Donor-Site Morbidity after Osteocutaneous Free Fibula Transfer: Longitudinal Analysis of Stair Climbing Asymmetry and Functional Outcome

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Abstract: The autologous vascularised free fibula flap is currently considered the best option for facial reconstruction after oncological surgery, but its donor-site morbidity has not been fully examined. The purpose was to evaluate donor-site changes in temporal and spatial kinematic gait parameters during stair climbing, as well as the gait symmetry. Fourteen patients (48 ± 16 years) were evaluated before and six months after harvest of a vascularised free fibula flap. Temporal gait variables for both the ascent and descent phases did not change after surgery (2-way ANOVA, $p > 0.05$). During stair ascent, ankle flexion (healthy side, increased; donor side, reduced; low effect size) had a significant time × side interaction. During stair descent, hip flexion was significantly larger on the donor side (medium effect size). Significant time × side interactions were observed for ankle inversion (healthy side, reduced; donor side, increased; and low effect size) and knee flexion (healthy side, increased; donor side, unchanged; and low effect size). Medium effect sizes were found for hip flexion side differences (significant). No relevant spatio-temporal nor kinematic asymmetry emerged apart from ankle joint kinematics. Overall, only the side effect of hip flexion during descent was both statistically significant and practically meaningful. Considering the slight modifications of the gait variables, no major functional limitations were found following vascularised free fibula flap reconstruction during stair climbing and descent.

Keywords: free fibular flap; morbidity; gait analysis; longitudinal; stairs

1. Introduction

Worldwide epidemiological reports estimate that each year approximately 630,000 new patients receive a diagnosis of head and neck cancer, with more than 350,000 annual deaths [1]. European estimates expect about 151,000 new patients for 2020 [2], with an increased incidence rate in Europe and worldwide [3–5]. Surgery is the preferred treatment modality, involving removal of facial soft and hard tissues that should be reconstructed using grafts [6].

In particular, the autologous vascularised free fibula flap (VFFF) is currently considered the best option, showing the most successful morphological, aesthetic and functional outcomes for both the receiving and donor sites [7–16].

A recent systematic review reported an overall success rate of 93% in 2305 patients assessed in 78 studies, with post-surgical complications described in 56 studies. In particular, 96 patients lamented donor-site morbidity with percentages ranging from 0 (68% of investigations) to 80% (one study with five patients only). Even if the average percentage

of donor-site morbidity was only 8%, ankle instability and pain during prolonged walking, paraesthesia, skin loss and wound dehiscence are alterations that should be attentively evaluated to be avoided or reduced [7,15,17,18]. Among the others, ankle instability, toe deformities, lower limb pain and walking impairments may be ascribed to (1) lesions of the muscles that are dissected during the harvest (extensor hallucis and digitorum longus, flexor hallucis longus, peroneal longus and brevis) from a too distal fibular osteotomy or (2) alterations of the peroneal nerve [11,17,19–22]. To date, the assessment of these deficits has been mainly performed with questionnaires and clinical scales [18]; a few investigations used quantitative measurements of the actual lower limb function [10,11]. In particular, lower limb peak power, body balance, overground walking, the Six-Minute Walking Test (a prolonged walking assessment) and stair negotiation have been performed on patients submitted to the VFFF, with the aim of analysing the functional status of the patients from a biomechanical standpoint [6,8–11,19,22–24]. As recently observed, a general reduction in step length, cadence, walking speed and walked distance, together with an increased variability of gait variables under additional cognitive or physical loads, was reported for flat ground or treadmill walking [10]. Unfortunately, a variety of experimental protocols and functional tests, as well as of follow-up duration, makes a global evaluation difficult. Only a fraction of the aforementioned assessments were made on a longitudinal base, thus allowing an accurate analysis of the individual effects of flap harvest, together with eventual additional adjuvant treatments [6,10,24–27].

In addition, when considering rehabilitation outcomes, side-to-side differences in lower limb mechanics should be addressed during the early post-operative period through additional interventions in order to normalize the differences and potentially improve long-term health [24,25].

Our group recently followed-up a group of patients submitted to VFFF harvest for the reconstruction of maxillofacial defects due to oncological surgery and analysed donor-site morbidity using instrumented gait analysis [10]. No significant differences were found in the range of motion of lower limb joints; among spatiotemporal parameters, only the double-support phase significantly reduced after surgery.

Even if stair ascent and descent are common daily life tasks, information regarding stair negotiation mechanics after VFFF harvest is rather scant.

To the best of our knowledge, no previous study longitudinally assessed the stair climbing functional symmetry in patients undergoing VFFF. The only existing example is from Baj et al. [6], who only reported minimal disturbances after a pilot case–control study.

To gain a better understanding of gait characteristics in this condition, in the current investigation, we analysed the bilateral kinematics of stair ascent and descent with the same longitudinal protocol: the patients were evaluated before and six months after the VFFF harvest with an optoelectronic motion capture system. Considering the successful results of the overground gait test [10], we hypothesised that VFFF harvest would result in negligible or minimal modifications of the gait characteristics during stair negotiation.

2. Materials and Methods

2.1. Patients

In the mainframe of an Italian multicentric collaborative study, 14 patients who were admitted to the Maxillo-Facial Surgery unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico of Milan (Italy) for VFFF harvest and subsequent facial (maxillary or mandibular) reconstruction were enrolled and participated in a pre- and post-surgical instrumented analysis of their gait [10]. A prior calculation estimated that ten patients would assure a power of 80%, with an alpha of 0.05 [10].

Seven women and seven men (mean age 48 ± 16 years) were followed-up longitudinally: the first evaluation was made before surgery and the second 6 months after surgery. On both occasions, the patients were recorded while performing flat ground walking and while ascending and descending a three-step wooden staircase [8]. One additional

patient (F6) participated in the data collection but was excluded from the analysis for technical reasons.

Details about the patients were previously reported [10] and are summarised in Table 1. Seven patients underwent a mandibular reconstruction via a bone-only flap, one via an osteocutaneous flap and five via an osteo-myocutaneous flap; the remaining patient had a maxillary reconstruction via an osteo-myocutaneous flap. Exclusion criteria were all those precluding the VFFF harvest: general patient conditions not suitable for the surgical procedure; previous or current vascular, nervous, and skeletal pathologies or abnormalities of their lower limbs.

Table 1. Study population (modified from Di Giuli et al. [8]).

Patients	Age (Years)	Height (m)	BMI (kg/m^2)	VFFF [1] Variant	Receiving Site Pathology	Notes
Bone						
M2	23	1.78	21.9	Left	R mandibular body keratocyst	
M4	30	1.58	33.6	Left	R mandibular ramus ameloblastoma recurrence	Pain
F2	38	1.76	32.6	Right	R parasymphysis jaw keratocyst	Pain
F4	45	1.60	26.0	Left	L mandibular ramus keratocyst	
F5	53	1.57	18.3	Left	R mandibular ramus adenoid cystic carcinoma	
F8	28	1.72	19.6	Right	R mandibular ramus pseudarthrosis	
M6	59	1.68	33.3	Mini Left	L retromolar trigone mucoepidermoid carcinoma	Flexor hallucis longus deficit—Stiffness
Osteocutaneous						
F1	54	1.69	17.9	Left	L parasymphysis jaw pseudarthrosis	-
Osteo-myocutaneous						
M1	64	1.78	33.1	Right	L mandibular ramus squamous cell carcinoma	Radiotherapy
M3	27	1.73	22.4	Right	L retromolar trigone squamous cell carcinoma	
M5	61	1.72	18.9	Right	L mandibular body and mouth floor squamous cell carcinoma	Extensor digitorum and hallucis longus deficit—Pain—Paraesthesia—Wound dehiscence
M7	59	1.78	25.2	Right	Jaw symphysis and mouth floor squamous cell carcinoma	Radiotherapy
F3	70	1.60	22.7	Right	L mandibular ramus squamous cell carcinoma	
F7	61	1.47	23.6	Mini Left	R mandibular body mucoepidermoid carcinoma	-
Mean	48	1.68	24.9			
SD	16	0.10	5			

[1] VFFF: vascularized free fibula flap; L = left; R = right; mini = minimally invasive technique [28].

The investigation did not involve dangerous or painful procedures and was minimally disturbing for the patients, who provided voluntary written informed consent to participate. The principles stated in the Declaration of Helsinki were followed, and a prior approval by the ethics committee of Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy #427 09 March 2017 was obtained.

2.2. Gait Analysis

Patients underwent instrumented gait analysis tests both before and 6 months after surgery. Data collection was conducted for both overground walking and stair negotiation at the Movement Analysis Laboratory (LAM), Department of Biomedical Sciences, Università degli Studi of Milan. Data about overground walking are reported elsewhere [10].

Twenty-nine passive infrared retro-reflexive markers (diameter 1.5 cm) were fixed with adhesive tape on selected anatomical landmarks on the midline (glabella, C7 spinous

process and S1 spinous process) and on the right and left sides (tragus, acromion, radial epicondyle, ulnar styloid process, anterior superior iliac spine, greater trochanter, medial and lateral femoral epicondyle, tibial tuberosity, medial and lateral malleolus, calcaneus and tip of the foot). The patients wore comfortable trainers and adherent clothes to improve marker proximity to bony landmarks (Figure 1).

Figure 1. Experimental setup. (**A**) Reflective markers placement; (**B**) wooden stairs and participant performing the task; (**C**) pelvis and lower limbs reference frames (superscript legend as follows: p, pelvis; t, thigh; s, shank; f, foot).

The position of the markers was recorded by a 9-camera optoelectronic motion analysis system with a 60 Hz sampling rate (SMART-E, BTS Bioengineering Spa, Milano, Italy) [8,10]. For each data collection session, the system was calibrated according to the manufacturer's guidelines with correction of optical and electronic distortions and definition of a three-dimensional reference system as follows (Figure 1): x-axis; parallel to the ground, pointing towards the longitudinal direction of gait; y-axis; orthogonal to the ground, pointing upwards; and z-axis; orthogonal to the sagittal plane, pointing to the right. System calibration defined a working volume of $2 \times 3 \times 4 \text{ m}^3$, allowing marker position to be detected with an error lower than 0.35 mm.

A preliminary 5 s static recording of the patient standing in orthostatic position with arms slightly abducted and looking forward was obtained. Then, the patient was asked to ascend and descend a three-step wooden staircase (rise height 16 cm and tread length 30 cm) at a self-selected, comfortable speed. The patient approached the stairs from farther away (5 m), and stair negotiation was performed alternatively with the healthy and donor limb. Ten trials were consecutively recorded [8]. Before data collection, each patient performed some gait tests to become acquainted with the requested task and the laboratory environment.

The events defining each gait cycle were defined as the time interval between two consecutive unilateral heel strikes. Double-support, swing and stance phases were obtained and presented as a percentage of gait cycle time. Cadence, velocity and step length were also computed. Step width was evaluated as the mean sagittal distance between the medial malleoli identified in each acquisition frame. Anatomical joints angle computation relied on Euler angles obtained from the relative rotation of adjacent body segments, as detailed in Di Giuli et al. [8]. The Range of Motion (RoM) of ankle, knee and hip joint were calculated, and in particular: ankle flexion/extension and inversion/eversion angles;

knee flexion/extension angle; hip flexion/extension and abduction/adduction; and pelvis inclination, rotation and tilt.

Each kinematic variable was analysed in the healthy and donor limb. To provide a measure of symmetry both before and after surgery, for each bilateral variable, the Symmetry Angle (SA, expressed as %) was calculated as (Equation (1)) [29]:

$$SA = \frac{\left(45° - \tanh^{-1}\left(\frac{Donor}{Healthy}\right)\right)}{90°} \cdot 100 \tag{1}$$

SA equal to 0% corresponds to perfect symmetry, while SA equal to ±100% means the two values are equal and opposite. Negative (positive) SA values mean that the donor-side variable is greater (lower) than the healthy one.

All calculations were performed within the SMART Analyzer software (BTS Bioengineering Spa, Milano, Italy).

2.3. Statistical Analysis

For each trial, the ascent and the descent phases were considered separately [10]. Mean and standard deviation of pre- and post-surgical gait variables were calculated. Given the sample size and the normal data distribution, a 2-way factorial Analysis of Variance (ANOVA) was used to compare the pre- and post-surgical values (Factor 1) and healthy and donor limb (Factor 2); a full interaction model was implemented. For each comparison, the variance effect size was calculated as partial eta squared (η^2) to provide a practical interpretation of the statistical difference, with $\eta^2 = 0.01$ as low, $\eta^2 = 0.059$ as medium and $\eta^2 = 0.138$ as high effects [30].

Differences in Symmetry Angle between the pre- and post-surgery conditions were tested using paired t-tests. Cohen's d effect sizes were also computed and interpreted as follows: values of $d \leq 0.5$, $0.5 < d \leq 0.8$ and $d > 0.8$ were considered low, moderate, and large effects [31].

For all comparisons, a *p* value of 0.05 or less was considered statistically significant.

3. Results

All patients coped well with the requested task without experiencing fatigue or pain. Patient F6 was excluded from the analysis for technical problems occurring during data acquisition; complete calculations were thus performed on 14 patients.

Table 2 reports the descriptive and inferential statistics of the pre-surgical and post-surgical spatial and temporal gait variables. No significant time or side (healthy/donor limb) effects were found (all *p* values from 2-way ANOVA > 0.05) for both the ascent and descent phases. A medium partial η^2 value was obtained: the duration of the double-support phase during stair ascent was shorter (but not significantly) on the donor side. No differences in Symmetry Angle between the pre- and post-conditions were observed for spatio-temporal parameters (Table 3) with low effect sizes; in absolute terms, the most asymmetric variable was the double-support time (post-surgery), approaching 5%. Figure 2 graphically displays the average SA change in spatio-temporal variables in all conditions.

During stair ascent, data about the RoMs of lower limb joints showed significant differences (*p* values < 0.05) only for the time × side interaction of ankle flexion (increased RoM on the healthy side, reduced on the donor side and low effect size, Table 4).

During stair descent, significant differences were found on the side factor on hip flexion (larger RoM on the donor side and medium effect size). Additionally, significant time × side interactions were observed for ankle inversion (reduced RoM on the healthy side, increased on the donor side and low effect size), knee flexion (increased RoM on the healthy side, unchanged on the donor side and low effect size). Medium effect sizes were found for ankle flexion modifications with time (not significant) and hip flexion side differences (significant). Concerning the Symmetry Angle, during ascent (Table 5), a small reduction in asymmetry was observed (from SA = −3.3% to SA = 1.9%) at the ankle flexion

RoM level, with a small effect size (p = 0.014). During descent, the knee turned out to be slightly less asymmetric after surgery (from SA = 1.7 to SA = −0.2, p = 0.049 and small effect), while ankle inversion/supination RoM symmetry worsened (healthy side increase) from 2.4% pre- to 7.3% post-surgery (p = 0.027, medium effect). The average SA change in ranges of motion is shown in Figure 3.

Table 2. Spatial and temporal variables measured for pre-surgical and post-surgical gait analysis for stair climbing. p values from 2-way ANOVA and relevant partial η^2 values. Significant p-values in bold.

| Variable | Healthy Limb | | | | Donor Limb | | | | Comparison | | | Effect Size | | |
| | Pre | | Post | | Pre | | Post | | 2-Way ANOVA | | | Partial η^2 | | |
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p Time	p Side	$p \times$	η^2 Time	η^2 Side	$\eta^2 \times$
Ascent														
Step cadence (step/s)	0.79	0.10	0.77	0.09	0.78	0.12	0.78	0.13	0.907	0.426	0.390	0.000	0.003	0.001
Stance (%)	0.61	0.02	0.62	0.03	0.62	0.03	0.61	0.04	0.899	0.757	0.098	0.000	0.001	0.009
Swing (%)	0.39	0.02	0.38	0.03	0.38	0.03	0.39	0.04	0.899	0.757	0.098	0.000	0.001	0.009
Double support (%)	0.14	0.02	0.13	0.03	0.14	0.03	0.12	0.03	0.964	0.079	0.261	0.000	**0.069**	0.006
Step duration (s)	1.31	0.15	1.32	0.15	1.32	0.24	1.32	0.21	0.753	0.793	0.753	0.001	0.000	0.000
Step width (m)	0.09	0.04	0.08	0.04	0.10	0.03	0.09	0.03	0.076	0.062	0.691	0.017	0.022	0.001
Velocity (m/s)	0.53	0.06	0.49	0.14	0.53	0.08	0.53	0.09	0.340	0.416	0.341	0.011	0.008	0.008
Descent														
Step cadence (step/s)	0.88	0.12	0.88	0.12	0.88	0.16	0.89	0.15	0.933	0.976	0.705	0.000	0.000	0.000
Stance (%)	0.61	0.03	0.61	0.03	0.60	0.03	0.60	0.03	0.258	0.677	0.563	0.017	0.002	0.004
Swing (%)	0.39	0.03	0.39	0.03	0.40	0.03	0.40	0.03	0.256	0.681	0.567	0.017	0.002	0.004
Double support (%)	0.12	0.02	0.11	0.02	0.12	0.02	0.12	0.02	0.641	0.952	0.820	0.003	0.000	0.000
Step duration (s)	1.15	0.15	1.19	0.20	1.10	0.37	1.16	0.20	0.511	0.222	0.841	0.008	0.012	0.000
Step width (m)	0.08	0.05	0.08	0.04	0.10	0.03	0.08	0.02	0.565	0.321	0.245	0.004	0.008	0.012
Velocity (m/s)	0.59	0.08	0.60	0.08	0.60	0.11	0.60	0.10	0.808	0.658	0.961	0.001	0.000	0.000

Table 3. Pre-surgical and post-surgical Symmetry Angle (%) for spatial and temporal variables. p values from paired t-test and relevant Cohen's d Effect Size (ES).

| Variable	Pre		Post		p-Value	ES
Ascent						
Step cadence	0.7	3.0	0.2	1.8	0.431	0.234
Stance	−0.4	1.4	0.2	1.6	0.097	0.391
Swing	0.7	2.1	−0.3	2.4	0.104	0.410
Double support	2.8	7.5	4.7	8.9	0.353	0.233
Step duration	−0.2	2.5	−0.1	2.0	0.805	0.061
Step width	2.2	12.1	4.2	7.4	0.500	0.211
Velocity	2.9	11.5	0.0	1.9	0.341	0.359
Descent						
Step cadence	0.1	2.5	−0.2	2.1	0.659	0.164
Stance	−0.4	1.2	0.0	2.4	0.571	0.211
Swing	0.5	1.9	−0.1	3.4	0.546	0.219
Double support	0.2	4.3	−0.4	7.1	0.710	0.114
Step duration	−1.0	3.2	0.2	2.1	0.236	0.448
Step width	−3.2	18.3	4.2	9.6	0.209	0.498
Velocity	−0.2	1.9	−0.2	2.1	0.922	0.044
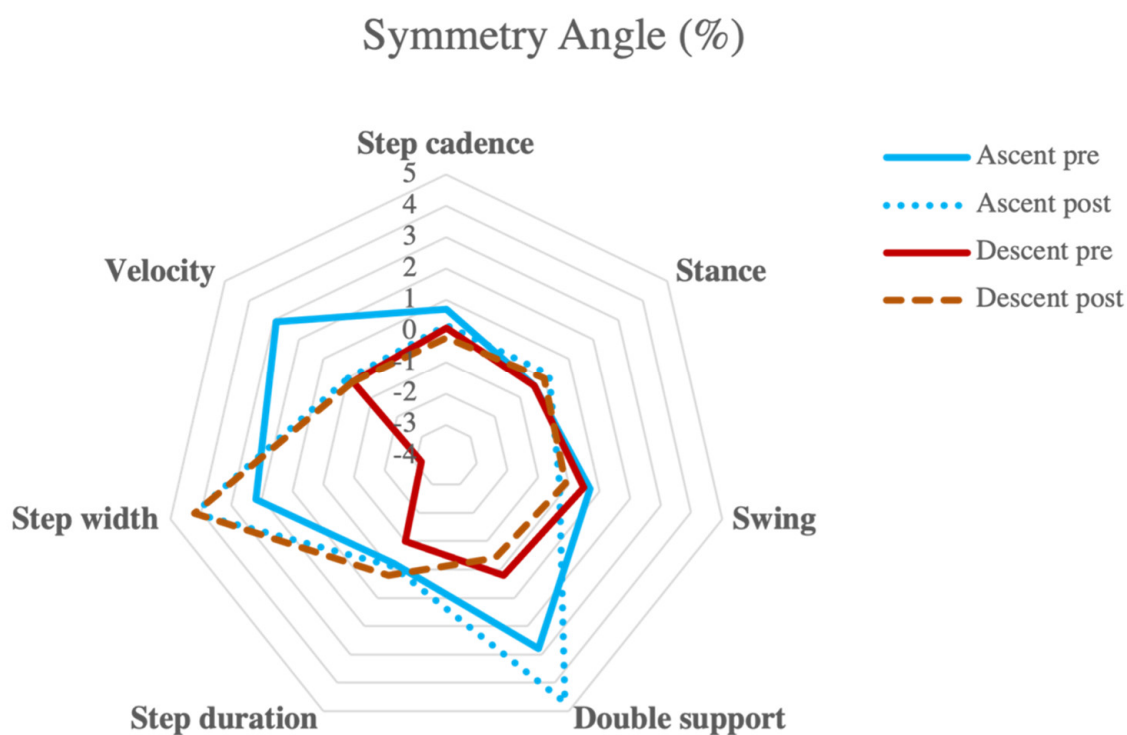
Figure 2. Radar plot showing the average Symmetry Angle (%) change between pre- and post-surgery for spatio-temporal parameters.

Table 4. Range of motion (RoM; degrees) of lower limb joints measured for pre- and post-surgical gait analysis for stair climbing. *p* values from 2-way ANOVA and relevant partial η^2 values. Significant *p*-values in bold.

Variable	Healthy Limb				Donor Limb				Comparison			Effect Size		
	Pre		Post		Pre		Post		2-Way ANOVA			Partial η^2		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*p* Time	*p* Side	*p* ×	η^2 Time	η^2 Side	η^2 ×
Ascent														
Ankle flexion	42.8	11.6	49.9	17.9	43.0	10.0	42.2	16.6	0.060	0.623	0.010	0.017	0.012	0.019
Ankle inversion	7.7	4.3	9.5	6.3	8.1	3.6	9.9	3.4	0.567	0.287	0.956	0.002	0.039	0.000
Knee flexion	65.2	19.5	73.0	15.8	61.2	20.6	69.0	17.1	0.090	0.403	0.987	0.012	0.045	0.000
Hip abduction	11.7	3.97	11.8	5.0	12.5	4.2	12.7	5.5	0.218	0.943	0.923	0.009	0.000	0.000
Hip flexion	53.2	5.8	53.8	4.7	54.3	6.4	54.8	3.0	0.440	0.701	0.964	0.011	0.003	0.000
Pelvis obliquity	12.8	4.3	13.5	5.4	13.4	7.3	13.5	5.5	0.818	0.467	0.598	0.001	0.001	0.001
Pelvis rotation	10.1	3.9	10.0	2.7	10.6	4.7	11.4	3.6	0.143	0.631	0.525	0.018	0.002	0.003
Pelvis tilt	7.1	2.2	6.9	2.5	6.5	2.1	7.3	2.5	0.760	0.612	0.283	0.001	0.005	0.012
Descent														
Ankle flexion	64.4	7.7	62.4	3.5	58.4	7.7	60.2	8.9	0.056	0.981	0.101	**0.076**	0.000	0.016
Ankle inversion	17.2	6.4	15.6	5.9	14.2	4.7	17.7	7.5	0.748	0.615	**0.028**	0.001	0.007	0.042
Knee flexion	84.3	7.3	88.8	7.1	84.9	8.3	85.1	4.4	0.148	0.401	**0.044**	0.012	0.028	0.024
Hip abduction	10.4	3.5	9.2	3.5	10.4	4.5	8.5	1.9	0.403	0.287	0.640	0.003	0.052	0.002
Hip flexion	24.6	4.1	25.6	3.6	25.2	4.1	28.6	4.7	0.129	**0.035**	0.173	0.045	**0.064**	0.020
Pelvis obliquity	6.3	1.1	6.8	2.4	6.4	1.6	6.8	2.2	0.934	0.146	0.938	0.000	0.015	0.000
Pelvis rotation	9.6	3.4	9.1	3.2	9.8	3.5	8.9	2.6	0.921	0.227	0.686	0.000	0.013	0.001
Pelvis tilt	5.3	1.4	5.0	1.3	5.1	1.5	5.0	1.4	0.815	0.296	0.753	0.001	0.006	0.001

Table 5. Pre-surgical and post-surgical Symmetry Angle (%) for ranges of motion of lower limb joints. *p* values from paired t-test and relevant Cohen's d effect size (ES). Significant *p*-values in bold.

|	Pre		Post			
Variable	**Mean**	**SD**	**Mean**	**SD**	***p*-Value**	**ES**
Ascent						
Ankle flexion	−3.3	16.6	1.9	17.0	**0.014**	0.315
Ankle inversion	−3.2	24.6	−6.1	17.1	0.512	0.139
Knee flexion	−3.8	14.6	−4.1	17.6	0.857	0.017
Hip abduction	0.3	15.5	0.3	17.5	0.994	0.001
Hip flexion	−0.4	2.5	−0.4	4.4	0.984	0.006
Pelvis obliquity	−3.2	7.3	1.4	4.6	0.080	0.715
Pelvis rotation	−1.3	9.5	−3.4	12.7	0.517	0.182
Pelvis tilt	1	8.7	−2.9	14.3	0.313	0.327
Descent						
Ankle flexion	0.8	3.2	−0.9	5.0	0.176	0.400
Ankle inversion	2.4	15.1	−7.3	14.2	**0.027**	0.643
Knee flexion	−1.7	4.1	−0.2	3.9	**0.049**	0.373
Hip abduction	3.7	17.3	3.5	17.6	0.958	0.011
Hip flexion	−1.2	5.9	−4.0	5.8	0.213	0.462
Pelvis obliquity	−1.2	7.6	−1.5	6.8	0.927	0.042
Pelvis rotation	1.2	8.4	2.4	9.2	0.686	0.132
Pelvis tilt	1.8	5.1	0.3	8.2	0.642	0.216
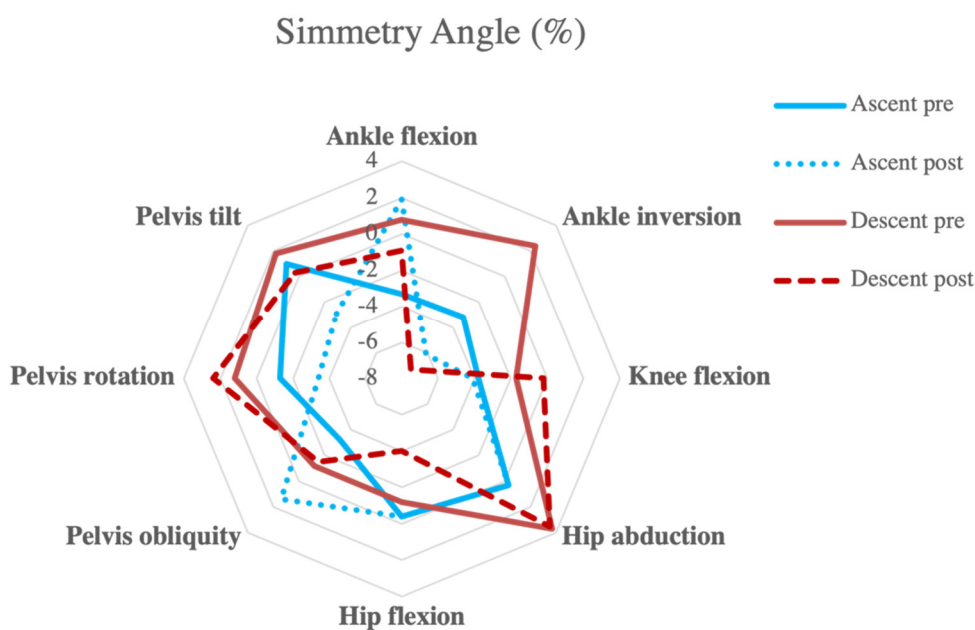
Figure 3. Radar plot showing the average Symmetry Angle (%) change between pre- and post-surgery lower limb joints range of motion.

Overall, only the side effect of hip flexion during descent was both statistically significant and had a medium effect size.

4. Discussion

Overall, no major functional limitations during stair ascent and descent were detected, nor any relevant asymmetry emerged apart from ankle joint kinematics. In the analysed patient sample, the VFFF harvest was generally associated with successful clinical outcomes of the donor site. While previous studies found some differences in the lower limb function, this is the first longitudinal investigation focused on stair climbing, as Bay et al. made

a cross-sectional investigation [6]. Comparison with prior publications is therefore only partially feasible.

In patients submitted to VFFF harvest, information regarding stair negotiation mechanics is rather scant. Stair ascent and descent are common daily life tasks whose mechanical demands could potentially exacerbate the negative effects of VFFF [16]: internal knee joint moments are deemed three times greater during stair negotiation compared with level walking [32].

Spatial and temporal variables of stair ascent and descent phases were modified by neither surgery nor side, consistent with our previous cross-sectional investigation [6].

Even the medium effect size for a shorter double-support phase during stair ascent on the donor side did not reach statistical significance. As a matter of fact, the post-surgical modifications were variable among the patients: F1 and M4 performed the post-surgical task with a general increment of double-support time, while patients M5, M6 and M7 had a reduction in double-support time. Consistently, during overground gait, Di Giuli et al. [8] reported a significantly reduced double-support phase after surgery (-6%), possibly due to a residual muscular impairment of the flexor hallucis longus muscle, as lamented by patient M6. Attia et al. found that their 68 patients scored stair climbing among the most difficult daily activities (on average 86%), even if their donor-leg score for a balance test was nearly 96% of those of the healthy one [23].

Muscular weakness has been reported to be minimised by early ambulation and to diminish with time [11,16,20,25]. Overall, our sample comprised only 14 patients, and even if our prior calculation estimated that ten patients would have assured type I and type II errors, respectively, of 0.05 and 0.20 [10], further investigations with an increased sample size and a longer follow-up are necessary to allow to draw more robust conclusions.

The analysed lower limb joint RoMs were scarcely modified by surgery and side; most of the significant differences were relative to time $\times$ side interactions, and only hip flexion during descent was significantly and practically larger on the donor side. The increased movement may be a proximal limb compensation of a distal (ankle) deficit. During the swing phase, the combined action of hip flexor, knee flexor and anterior leg muscle groups mainly provides a clearance sufficient to avoid limping and steppage [24]. The reduction in one component will involve concomitant modifications in the other joints. For example, patient F2 showed increments in hip abduction, pelvis obliquity and tilt RoMs of her donor limb, coupled with reductions in ankle inversion and flexion on both sides; she lamented pain after surgery—it should be mentioned that she was obese (Body Mass Index, BMI > 30 kg/m^2). Patient M5 (BMI = 18.9 kg/m^2) showed similar post-surgical modifications, with reduced ankle flexion and generally increased pelvis RoMs; in contrast, patients F1 (BMI = 17.9 kg/m^2) and F5 (BMI = 18.3 kg/m^2) showed decrements in pelvis RoM. As Zimmermann et al. (2001) reported no relationships between Body Mass Index and donor-site alterations, this topic is probably worth further investigation and could not draw final conclusions based on the current results.

During stair descent, knee flexion RoM increased after surgery. Again, this may be an effect compensating the modifications in ankle joint, as seen for the hip. It has to be mentioned that the findings about hips and knees contrast with our previous pilot study, where no significant differences in the RoMs of these joints were described [8]. However, the cross-sectional nature of the former investigation and the reduced number of patients (approximately half of the current sample) hinders a straight comparison. In contrast, during stair descent, Baj et al. [6] reported that patients had a significantly larger pelvis inclination RoM than control subjects, with a small effect size. Another explanation for the post-surgical combined increase in hip and knee flexion may be an attempt to limit the extension of the lower limb, as this movement provokes elongation of possibly painful soft tissues of the donor leg [6].

The ankle joint, anatomically and functionally close to the donor site, showed time $\times$ side modifications for both the flexion (ascent phase) and inversion (descent phase) of opposite directions; ankle flexion RoM on the donor side reduced after surgery, while ankle inversion

RoM increased. Ankle flexion during stair descent was also reduced after surgery, but not significantly (low-to-medium effect). Surgery also appeared to be detrimental in terms of ankle inversion RoM symmetry, as the Symmetry Angle exceeded 6% in post-evaluation both in stair ascent and descent (while only the latter resulted in a statistically significant change). The surgical removal of extensor and flexor hallucis longi muscles plays a key role in these RoM modifications, especially for the sagittal plane movements, as found in patients F2, F4, M1, M3, M5 and M6. Indeed, alterations in absolute ankle joint RoM and in this muscle are reported in the literature [11,21,24,25]. The same muscle has an inversion component (Lee et al., 2008) that was significantly modified in the follow-up assessment of the donor leg. In the current patients, ankle supination RoM reduced in patients F2, F4 and F7 and increased in M2, M3, M4 and M7. Apart from sex, no specific characteristics were identified. Indeed, this sex-related difference may be more apparent than real, and consistent patterns of deficits were found neither in the current group of patients nor in the literature. Indeed, the small number of patients does not allow to perform meaningful statistical tests. Of course, considering the 2.8:1 ratio in the prevalence of oral cancer in men and women, side effects should be investigated with specific tests that take sex into account [33].

Unfortunately, Baj et al. [6] did not measure ankle joint RoM. A quantitative evaluation of hallux position in the horizontal plane was performed by Hadouiri et al. [16] for an overground gait test: the donor side had significantly larger excursions than those measured in a reference population.

To reduce these adverse events, a recent biomechanical ex vivo study suggested that the harvesting procedure should be performed by removing the shorter possible fibular length and preserving as much as possible the attachments of the muscles. Moreover, tension of the skin of the donor site should be avoided, as major wound complications may involve neuromuscular damages with important reductions in daily activities [15]. Considering that several patients had a shorter double-support phase during the post-surgical stair ascent on the donor side, we may suggest a specific rehabilitation protocol aimed to increase motor control, spatial awareness and self-confidence both during the gait cycle (confidence in transferring weight between the healthy and donor limbs) and in general during locomotory tasks. For instance, patients who had only a 5% deficit relative to their healthy side in a balance test self-considered their ability in stair negotiation at only 86% [23].

In the analysed patients, the follow-up time was sufficient for a general recovery of mobility, as previously reported by Maben et al. [34], and no major problems in joint RoMs were found as a group, apart from ankle joints, where individual considerations are necessary to improve gait performance. Considering the significant side×time differences in ankle inversion and flexion, the same increment in self-confidence may be beneficial.

Our patients had to climb stairs consisting of only three steps, which represented a relatively easy task. We could not use a longer stair set because of laboratory size, and this should be acknowledged as a study limitation. Clinical studies analysing gait impairments after VFFF harvest reported problems in daily stair climbing in part of their patients [16,23,35,36], probably for a higher number of consecutive steps. As underlined in the literature [19,24]. The selection of tasks should be sufficiently demanding to be clinically useful, and future studies should include other settings or instruments allowing a larger number of steps.

Lastly, the inclusion of kinetic assessments [24,25] and of surface electromyography may allow a better and more complete description of the patients' status. A major limitation is that patients were neither consecutive nor randomly chosen, and therefore represent a convenience sample; thus, generalizing these results to the whole population should be conducted cautiously, also considering the reduced sample size.

In conclusion, considering the slight modifications of the gait variables assessed during stair negotiation, no major functional limitations were found following the VFFF during stair climbing and descent.

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