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Gait asymmetries after fibular free flap harvest: A cross-sectional observational study

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ABSTRACT

Background: The ability to walk safely after head and neck reconstruction with fibular free flaps in tumor surgery is a high priority for patients. In addition, surgeons and patients require objective knowledge of the functional donor-site morbidity. However, the effects of fibular free flap surgery on gait asymmetries have only been studied for step length and stance duration. This study analyses whether patients who have undergone fibular free flap reconstruction have enduring gait asymmetries compared to age-matched controls.
Methods: Patients who underwent head and neck reconstruction with fibular free flaps between 2019 and 2023 were recruited, as well as age-matched controls. Participants walked on an instrumented treadmill at 3 km/h. The primary outcome measures were 22 gait asymmetry metrics. Secondary outcome measures were the associations of gait asymmetry with the length of the harvested fibula, and with the time after surgery.
Findings: Nine out of 13 recruited patients completed the full assessment without holding on to the handrail on the treadmill. In addition, nine age-matched controls were enrolled. Twenty out of the 22 gait asymmetry parameters of patients were similar to healthy controls, while push-off peak force ($p = 0.008$) and medial impulse differed ($p = 0.003$). Gait asymmetry did not correlate with the length of the fibula harvested. Seven gait asymmetry parameters had a strong correlation with the time after surgery.
Interpretation: On the long-term, fibular free flap reconstruction has only a limited effect on the asymmetry of force-related and temporal gait parameters while walking on a treadmill.

1. Introduction

Microvascular fibular flaps have been used since Taylor described the technique in 1975 for the reconstruction of long bone defects (Taylor et al., 1975). Later in 1989, Hidalgo used this reconstruction technique for maxillofacial defects (Hidalgo, 1989). The fibular flap offers several advantages, including good bone quality and length, a reliable vascular pedicle, and a skin paddle for simultaneous soft-tissue reconstruction (Chen and Yan, 1983). In head and neck reconstruction, the flap can be harvested using a two-team approach (Hidalgo, 1989). Donor-site morbidity, especially gait asymmetries, remains a significant concern of patients.

Some patients who underwent free fibular flap (FFF) reconstruction reported postoperative instability in their legs, despite a lack of clinical findings (Ling and Peng, 2012). The fibula plays an important role in muscle attachment and load transfer, stabilizing the ankle during the loading phase of gait when it receives the largest impact (Vail and Urbaniak, 1996). Previous studies have shown that in the first three to six months after the surgery, several spatio-temporal gait parameters and joint angles were significantly different compared to before the surgery (Di Giuli et al., 2019; Lee et al., 2008; Syczewska et al., 2018). Other studies that reported about gait after FFF transfer analyzed the gait pattern between one and three years after the surgery. Most of these studies found that a small part of their analyzed gait parameters was significantly worse at the donor side compared to the non-operated side or a control group, but contradicting results were found among these studies in especially the spatio-temporal gait parameters (Bodde et al., 2003; Chou et al., 2009; Farhadi et al., 2007; Hadouiri et al., 2018; Youdas et al., 1988). There were also studies that found no differences at all in spatio-temporal gait parameters, kinematics and kinetics (Lin

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et al., 2009; Maurer-Ertl et al., 2012), while another study showed that more than half of the spatio-temporal gait parameters were significantly worse after the surgery compared to controls (Feuvrier et al., 2016). Because of these conflicting results, other factors that differed between the studies might play a role, such as the length of the walkway, the time after surgery that the patients were measured, and the size of the harvested fibula.

A gait domain neglected by most studies is asymmetry. It is important to walk symmetrically, because gait asymmetry is known to increase the risk of falls (Ehrhardt et al., 2020; Sen et al., 2017), leads to comorbidities (Kowalczyk et al., 2023) and can reduce independence (Bautmans et al., 2011). Moreover, it can lead to asymmetric loading of the joints which causes joint degeneration on the long term, with many consequences such as pain and stiffness (Andriacchi et al., 2006; Hendershot and Wolf, 2014; Khury et al., 2024). Therefore, gait asymmetry may be clinically more relevant than previously assumed. Only one study evaluated asymmetry of step length and stance duration, but found no significant difference between FFF patients and controls on a 6 m walkway (Feuvrier et al., 2016). Only two gait asymmetry parameters were studied on a rather short walkway with different gait speeds between the groups. More extensive knowledge about gait asymmetry after FFF could help to shape additional therapies if needed, to reduce the risk of falls and comorbidities, and increase the independence after FFF reconstruction surgery. Additionally, patients undergoing FFF surgery can be better informed about the consequences of the surgery on their gait pattern on the long-term. Therefore, the present study investigated the presence of many different gait asymmetries using an instrumented treadmill at a fixed speed. Moreover, the influence of the size of the harvested fibula and the time after surgery on gait asymmetry was analyzed. By quantitatively measuring the functional outcomes of patients who underwent FFF reconstruction, we aimed to provide insights into the long-term effects of the procedure on gait.

2. Methods

This cross-sectional observational study was approved by the local Institutional Review Board (Ärztekammer des Saarlandes, Germany, application number 30/21). All participants provided written informed consent before they were included in the study.

2.1. Subjects

All patients who received a microvascular FFF for mandibular or maxillar reconstruction between January 2019 and January 2023 in Saarland University Hospital (Germany) were recruited by the treating physician. Patients were excluded if they had a gait disorder before the FFF surgery or were unable to walk on a treadmill at 3 km/h. A control group without motor or neurological deficit of the lower limbs was recruited and matched for age. The healthy participants were recruited among the spouses of the patients, employees of the University Hospital and acquaintances of the study team.

2.2. Surgical technique

A computed tomography angiography was performed on all patients before harvesting the FFF to allow surgical planning. The fibular osteoseptocutaneous flap harvested in all patients included minimal muscle cuffs around the fibula to preserve periosteal circulation. The flap harvest involved preserving the fibular head and 6 cm of the distal fibula, and included a skin paddle. To ensure the preservation of great toe flexor function, the detached flexor hallucis longus-muscle was carefully anchored to the interosseous membrane and posterior tibial muscles with proper tension. Donor-sites were covered with a vacuum-assisted closure pump for 10 to 14 days. Postoperatively, patients were allowed to walk with partial weight-bearing after 5–7 days. At this moment, they also started with physiotherapy. Full weight-bearing was allowed after 14 days.

2.3. Evaluation of gait asymmetry

Data were collected at the Saarland University Hospital between June 2022 and August 2023. The measurement of the patients took place during one of their routine outpatient visits. All participants were asked to walk on a treadmill (Gaitway 3D, h/p/cosmos, Nussdorf, Germany; size walking surface: 150 × 50 cm) with embedded 3D force plates at 3 km/h that was located in a movement analysis lab of the hospital. A one-minute data collection period started as soon as the participant showed a stable walking pattern and responded positive to the question whether they felt comfortable enough to start the measurement.

The ground reaction forces were collected with a sample frequency of 1000 Hz. Raw data were filtered with a 4th order Butterworth filter. Gait parameters, such as maximal values and impulses (amount of force applied over a certain amount of time), were calculated from the force data. The following parameters were analyzed in this study (Fig. 1 a and b): vertical impulse, which is the amount of vertical force applied during the stance phase; loading peak, which is the first maximum; loading slope, the rate in which the force increases during the loading phase; mid-support force, the minimal force between the two maxima; push-off peak force, the second maximum; push-off slope, the rate in which the force decreases during the push-off phase; peak ratio, is the ratio between the loading peak and the push-off peak. The following parameters were calculated from the anterior-posterior ground reaction force (Fig. 1 c and d): breaking impulse, the amount of force applied during the breaking phase; breaking peak force, maximal force during the breaking phase; propulsive impulse, the amount of force applied during the propulsive phase; propulsive peak force, the maximal force during the propulsive phase. The following parameters were calculated from the medio-lateral ground reaction force (Fig. 1 e and f): medial impulse, the amount of force applied in medial direction; medial peak, the maximal force in medial direction. In addition, temporal parameters were calculated which included: the time to several of the before mentioned events; stance time, the time the foot is in contact with the treadmill; double-support time, the time that there are two feet in contact with the treadmill during a stride; single-support time, the time that there is only one foot in contact with the treadmill during a stride. The parameters were extracted with the Gaitway 3D software (version 1.7.10, Arsalis SRL, Glabais, Belgium). From all these parameters, the asymmetry was assessed by computing the absolute difference between the average of the left and right side, which was then divided by the average of both sides.

2.4. Statistics

Statistical testing was performed with JASP (version 0.17.3, Amsterdam, Netherlands). Non-parametric tests were used because of the small number of subjects. Mann-Whitney-*U* tests were used to compare demographics, as well as gait asymmetry of the patients with those of the age-matched controls. Spearman correlations were used to analyze potential associations between gait asymmetry and the length of the harvested fibula, and gait asymmetry and the time of gait analysis since surgery. Significance was defined as $p < 0.05$.

3. Results

3.1. Subjects

Thirteen patients who received a microvascular FFF for mandibular or maxillary reconstruction were recruited. Four patients were excluded, three patients were unable to walk on the treadmill without holding on to the handrails, and one patient was unable to walk at 3 km/h. Nine patients were included in the final analysis. Flap characteristics and reconstruction information for the included patients are summarized in

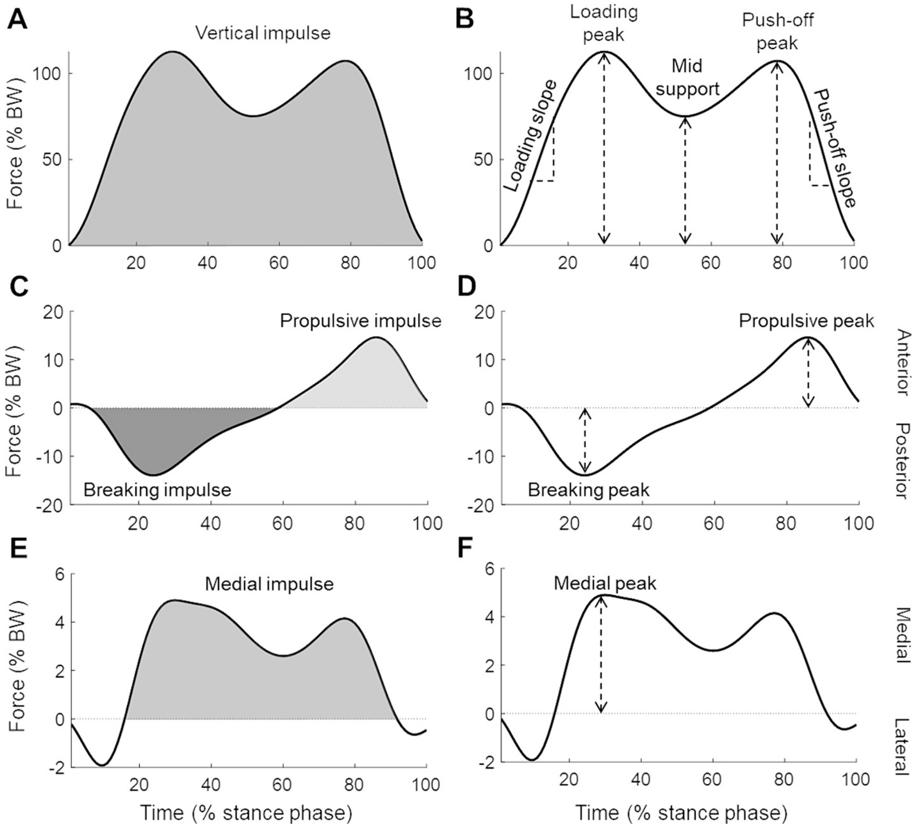

Fig. 1. Representation of the gait parameters calculated from the ground reaction force data in vertical (a and b), anterior-posterior (c and d) and medio-lateral (e and f) direction.

Table 1
Demographics, flap characteristics and reconstruction information of the subjects with standard deviation.

	Patients who received FFF	Healthy controls
N (male/female)	9 (4/5)	9 (3/6)
Age (years)	58 ± 14	56 ± 14
Height (m)	1.69 ± 11	1.70 ± 12
Weight (kg)	72.2 ± 22.8	71.3 ± 13.2
Type of tumor	2 benign; 7 malignant	
Length of fibula harvested (mm)	77 ± 25	
Time between surgery and gait analysis (days)	370 ± 277	

Table 1. The surgeries of four patients were virtually planned using the Individual Patient Solutions Case Designer by KLS Martin to design and manufacture patient-specific implants and cutting guides.

A control group of nine healthy subjects matched for age was included (Table 1). No significant differences were found in the demographics between patients and controls.

3.2. Evaluation of gait asymmetry

The results of the gait asymmetry analysis are presented in Fig. 2. The asymmetry in peak forces exerted during the push-off phase was significantly higher in patients compared to controls ($p = 0.008$). The medial impulse asymmetry was significantly lower in patients compared to controls ($p = 0.003$). No significant differences were found for the other gait asymmetry parameters.

There was a strong correlation ($0.6 \leq \text{rho} < 0.8$) (Evans, 1996) between the length of the fibula harvested and the breaking impulse. However, none of the correlations were significant (Table 2). Six moderate correlations were found between days after FFF surgery and gait asymmetry parameters (mid-support force, time to push-off peak force, ratio between loading and push-off peak force, propulsive

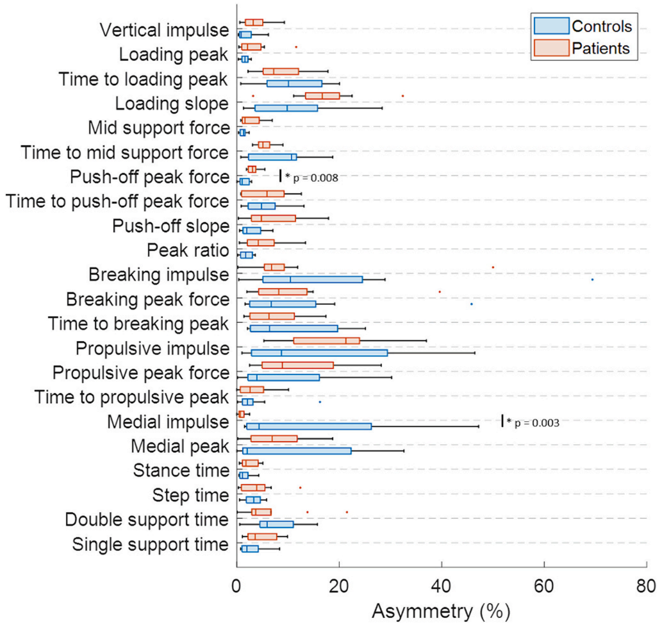

Fig. 2. Gait parameters of patients and controls. Significant differences are indicated by '*' and the accompanying *p*-value is given. The boxplot displays the median, lower and upper quartiles, outliers, and the minimum and maximum without outliers.

Table 2
Correlations between gait asymmetry parameters and length of harvested fibula, and time between surgery and gait analysis. Significant *P*-values and their corresponding Spearman Rho are shown in bold.

	Length of fibula harvested		Days between surgery and gait analysis	
	Spearman Rho	P-value	Spearman Rho	P-value
Vertical impulse	0.050	0.912	−0.283	0.463
Loading peak	−0.483	0.194	−0.300	0.437
Time to loading peak	−0.450	0.230	0.267	0.493
Loading slope	−0.301	0.428	0.033	0.937
Mid-support force	−0.150	0.708	−0.683	0.050
Time to mid-support force	−0.117	0.776	−0.150	0.708
Push-off peak force	0.226	0.558	−0.075	0.854
Time to push-off peak force	0.084	0.833	**−0.745**	**0.027**
Push-off slope	−0.217	0.581	−0.517	0.162
Peak ratio	−0.400	0.291	−0.683	0.050
Breaking impulse	0.628	0.078	0.042	0.923
Breaking peak force	0.083	0.843	0.217	0.581
Time to breaking peak	0.400	0.291	0.317	0.410
Propulsive impulse	0.350	0.359	−0.633	0.076
Propulsive peak force	0.217	0.581	−0.633	0.076
Time to propulsive peak	−0.133	0.744	**−0.867**	**0.005**
Medial impulse	0.437	0.241	−0.084	0.835
Medial peak	0.200	0.613	0.183	0.644
Stance time	−0.100	0.810	−0.283	0.463
Step time	−0.067	0.880	**−0.717**	**0.037**
Double-support time	−0.385	0.305	−0.427	0.254
Single-support time	−0.217	0.581	−0.233	0.552

impulse, propulsive peak force and step time). The time to the propulsive peak had a very strong correlation (rho $\geq$0.8) with the number of days between surgery and gait analysis. Three of these gait asymmetry parameters, the time to push-off peak force, the time to propulsive peak force, and step time correlated significantly with the time after FFF surgery (Table 2).

4. Discussion

This study analyzed the effect of FFF reconstruction surgery on gait asymmetry. The asymmetry of ground reaction force-based gait parameters was not significantly worse compared to healthy controls, except for the push-off peak force. The length of the fibula harvested did not influence gait asymmetry significantly. However, time to push-off peak force, time to propulsive peak and step time were significantly associated with time after surgery.

Gait in the studied patients was significantly more asymmetric compared to healthy controls only in one gait parameter, which was the maximal force exerted in vertical direction during the push-off phase. The lower push-off peak forces are comparable with another study that also found lower push-off forces at the donor-site (Youdas et al., 1988). The fibula serves the biomechanical purposes to stabilize the ankle joint on uneven surfaces and to store elastic energy to jump (Rittweger et al., 2018). The finding could thus be related to increased ankle instability, as has been subjectively reported by patients in other studies (Feuvrier et al., 2016; Tang et al., 1998), or loss of muscle strength (Farhadi et al., 2007; Youdas et al., 1988), or potentially pain. However, in the current study, only two patients reported having pain at the donor site.

The medial impulse, which is the amount of force exerted in medial direction, showed less asymmetry in patients compared to controls. A possible explanation could be that healthy controls can afford more variation. Patients after FFF reconstruction might not exert much force in the medial direction to prevent problems with medio-lateral ankle instability (Feuvrier et al., 2016; Tang et al., 1998).

There were no significant correlations between the length of the fibula harvested and gait asymmetry. This is in line with another study that found a significant correlation only in one out of 13 gait parameters analyzed (Feuvrier et al., 2016). Therefore, the length of the harvested fibula seems to have no to minor effects on gait. The harvesting technique used, only resects parts of the mid-fibula. Maintaining a residual distal fibula length of at least 10% of the total fibula length was found to preserve ankle stability (Pacelli et al., 2003). A biomechanical study showed that resection of the mid-fibula, did not cause significant changes in the kinematics and kinetics during walking, but resecting the proximal or distal end of the fibula did change the biomechanics during walking (Bozkurt et al., 2005). The fibula also only carries a small portion of the body weight (Funk et al., 2007). Therefore, the middle part of the fibula seems to play a limited role during walking and can be taken out without large effects on gait on the long-term. In addition, the resection of the mid-fibula should be preferred over an iliac crest flap, since it has a smaller effect on gait the resection of the mid-fibula has a smaller effect on gait compared to an iliac crest flap (Syczewska et al., 2018).

Seven gait asymmetry parameters had a strong or even very strong correlation with the time between the FFF reconstruction surgery and the gait analysis. With more time between the surgery and the gait analysis, less asymmetry was present. An association between time after surgery and spatio-temporal gait parameters in FFF patients was also shown previously (Feuvrier et al., 2016). These results fit with other studies that were performed within the first six months after surgery that found significant differences for several gait parameters compared to before the surgery (Di Giuli et al., 2019; Lee et al., 2008; Syczewska et al., 2018) or compared to the non-operated side (Youdas et al., 1988). A study where gait analysis was performed 33 months after surgery did not find significant differences in spatio-temporal gait parameters, kinematics and kinetics (Maurer-Ertl et al., 2012). Another study, with gait analysis performed 27 months after surgery, found a significant difference in only one parameter compared to a control group (Chou et al., 2009). Nonetheless, several studies reported multiple significant differences more than a year after the surgery (Feuvrier et al., 2016; Hadouiri et al., 2018). It could be that additional treatment for patients with malignant tumors, such as radiation and chemotherapy extend the rehabilitation time and time to return to a symmetrical gait pattern. Based on our limited data and the different timepoints of measurements, it looks like as if the asymmetry improves throughout the first year after FFF reconstruction. Therefore, studies analyzing gait after FFF reconstruction should ideally be performed at least a year after surgery.

Findings in vertical ground reaction force-related gait parameters are contradictory. Vertical ground reaction force after FFF reconstruction was 14% lower at the affected leg compared to the non-affected leg about 5 months after FFF reconstruction, and time to peak force was significantly extended (Youdas et al., 1988). However, another study found no significant differences in ground reaction force in all three directions between healthy controls and patients about 27 months after surgery (Chou et al., 2009). These studies did not analyze the asymmetry of the ground reaction force. Only, asymmetry of the step length and the stance phase duration were reported before, they did not find significant differences between the FFF patients and controls about 28 months after the surgery (Feuvrier et al., 2016). In the present study, only two out of 22 asymmetry parameters of patients about 12 months after surgery were significantly different from age-matched controls. The alpha-value was not corrected for the multiple comparisons to make it more sensitive to detect any differences, so there is a chance on type 1 errors. Moreover, the majority of the patients was measured within the first year after the surgery, with even two patients measured already five months after the surgery, especially their gait pattern is still likely to improve in the months after the measurements. Therefore, gait asymmetry does not seem to be affected by FFF reconstruction surgery, but it might take about a year for the gait pattern to return to normal. Based on the results of this study and the existing literature, we can conclude that FFF has only a very minor effect on gait asymmetry. Undergoing FFF reconstruction is unlikely to lead to major mobility limitations for patients on the long-term and can therefore be safely recommended by surgeons regarding the effects on mobility.

For most studies, gait analysis was performed over ground. The benefit of measuring patients on a treadmill is that gait is analyzed over a longer distance, compared to when walking in the lab. To analyze gait asymmetry and also variability, longer walking distances are preferable for more reliable results (Hansen et al., 2022; Owings and Grabiner, 2003). The disadvantage is, however, that walking on a treadmill can initially feel slightly different from over-ground walking. From the four patients that were excluded in this study, three were unable to walk on the treadmill without holding on to the handrail. Even after a few minutes of practicing, they did not show a normal walking pattern and they seemed to have problems adjusting to the treadmill. This could be related to age, since it is known that older adults have a harder time adjusting to treadmill walking (Wass et al., 2005). Two of the three patients were 76 and one was 71 years old. The fourth patient that was excluded, was able to walk on the treadmill, but 3 km/h was too fast for this patient who was 6 months after surgery at the time of the measurement.

This study has several limitations. The sample size is relatively small, because the FFF reconstruction surgery is infrequent at our hospital. Unfortunately, some of the patients were unable to walk on the treadmill without holding on to the handrail as required. Moreover, the time after surgery differed. This made it possible to analyze the association between gait asymmetry and time after surgery, however, the variance between patients might have been smaller if they had been measured at similar times after surgery. Besides that, all participants were assessed at a speed of 3 km/h, which made it easy to compare differences, but it might not necessarily be the individually preferred walking speed.

5. Conclusions

This study showed that FFF reconstruction surgery has no long-term effect on gait asymmetry as measured by ground reaction force-based and temporal parameters, except for the push-off peak force. The time after surgery was associated with changes in several gait asymmetry parameters. It seems that gait asymmetry improves throughout the first year after surgery. The length of the fibula harvested had no effect on gait asymmetry.

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CRediT authorship contribution statement

Elke Warmerdam: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dominik Horn:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. **Ramona Filip:** Investigation, Writing – review & editing. **Kolja Freier:** Conceptualization, Methodology, Writing – review & editing. **Bergita Ganse:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Carolina Classen:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft.

Declaration of competing interest

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

Data availability

Data are available upon reasonable request.

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