tendency for the correction loss rate when compared according to the filler type and fixation method.

3. Comparative Studies

Only one randomized prospective study was identified. Zorzi et al.¹⁰⁾ reported there was no significant difference in bone union period based on the review of a two-year comparison of 23 cases of OWHTO using autografts and another 23 cases of OWHTO without filling. As for comparative studies, there were four. Pornrattananeewong et al.³³⁾ reported that there were

no significant differences of bone union period between their groups. Kuremsky et al.³⁵⁾ found that there was a 6-fold higher failure rate for the allograft group compared with the autograft group. Gouin et al.³⁶⁾, comparing an autologous bone graft group with a synthetic-material graft (BMCaPh) group, determined that correction loss was more frequent in the latter group (5% vs. 27%). Specifically, the presence of lateral cortical hinge tears significantly increased the risk of correction loss in the BMCaPh group. These results indicated that the synthetic material was less tolerant to high mechanical stress, and that radiological union occurred significantly later in the BMCaPh group than in the autologous bone graft group. Jung et al.³⁴⁾ defined loss of correction as less than 0 degrees of mechanical tibiofemoral angle at

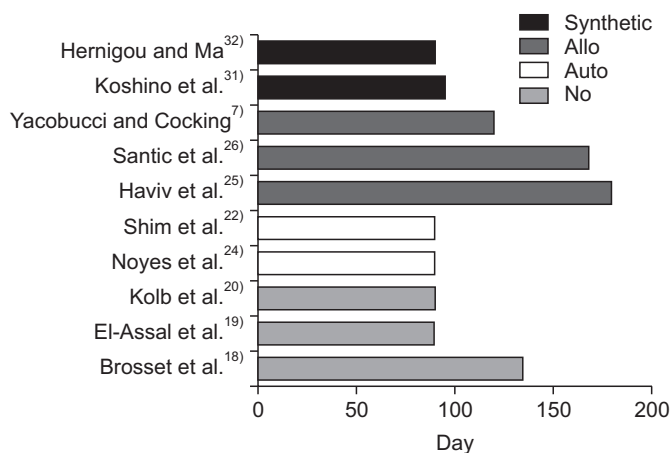


Fig. 2. Bone union period. No: no filling, Auto: autogenous bone graft, Allo: allogeneous bone graft, Synthetic: synthetic material filling.

Table 8. Rates of Nonunion/Delayed Union by Filler Type

Filler type	Author	Non-union	Event rate	I ₂ (%)	Delayed union	Event rate	I ₂ (%)	
No filling		3/313	0.018	0.0	7/263	0.03	0.0	
	Bode et al. ¹⁵⁾	2/52	0.038		2/52	0.04		
	El-Azab et al. ¹⁷⁾	0/50	0.010		3/50	0.06		
	Brosset et al. ¹⁸⁾	0/51	0.008		2/51	0.04		
	El-Assal et al. ¹⁹⁾	0/59	0.020		0/59	0.01		
	Kolb et al. ²⁰⁾	1/51	0.010		0/51	0.01		
	Zaki and Rae ²¹⁾	0/50	0.023		N/A	N/A		
Auto		0/230	0.005	0.0	4/92	0.04	0.0	
	Chae et al. ⁵⁾	0/138	0.004		N/A	N/A		
	Shim et al. ²²⁾	0/37	0.013		1/37	0.03		
	Noyes et al. ²⁴⁾	0/55	0.009		3/55	0.05		
Allo		2/402	0.004	0.0	1/352	0.00	0.0	
	Yacobucci and Cocking ⁷⁾	2/50	0.040		N/A	N/A		
	Haviv et al. ²⁵⁾	0/22	0.022		0/22	0.02		
	Santic et al. ²⁶⁾	0/310	0.002		0/310	0.00		
	DeMeo et al. ²⁷⁾	0/20	0.024		1/20	0.05		
	Synthetic		1/427	0.013	0.0	10/427	0.02	0.0
		Saito et al. ²⁸⁾	0/64	0.004		1/64	0.02	
Saraglia et al. ²⁹⁾		0/124	0.031		7/124	0.06		
Ozalay et al. ³⁰⁾		0/15	0.005		0/15	0.03		
Koshino et al. ³¹⁾		0/21	0.008		0/21	0.02		
Hernigou and Ma ³²⁾		1/203	0.009		2/203	0.01		

N/A: not available, Auto: autogenous bone graft, Allo: allogeneous bone graft, Synthetic: synthetic material filling.

Table 9. Nonunion/ Delayed Union/ Correction Loss for MOWHTO with Plate Fixation

Fixation type	Nonunion	Event rate	I ₂ (%)	Delayed union	Event rate	I ₂ (%)	Correction loss	Event rate	I ₂ (%)
Non-locking plate	2/576	0.02	0	15/388	0.04	0	13/524	0.02	0
No filling	0/109	0.02	0	3/109	0.03	11	4/94	0.04	25.8
Auto	0/230	0.01	0	4/92	0.04	0	7/193	0.04	0
Allo	2/92	0.03	0	1/42	0.04	0	1/92	0.02	0
Synthetic	0/145	0.03	0 ^{a)}	7/145	0.05	0	1/145	0.01	0
Locking plate	3/578	0.00	0	5/528	0.01	0	0/526	0.00	0
No filling	3/204	0.02	0	4/154	0.03	0	0/152	0.01	0
Auto	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Allo	0/310	0.00	0 ^{a)}	0/310	0.00	0 ^{a)}	0/310	0.00	0 ^{a)}
Synthetic	0/64	0.00	0	1/64	0.02	0 ^{a)}	0/64	0.01	0 ^{a)}

MOWHTO: medial opening wedge high tibial osteotomy, N/A: not available, Auto: autogenous bone graft, Allo: allogeneous bone graft, Synthetic: synthetic material filling, I₂: heterogeneity.

^{a)}Only one case series.

Table 10. Rates of Correction Loss by Filler Type

Filler type	Author	Loss of correction	Event rate	I ₂ (%)	Treatment
No filling		4/246	0.02	0.0	
	Schroter et al. ¹⁶⁾	3/35	0.09		Two-medial dislocation of tibial plateau Fixation with TomoFix and iliac creset autologous bone wedge No correlation with osteotomy size
	Brosset et al. ¹⁸⁾	0/51	0.01		
	El-Assal et al. ¹⁹⁾	1/59	0.02		Partial loss of correction (4 degrees) No intervention
	Kolb et al. ²⁰⁾	0/51	0.01		
	Zaki et al. ²¹⁾	0/50	0.01		
Auto		7/193	0.04	0.0	
	Chae et al. ⁵⁾	6/138	0.04		No intervention
	Noyes et al. ²⁴⁾	1/55	0.02		Revision
Allo		1/402	0.00	0.0	
	Yacobucci and Cocking ⁷⁾	1/50	0.02		Correlation with nonunion and lateral hinge fracture Revision with Puddu plate and iliac crest autologous graft
	Haviv et al. ²⁵⁾	0/22	0.02		
	Santic et al. ²⁶⁾	0/310	0.00		
	DeMeo et al. ²⁷⁾	0/20	0.02		
Synthetic		1/224	0.01	0.0	
	Saito et al. ²⁸⁾	0/64	0.01		
	Saragaglia et al. ²⁹⁾	1/124	0.01		New osteotomy at the femoral level to correct the deformity 2 years later
	Ozalay et al. ³⁰⁾	0/15	0.03		
	Koshino et al. ³¹⁾	0/21	0.02		

Auto: autogenous bone graft, Allo: allogeneous bone graft, Synthetic: synthetic material filling.

the latest follow-up in the absence of an initial under-correction. The rate of correction loss or varus recurrence was higher in the group receiving the Asecula plate (B. Braun Korea, Seoul, South Korea) with the β -tricalcium phosphate wedge. The outcomes of all of the comparative studies are documented in Table 11. There was no significant difference in bone union period between the autogenous graft groups and no filling groups (Fig. 3).

4. Starting Point of Weight-Bearing

All twenty studies included in this meta-analysis reported on the starting point of weight-bearing (Table 6). There was a tendency of delayed onset of weight-bearing in patients with allograft. Jung et al.³⁴⁾ permitted full weight-bearing walking one month after surgery to their allograft patients. Pornrattanamaneewong et al.³³⁾ allowed full weight-bearing walking at the same time point for both groups (tricortical iliac crest autologous

bone graft group and no filling group), and Zorzi et al.¹⁰⁾ allowed partial weight-bearing walking at the same time point for both groups (cancellous iliac crest autologous bone graft group and no filling group); it must be noted, however, that the time point was not the endpoint of full weight-bearing walking but rather was the starting point of their rehabilitation protocol.

5. Bone Graft-Related Problem

Pornrattanamaneewong et al.³³⁾ and Kuremsky et al.³⁵⁾ described the graft harvest site as the source of pain that prolonged patient recovery time. Chae et al.⁵⁾ also reported the graft harvest site as the source of pain for patients in the early postoperative period especially during trunk flexion. In addition, three of their patients underwent linear fracture of the iliac bone, which was treated conservatively. Schroter et al.²³⁾ reported that six patients suffered from hyperaesthesia or dysaesthesia at the iliac crest. Gouin et al.³⁶⁾, Koshino et al.³¹⁾ and Ozalay et al.³⁰⁾ all reported

Table 11. Comparative Studies

Study	Bone graft	Bone union period (day)	p-value	Opening size (mm)	Nonunion	Delayed union	Loss of correction	Fixation type
Zorzi et al. ¹⁰⁾	Auto	86.7	0.128	9.9	0	N/A	1/23	Nonlocking (Puddu) plate
	No	95.7		10.2	0	N/A	2/23	Nonlocking (Puddu) plate
Pornrattanamaneewong et al. ³³⁾	Auto	66.5	0.125	N/A	0	0	N/A	Nonlocking (T buttress) plate
	No	72.1		N/A	0	0	N/A	Locking (TomoFix) plate
Jung et al. ³⁴⁾	Allo	N/A	N/A	N/A	1/94	0	N/A	Nonlocking (Aescula) plate
	Synthetic	N/A		N/A	0	0	N/A	Locking (TomoFix) plate
Kuremsky et al. ³⁵⁾	Auto	N/A	N/A	12.9	0	N/A	N/A	Nonlocking (Arthrex opening wedge osteotomy plate prototype set)
	Allo	N/A		11.8	0	N/A	N/A	Nonlocking (Arthrex opening wedge osteotomy plate prototype set)
Gouin et al. ³⁶⁾	Auto	78	0.001	10	0	N/A	1/18	Locking (Surfix) plate
	Synthetic	154		10	0	N/A	6/22	Locking (Surfix) plate

Auto: autogenous bone graft, N/A: not available, No: no filling, Allo: allogeneous bone graft, Synthetic: synthetic material filling.

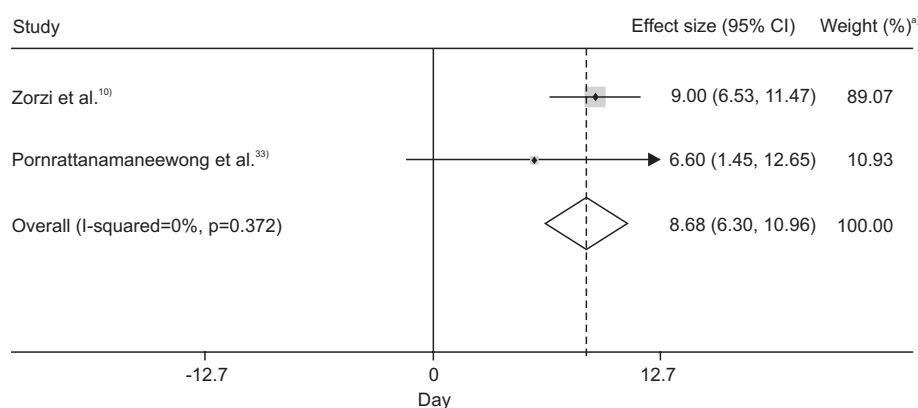


Fig. 3. Bone union period of autogenous bone graft group and no filling group. Forest plot of mean difference and 95% confidence interval (CI) for constant scores among patients assigned to Auto group or no filling group for opening wedge high tibial osteotomy. Mean difference: 8.68 (day)=heterogeneity (I₂)=0, p=0.372. ^{a)}Weights are from random effects analysis.

poor incorporation of substitute material.

Discussion

In this meta-analysis, the RCT was found to have demonstrated similar bone union period, union rate and correction loss rate between the patients with autogenous bone graft and those without filling. One comparative study presented similar bone union period and union and delayed union rates between the autogenous graft group and the no filling group. Another comparative study showed similar union and delayed union rates between allogeneous bone graft group and the synthetic material group. One comparative study reported the autogenous bone graft group showed shorter bone union period and lower correction rate compared to the synthetic material group. In analyzing the case

series, there was a similar tendency for nonunion, delayed union or correction loss rates among the groups classified according to the filler type. The bone union period showed a tendency to increase in the allogeneous bone graft groups. The results of case series showed a similar tendency for union and delayed union rates among groups classified according to the graft type but a different was noted with regard to the correction loss rate.

The surgical techniques for opening wedge HTO underwent many modifications with regard to augmentation with bone grafts or bone substitutes. In general, autogenous bone graft is considered as the most successful bone filling material, owing to its osteoconductive, osteoinductive and osteogenic properties. Nevertheless, autograft harvesting involves increased operative time as well as donor-site morbidity (hyper- or dysaesthesia, pain source and iliac crest fracture)²⁴⁾. Aryee et al.³⁷⁾ suggested that

iliac bone graft should be used only in high-risk patients (obese, smoker or opening gap larger than 10 mm). The use of bone allograft provides only an osteoconductive benefit, though, thanks to its availability without the need for additional surgical access, potential complications associated with the harvesting procedure of autogenous bone graft can be avoided²⁶⁾. However, allografts entail the risk of virus transfer³⁸⁾. Synthetic materials provide the osteoconductive benefit along with initial support; however several disadvantages such as soft-tissue irritation and infection have been reported³⁹⁾. van Hemert et al.⁴⁰⁾ reported synthetic bone augmentation does not aid much in primary stability and is not intended for load-bearing. Furthermore, it must be used in a mechanically stable environment; otherwise, it cannot remodel into bone and shows slow incorporation into bone⁴⁰⁾. Seven studies in this meta-analysis noted the disadvantages of autogenous grafts and synthetic materials. There were no studies reporting any disadvantages of allografts.

The recent trend of leaving the osteotomy with no graft is supported by some authors^{3,41)}. Zorzi et al.¹⁰⁾ included in this meta-analysis reported that there was no significant difference in the time to bone healing between patients that had an autologous bone graft and those that did not. They suggested that bone grafts could be reserved for special situations such as larger corrections and patients with conditions that impair bone healing. In the study, the no filling group also obtained satisfactory results and showed no differences compared with the other groups. Pornratnamaneewong et al.³³⁾ included in this meta-analysis reported that a significantly higher percentage of osteotomies with medial defects was found in the no bone graft group and all defects remained until the time of the 2-year follow-up. Recent studies attributed such medial defects in OWHTO to low interfragmentary movement and tissue strain underneath the locking plate. They suggested that the use of dynamic locking screws in combination with early full load-bearing would increase the interfragmentary movement and tissue strain and potentially induce good bone healing underneath the plate⁴²⁾.

El-Assal et al.¹⁹⁾ performed OWHTO without bone graft for the opening size of 14 mm in 9 cases, and the outcome was good. Kolb et al.²⁰⁾ also performed OWHTO (up to 14 mm) and obtained favorable results. These two studies support the contention that OWHTO gaps of up to 14 mm in size can be healed without graft. Staubli et al.²⁾ reported that the cases with opening sizes less than 15 mm did not have filling defects and showed good results overall. When an osteotomy size is smaller than 14 mm and rigid fixation and locking system are acquired, “no filling” of the osteotomy space can be a good option for OWHTO. OWHTO without bone graft is certainly very attractive particularly because

it is effective for reducing the length of surgery as well as patient morbidity.

The bone-healing process is complex and requires ideal biological and mechanical environments and factors. Kuremsky et al.³⁵⁾ included in this meta-analysis reported that lateral cortex fracture and opening size play a major role in bone union and construct failure. With higher varus angles, stability is largely dependent on the intact lateral hinge, which, if lost, would lead to the loss of resistance to axial compression forces and, thereby, loss of correction. Stability plays a major role in this regard: the mechanical factors are functions of osteotomy stability, which depends on the osteotomy size, intact lateral cortex and rigid internal fixation^{43,44)}. Miller et al.⁴⁵⁾ detected a 58% reduction in axial stiffness and a 68% reduction in torsional stiffness in the case of lateral tibial cortex disruption. In case of lateral cortex fracture, there is instability resulting from the insufficient primary stability provided by non-angular stable wedge plates⁴⁶⁾. Spahn et al.⁴⁷⁾ suggested that high body mass index (BMI) after weight-bearing could be the cause of correction loss. van Houten et al.⁴⁸⁾ noted that the use of tobacco was a major risk factor for development of nonunion in patients undergoing OWHTO. Rigid fixation, opening size and the presence/absence of lateral cortex fracture all affect bone union and maintenance of correction. In cases where there is a possibility of either correction loss or nonunion caused by lateral cortex fracture or large opening size, smoking or high BMI with non-rigid fixation, additional autologous bone graft is a better choice, with all due caution, to prevent harvest-site morbidity.

Limitations

There are several limitations to the present analysis. First, most of the reviewed studies were level IV case series; only one RCT and four comparative studies were found on the topic of OWHTO. Thus, the level IV study results could not be directly compared, which may affect the reliability of the analysis results.

Second, although the number of reviewed studies was large, the study designs were different: there were one RCT, four non-randomized trial studies and twenty uncontrolled trial studies. If the results are arranged according to the study design, the number of studies per one result analysis becomes less than 6 at the most. On the assessment of publication bias, the power of the test of a meta-analysis based on the review of less than 10 studies is too low to derive definitive conclusions. In such a case, assessment for publication bias is not appropriate according to Cochrane handbook⁴⁹⁾. Accordingly, publication bias could not be assessed for our analysis.

Third, there were no precise common definitions of radiological

union, non-union, delayed union and loss of correction. Rather, these outcomes were assessed by the authors' own subjective methods.

Fourth, there were not sufficient studies on OWHTO without bone graft. Finally, we did not include age, varus deformity angle and bone marrow density severity into the inclusion criteria. These might have affected patient selection bias.

Conclusions

This meta-analysis evaluated the effects of four established methods of augmentation for osteotomy defect in OWHTO. According to the published studies, all of the methods (autogenous bone grafting, allogeneous bone grafting, synthetic material filling and no filling) appear to be appropriate operative treatment options for osteotomy defect in OWHTO.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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