

Smoking and obesity influence the risk of nonunion in lateral opening wedge, closing wedge and torsional distal femoral osteotomies

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Abstract

Purpose Lateral distal femoral osteotomies (DFO) have recently been performed more frequently. In addition to realignment for varus and valgus deformity, the indication was extended with the introduction of torsional osteotomies in patellofemoral instability. The purpose of this study was to assess the general and technical risk factors for nonunion in lateral opening, closing and torsional DFO.

Methods A total of 150 lateral DFO [98 opening wedge (LOWDFO) and 52 closing wedge (LCWDFO)] were analyzed in regard to potential risk factors for nonunion until plate removal. Nonunion was defined as failure of

osseous consolidation according to clinical and radiological evaluation.

Results In LOWDFO, the nonunion rate was 2%, in LCWDFO the rate was higher with 9.6%. Nicotine abuse ($p=0.009$) and a higher body mass index ($p=0.003$) were significant risk factors. Patient's age and gender, the wedge height, hinge fractures, monoplanar versus biplanar osteotomy as well as additional torsional osteotomies were not significant in regard of nonunion.

Conclusions Lateral DFO have a low rate of complications and nonunion. Smoking and obesity were significantly associated with the risk of nonunion. Hinge fractures, monoplanar technique or complete bone cuts of the opposite hinge in torsional osteotomies did not negatively influence the nonunion rate in DFO.

Level of evidence Level IV.

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Introduction

Lateral opening wedge distal femoral osteotomies (LOWDFO) with the aim of a varus producing realignment has been abandoned in the last decades due to the suggested high complication rate [14, 19]. Particularly, the high rate of nonunions was the main reason why surgeons preferred medial closing wedge procedures [17, 25]. However, with the introduction and improvement of locking plates and the potential of creating an internal fixation with a high primary stability, the possibility of a LOWDFO regained the focus of interest [4, 6, 11]. Current studies led to a better understanding of osteotomies around the knee, especially DFO, with the aim of maintaining an even joint line depending

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on the preoperative analysis of the mechanical lateral distal femoral angle (mLDFA) and the mechanical medial proximal tibial angle (mMPTA) [10, 26]. The recently reported rates of nonunions as well as other intraoperative complications are almost equal to those of medial closing wedge techniques [5, 18, 34]. With the ability to fine-tune the intraoperative correction, the technique of a LOWDFO provides technical advantages during surgery compared to a medial closing wedge technique, an analogue to open wedge high tibial osteotomy [23, 27]. Furthermore, the indication for these osteotomies has been extended. In addition to the correction of a coronal malalignment, such as valgus or varus deformity, DFO can be used for the correction of excessive femoral antetorsion in patients with patellofemoral instability (PFI) [3, 8, 24]. However, in torsional osteotomies, the contralateral cortex, which is maintained in plain DFO, has to be cut completely to allow a rotation in the axial plane, resulting in a potentially increased instability of the internal fixation. This inevitably leads to the question whether there is a higher nonunion rate in additional torsional osteotomies compared to plain lateral opening or closing wedge osteotomies where the hinge is kept intact. Thus, the aim of this study was to evaluate the effect of general risk factors like smoking habits and obesity on the nonunion rate in LOWDFO and lateral closing wedge DFO (LCWDFO). Furthermore, specific risk factors, such as an additional torsional osteotomy, the wedge height and biplanar versus monoplanar osteotomy techniques, were evaluated to give advice for possible limitations of this technique. The hypothesis was that besides smoking and obesity, increasing wedge heights, an additional torsional osteotomy and the monoplanar technique would lead to higher nonunion rates.

Materials and methods

Between 2008 and 2016, all consecutive lateral DFO that were performed at our institution were assessed for the present study. All cases were studied retrospectively. Cases with a follow-up less than 12 months and cases in which patients were not available for clinical follow-up were excluded. Demographic data, such as age, gender, laterality, body mass index (BMI), and smoking habits, were collected. Furthermore, specific data including axis malalignment, femur antetorsion, the heights of the osteotomy wedge, as well as the type of osteotomy (monoplanar versus biplanar), open wedge with or without torsional osteotomy, closing wedge, hinge alteration and the time of plate removal were collected. Patients whose plate removal was not performed at our institution were invited for a clinical follow-up or were interrogated by phone about their medical course.

Preoperatively, radiographic assessment consisted of anterior–posterior and lateral views of the knee. The

mechanical axis for varus or valgus malalignment was evaluated on X-ray using a standing full-length alignment view. A pathological mLDFA ($<85.0^\circ$ or $>90.0^\circ$) and a normal mMPTA led to the indication of using a DFO as a site for realignment of valgus or varus deformity. Preoperative planning was performed using a digital planning software (medCAD, HECTEC GmbH, Germany) with an established high test–retest reliability [28]. Torsional deformity in patients with PFI was assessed by performing a magnetic resonance imaging. Postoperative radiographs were made the day after surgery, then subsequently at 6 and 12 weeks. Afterwards, radiographs were conducted according to the patient's medical course, especially symptoms like pain and swelling as well as tenderness at the osteotomy site, which led to further follow-ups every 6 weeks. Nonunion was defined on one hand on radiographs and/or computed tomography scans showing no signs of bone consolidation after at least 6 months, but more important, without radiologic progress in bone healing (Fig. 1). On the other hand, nonunion had to come along with clinical symptoms, mainly load-dependent pain, and requiring revision surgery [18].

Surgical technique

Arthroscopy was performed immediately prior to the osteotomy to assess the cartilage of the non-involved compartment and to evaluate and treat intra-articular lesions. Concomitant procedures are shown in Table 1 for LOWDFO, in Table 2 for LCWDFO. A standardized lateral subvastus approach for the distal femur was used in all osteotomies. The osteotomy was performed either in monoplanar or in

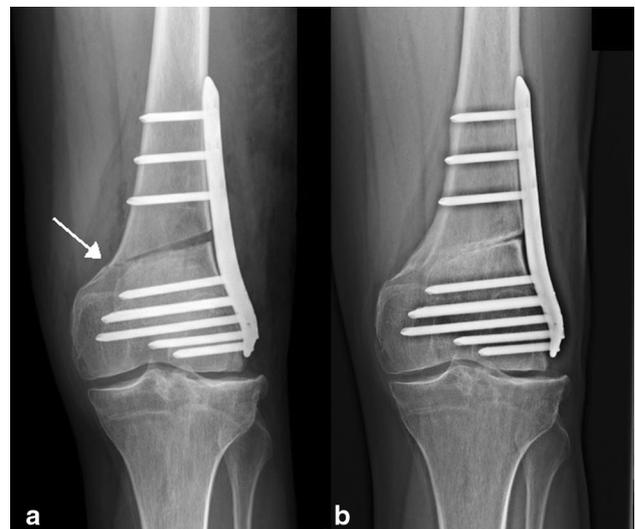


Fig. 1 **a** Radiograph showing a biplane LOWDFO in a-p. view; an interruption of the medial cortex is evident (white arrow). **b** Same patient after 7 months. Although the medial cortex healed, a nonunion occurred in the lateral aspect

Table 1 Concomitant surgical procedures at the time LOWDFO (*n* number of procedures, *lat.* lateral, *MPFL* medial patellofemoral ligament, *PFJ* patellofemoral joint, *OATS* osteochondral autologous transplantation, *FC* femoral condyle, *MACT* matrix-associated autologous chondrocyte transplantation, *ACL* anterior cruciate ligament)

	LOWDFO				
	<i>n</i>	%		<i>n</i>	%
Arthroscopic osteophyte removal	6	6.1	Tibial tuberosity transfer (medialization)	6	6.1
Partial synovectomy	6	6.1	Trochleoplasty	4	4.0
lat. meniscus surgery	6	6.1			
High tibial osteotomy	4	4.0	OATS lat. FC	4	4.0
			Subchondral microfracture lat. FC	3	3.0
MPFL reconstruction	35	35.7	MACT lat. FC	2	2.0
Release of tractus iliotibialis	8	8.1	MACT Patella	2	2.0
Repair of lateral retinaculum	6	6.1	Primary repair osteochondral fragment lat. FC	1	1.0
MPFL repair	6	6.1			
Lateral retinaculum lengthening	1	1.0	Hardware removal (intramedullar rod)	1	1.0
			ACL reconstruction	1	1.0
PFJ replacement	15	15.3	Medial collateral ligament repair	1	1.0
lat. patellar facetectomy	13	13.2			

Table 2 Concomitant surgical procedures at the time LCWDFO (*n* number of procedures, *lat.* lateral, *med.* medial, *POL* posterior oblique ligament)

LCWDFO	<i>n</i>	%
Arthroscopic osteophyte removal	6	11.5
Partial synovectomy	4	7.7
lat. meniscus surgery	1	1.9
med. meniscus surgery	9	17.3
POL release	14	26.9
HTO	14	26.9
OATS med. FC	2	3.8

biplanar technique. The axial osteotomy cut was stopped 5–10 mm before the medial cortex, creating a fulcrum when the osteotomy was opened or closed. Only in torsional osteotomies, the medial cortex was cut completely to allow an external rotation of the knee relative to the femur. Correction of the leg axis was controlled by measuring the osteotomy gap size and fluoroscopy. The osteotomy was fixed with an internal plate fixator with locking screws, either the Tomofix distal femoral plate (DePuy Synthes, Umkirch, Germany) or a PEEKPower plate (carbon-fibre reinforced polyether ether ketone (PEEK) Arthrex, Germany). Postoperatively, patients were allowed to partially bear weight (20 kg) for 6 weeks followed by full weight bearing.

Statistical analysis

Categorical data are described by absolute and relative frequencies, quantitative data by medians and first and third quartile (IQR). For the assessment of associations between potential categorical risk factors and complications of non-unions, Fisher's exact test was performed. For comparison

of the mean values of quantitative data (age, BMI, wedge height) between patients with and without complications or with and without nonunions, respectively, *t* tests for independent samples were used. All statistical tests were performed two-sided on a significance level of $p < 0.05$. The analysis was conducted with SPSS version 22.0 (IBM, Armonk, New York).

Results

One-hundred and fifty lateral DFO could be included in this study. The LOWDFO group consisted of 98 cases, and the LCWDFO group consisted of 52 cases. The demographic data is given in Table 3. For internal fixation, the Tomofix distal femoral plate was used in 94 (95.9%) osteotomies, and a PEEKPower plate was used in 4 (4.1%) patients. The median time until plate removal was 1.2 years (IQR 1.0–1.5). Hinge alterations that occurred intraoperatively, as well as any slightest interruption of the medial cortex on follow-up radiographs, were seen in 13 osteotomies (18.6%). In addition to correction in frontal plane, in 28 cases (28.6%), a supplementary torsional osteotomy was performed. In these cases, the surgical external de-rotation ranged from 5° to 20°. The LCWDFO group consisted of patients with varus malalignment due to a pathologic higher mL DFA. A specification of all complications is given in Table 4.

In the LOWDFO group, five patients (5.1%) showed an asymptomatic delayed union, eventually healing in the course 14–16 months. Revision surgery was necessary for two patients (2.0%) suffering from nonunion (Table 5). Revision was performed with plate exchange and transplantation of autologous bone graft from the iliac crest. In the LCWDFO group, two delayed unions (3.8%) occurred without pain or limitation in weight bearing and eventually plate

Table 3 Demographic data and surgical parameters with suspected negative influence on nonunion rate (*n* number of cases, *OT* osteotomy, *BMI* body mass index, *IQR* interquartile range)

	LOWDFO (<i>n</i> =98)		LCWDFO (<i>n</i> =52)	
	<i>n</i>	%	<i>n</i>	%
Female	57	58.1	19	36.5
Male	41	41.9	33	63.5
Smoking	26	26.5	8	15.4
Hinge alteration	13	18.6	26	52.0
Monoplanar	44	44.9	26	50.0
Biplanar	54	55.1	26	50.0
Torsional OT	28	28.6	2	3.8
	Median	IQR	Median	IQR
Age (years)	32.1	22.3–41.1	46.3	40.1–54.3
BMI	25.9	22.7–29.4	28.3	26.7–31.2
Valgus/varus (°)	5.2	3.0–6.5	8.3	5.5–11.5
Wedge height (mm)	5.0	3.7–6.0	7.3	5.7–8.0

Table 4 Intra- and post-operative complications in 150 cases (*n* number of reported events, *cons.* conservative treatment, *PR* plate removal, *OT* osteotomy)

Complication type	<i>n</i>	%	Treatment
Impaired wound healing	4	2.7	cons.
Arthrofibrosis	3	2.0	2 cons, 1 arthrolysis while PR
Deep infection	3	2.0	Debridement and plate exchange
Screw loosening	2	1.3	1 screw removal
Overcorrection	1	0.7	Revision surgery
Bleeding	1	0.7	Venous graft interposition
Wound granuloma	1	0.7	Excision while PR
Sural nerve lesion	1	0.7	cons.
Delayed union			
Open wedge OT	5	5.1	Delayed PR
Closed wedge OT	2	3.8	Delayed PR
Nonunion			
Open wedge OT	2	2.0	Revision surgery
Closed wedge OT	5	9.6	Revision surgery

removal after 15 and 24 months. Revision surgery became necessary for five patients suffering from nonunions (9.6%). All cases reached bony union after surgical revision.

Smoking was a significant factor for nonunion ($p=0.009$). Besides nicotine abuse, a higher BMI > 30.0 was significantly associated with the risk of nonunion ($p=0.003$). Patient age as well as the wedge height did not influence the nonunion risk. For osteotomies with additional torsion, monoplanar osteotomies as well as hinge alterations, a tendency could be seen showing a positive association with the incidence of nonunions, but this was not significant.

Discussion

The most important finding of the present study is the low nonunion and complication rate. Smoking and a higher body mass index were found to be significant risk factors for the development of nonunions. Patient age and gender, hinge

Table 5 Features of the patients that developed a nonunion and required revision surgery (*OT* osteotomy, *F* female, *M* male, *LOWDFO* lateral open wedge distal femoral osteotomy, *LCWDFO* lateral closing wedge distal femoral osteotomy, *mp* monoplanar, *bp* biplanar)

Patient no.	Age	Gender	BMI	Nicotine abuse	Type of OT	Wedge height (mm)	Technique of OT	Additional torsional OT	Medial hinge intact
1	23	F	18.8	Yes	LOWDFO	2.0	mp	Yes	No
2	46	F	34.7	Yes	LOWDFO	6.0	bp	No	Yes
1	40	F	44.5	No	LCWDFO	6.0	mp	No	No
2	52	F	26.4	No	LCWDFO	7.0	bp	No	Yes
3	43	M	34.0	No	LCWDFO	7.0	mp	No	No
4	58	M	30.5	No	LCWDFO	5.0	mp	No	No
5	54	F	28.3	No	LCWDFO	7.0	mp	No	No

alterations, monoplanar osteotomies, additional torsional osteotomies and increasing wedge heights did not negatively influence the nonunion rate. Lateral DFO provide an effective treatment option in restoring coronal and axial limb alignment.

Many factors can contribute to the development of a nonunion in the distal femur. In literature, only small case series exist that describe the rate of nonunions in DFO in contrast to HTO. A recent systemic review comparing the lateral opening versus the medial closing wedge technique states a low incidence of nonunions. In lateral open wedge osteotomies, the rate of nonunion was 2.2% (3/138) [34]. For the medial closing wedge technique, they found a nonunion rate of 3.8% (6/157), which is even slightly higher than in LOWDFO. However, no correlation to risk factors had been investigated, mainly because the average study group only consists of 20 DFO. The aim of this retrospective study was to determine the influence of general risk factors as well as technical risk factors for nonunion rates in DFO.

Regarding general risk factors, it is still controversially discussed whether nicotine abuse and obesity have a scientifically proven influence in bone healing. Smoking can lead to local vasoconstriction, and the high affinity of carbon monoxide to haemoglobin can decrease the total amount of oxygen transported to the healing site [12, 30]. This may result in local complications after surgery, such as nonunion or delayed union. More data regarding obesity as a risk factor is available for osteotomies, mainly for HTO, although the results differ widely. Birmingham et al. evaluated 126 patients 2 years after HTO with a median BMI of 29.5 [2]. Despite obesity, the rate of nonunion was 2.4% and the common complication rate was 6.3%. Another investigation with 533 HTOs as well stated no correlation between obesity or smoking habits and the complication rate including nonunion [13]. On the other hand, other studies confirm the negative influence of nicotine abuse and bone healing in HTO [20]. The present study revealed a significant higher nonunion rate with increased BMI for LCWDFO ($p=0.003$). Nicotine abuse negatively influenced the nonunion rate in LOWDFO as well significantly ($p=0.009$). Another parameter that can influence bony healing is the patient's age. It is assumed that the bone healing potential is altered with increased age [33]. The presented data seems to support this tendency, but the data does not confirm a statistically significant association between age and nonunion risk. However, the age difference of our LCWDFO and the LOWDFO group is small, and the mean age is low resulting in an adequate bony healing potential.

Particular technical features of the surgical procedure performed, such as wedge height, monoplanar versus biplanar osteotomy, increased instability by alteration of the hinge and complete cut in torsional osteotomies, could alter the healing rate as well. In DFO, the osteotomy should be as

distal as possible in the metaphysis to obtain a large bed of cancellous bone. To increase the cancellous bone surface, monoplanar osteotomies were abandoned and biplanar osteotomies are preferred due to the increased bone surface [32]. Besides surgical advantages in terms of torsional control, an enlarged bone surface with metabolically active trabecular bone mitigates against the development of nonunion [15]. In the presented data, a positive association between monoplanar osteotomies and nonunions can be observed, but the association was not statistically significant.

The results of this study show the same correlation for the wedge height. Especially in LOWDFO, a higher nonunion rate was supposed with increased wedge heights. Higher wedge heights subsequently create a higher wedge volume with assumed impaired bony healing [25, 32]. A positive yet not statically significant association between increasing wedge heights and nonunions can be detected.

The importance of maintaining the integrity of the opposite hinge of the osteotomy is well documented [7, 31]. Its maintenance is set to be important for primary stability [1, 20]. Fracture of the opposite cortex results in a considerable reduction in axial and rotational stiffness, as well as an increase in micromotion at the osteotomy site [21]. This cannot only impair the intended surgical angular correction, but also can lead to delayed union or even nonunion of the osteotomy [22]. In torsional osteotomies, the hinge has to be cut to allow the torsional correction. This loss of stability was assumed to lead to a higher rate of nonunions. However, this presumption could not be confirmed. With partial weight-bearing for 6 weeks in all cases, neither a hinge alteration in coronal correction osteotomies nor the complete cut in additional de-rotation showed significantly higher nonunion rates. This can be explained by the good biomechanical properties of the locking internal fixation devices used. Some authors recommend a simultaneous medial fixation in DFO in hinge fractures to provide greater stability [16]. According to the presented data, this is reserved for cases with high risk of primary or secondary failure of the fixation device, especially in obese patients that have difficulties in coordination.

As expected, the delayed union rates were higher in the LOWDFO group. The opening wedge technique leads to a gap between the bone cuts which can extend the time until complete bony consolidation [4, 18]. Unexpectedly, the nonunion rate was lower in LOWDFO than in LCWDFO, in which a bone-to-bone contact is achieved and therefore should guarantee a better bone healing analogous to fracture healing. Correspondent to delayed union, the open wedge technique was expected to have higher nonunion rates especially as it is discussed frequently whether or not the gap in LOWDFO should be filled with bone graft. However, the result of a higher nonunion rate in LCWDFO is equal to the findings of Wylie et al. [34]. It can be argued that in

closing wedge techniques, a hypomochlion is created at the intact medial cortex when not enough cancellous bone is removed. While trying to close the gap in this situation, the hypomochlion leads to high strain forces that might act as an antagonist for the closing wedge procedure. However, the features and results evaluated in the presented study as well as the data in literature cannot give a sufficient explanation for this unexpected finding.

It cannot be testified whether an iliac crest grafting in LOWDFO can decrease the risk of nonunion. In literature, some authors use iliac bone grafting innately [9]. Puddu et al. recommend that opening wedge heights of over 7.5 mm should be filled with autologous, allogeneic or synthetic bone, while smaller gaps should stay unfilled [25]. However, the low rate of nonunions in LOWDFO with 2.0% seem to make accessory bone grafting expendable as long as a sufficient and stable osteosynthesis can be achieved. The risk of a donor site morbidity can be avoided. This finding is similar to the results of Slevin et al. [29].

This study has some limitations. Although the study group proposes a high case number of lateral DFO compared to previous studies and clinical recommendations can be given, the case number remains too small to estimate the influence of potential risk factors precisely. Furthermore, it is a retrospective study. Data were only collected until plate removal for the purpose of identifying the healing time and complications. Further trials are required to validate these findings.

The present study is of distinct clinical relevance as it provides important information about the complication rate of DFO. In contrary to anecdotal reports, the results represent a low risk of nonunion in both opening wedge and closing wedge techniques. Therefore, these surgical procedures must not be evaded in the indication of osteotomies around the knee. However, an increased risk of a nonunion has to be considered in obese patients and patients with nicotine abuse. When several risk factors convene, and the patient's compliance remains unknown, supportive options, such as autologous bone grafting and contralateral plate fixation, should be taken into consideration. Furthermore, a closing wedge technique does not seem to have a reduced risk of nonunion, which should also be clarified to the patient before surgery.

Conclusion

As the nonunion rate in lateral DFOs and the overall complication rate is small, this technique provides an adequate alternative for osteotomies around the knee joint. Smoking and obesity are significant risk factors for nonunion. With locking internal fixation devices, hinge fractures as well

as complete bone cuts of the opposite hinge in torsional osteotomies do not negatively influence the nonunion rate in lateral DFO.

Compliance with ethical standards

Conflict of interest The corresponding author is a consultant for Arthrex, Munich, Germany. Besides that, all authors declare that they have no competing interests.

Ethical approval Ethical approval was obtained from the Ethics Committee of the technical University Munich. All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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Informed consent Informed consent was obtained from all individual participants included in the study.

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