Long-Term Follow-Up on the Donor Foot After Thumb Reconstruction Using Big Toe Wrap-Around Flap in Two Different Operation Methods

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Abstract The function of the donor foot has been affected after using big toe wrap-around flap for thumb reconstruction. A modified operation method has been developed to reduce the adverse effect on the donor foot. The current study compared the long-term effect of the classic and the modified operation methods on the donor foot. Gait analysis was carried out, including how the patient walked, the walking speed and walking distance, and how the patient jumped and ran. Plantar pressure was measured while the patient was standing and moving. A total of 45 patients who received the 2 different operation methods were included. The follow-up time was 4–10 years with a mean of 6.5 years. Various degrees of complications occurred for the 21 patients who received the classic operation method. For these patients, plantar pressure of the donor foot was obviously different comparing with the healthy unaffected foot while the patient was standing or walking. For the 24 patients who received the modified operation method, no obvious complications were observed and the plantar pressure of the donor foot and the healthy unaffected foot was similar while the patient was standing or walking. In conclusion, both the classic and the modified operation methods have affected the function of the donor foot after using the big toe wrap-around flap for thumb reconstruction. However, the donor foot was less affected when the modified operation method was used.

Keywords Big toe wrap-around flap · Thumb reconstruction · Donor foot · Gait analysis · Plantar pressure · Foot function

Introduction

Since Morrison et al. reported using free big toe wrap-around flap for thumb reconstruction in 1980 [1], it has become the routine surgical treatment for thumb defect. Post operation, the reconstructed hand regains the maximum amount of its function with nearly normal shape and appearance. Meanwhile, it causes traumatic damage to the donor foot, which affects working ability and life quality of the patient. With time, more problems related to the donor foot have been observed and various attempts have been made to improve the outcome. Pan et al. [2] reported a modified operation method of thumb reconstruction using big toe wrap-around flap that showed improvement in the function of the donor foot.

In the current study, 45 patients were treated with either the classic (by Morrison et al. [1]) or the modified (by Pan et al. [2]) operation method and a follow-up analysis was carried out at an average of 6.5 years post operation; the function of the donor foot was analyzed and the outcomes were compared between the 2 operation methods.

Methods

The Patients

Forty-five patients who had thumb reconstruction were included in this long-term follow-up analysis. The classic operation method was used for 21 patients, and 24 patients were treated with the modified method. In brief, the wrap-around flap in the classic operation included the complete

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nail bed, the skin of the fibular side, and the pulp of the big toe. The artery in the flap was the dorsal artery—the first dorsal metatarsal artery, the vein was the saphenous vein, and the nerve was the planter nerve of the fibular side. The flap reserved for the donor toe was on the tibial side. After the flap was harvested, direct skin graft was performed on the donor toe. For the modified method, on the donor foot, the separation of the dorsal arteries, veins, and the nerves was the same as in the classic method. The flap contained the plantar arteries, veins, and the nerves of the fibular side. A rectangular area of skin and tissue under the plantar weight-bearing area remained intact with the plantar arteries, veins, and the nerves of the tibial side kept inside, which prevented the occurrence of dermonecrosis at the donor site and maintained the sensory ability of the plantar skin. The distal phalange under the big toe was partially (approximately 1/2 of its original length) removed and used with the free neurovascular “wrap-around” flap without separating the distal phalange from the nail body. The study was approved by the ethics committee of the hospital. All patients provided written informed consent before taking part in the follow-up examinations. The patients then received brief training (i.e., watching demonstrations with explanation and instructions) on how to take certain tests.

General Observations

General observation on the donor foot was carried out, including the appearance, the general feel, and the occurrence of redness, swelling, calluses, ulcers, and plantar deformities. Patients were asked to walk for over 1000 m and the walking speed was compared with the mean value for healthy adults (1.4 m/s). They were also asked to run and jump in situ for over 10 min and the reactions of the donor foot (including the feelings at the donor site of the wrap-around flap and for the whole donor foot) were recorded.

Foot Function Tests

Footprints were collected on a footprint collecting device. The patient was instructed to stand naturally on the device, then on one foot alternately with the donor foot and the healthy unaffected foot. The collected footprints were compared.

Patients were further asked to stand naturally on both feet on the plate of a computerized plantar pressure measuring device to have the static plantar pressure measured. They were then asked to stand on one foot alternately with the donor foot and the healthy unaffected foot, and the plantar pressure was measured again. On the pressure graphs, the same analysis indicator was placed to the positions correlated to the metatarsal bones. Data obtained were then used for comparison.

Before the dynamic plantar pressure measurements were collected, patients were given training and were asked to get familiar on how to walk naturally on the computerized plantar pressure measuring device. For the examination, patients were asked to walk in a relaxed manner with the donor foot and the healthy unaffected foot stepping on to the plate of the device for at least 3 times each to obtain an average for each foot. The data were collected and analyzed the same way as for the static plantar pressure measurement.

Statistic Methods

All data were analyzed using SPSS 13.0. The healthy unaffected foot was used as the control for individual patient, and various measurements were compared between the control and the donor foot. Paired *t* test was used. $P < 0.05$ was considered as statistically significant.

Results

Of the 45 patients, 29 were male, 16 were female; the mean age was 23.6 years (range 16–40 years). Time from the operation to the follow-up study was between 4 and 10 years with a mean of 6.5 years.

The Performance of the Donor Foot After the Operation

None of the 21 patients who received the classic method of operation had the full length of the big toe of the donor foot. The tip of the big toe of the donor foot was missing from the proximal interphalangeal joint, and the plantar surface of the donor toe was covered with scar tissue and calluses (Fig. 1a). In 5 patients, skin ulceration occurred on the scar tissue. All patients showed various degrees of limping during fast walking or running. The average walking speed was 1.3 m/s for the first 100 m. However, the walking speed decreased gradually when the walking distance increased, and for the last 100 m, the average walking speed decreased to 0.6 m/s. When they were asked to run and jump in situ, for all patients, various degrees of pain were reported in the donor foot, the skin of the donor foot became red, and the donor foot touched the ground later than the healthy foot during jumping. None of the patients could stand steadily only on the donor foot. Direct footprints showed that compared with the healthy unaffected foot, the weight-bearing mark under the first metatarsal head was lighter, the point for weight-bearing shifted inwards, while the weight-bearing marks under the second and the third metatarsal heads became darker (Fig. 2a).

For the 24 patients who received the modified operation method, they could maintain the full length of the big toe of the donor foot, and no scar tissue or calluses were seen (Fig. 1b, c). None of the patients showed limping when

Fig. 1 General condition of the donor foot in patients who received thumb reconstruction using big toe wrap-around flap in two different operation methods. The *left* shows the healthy unaffected foot; the *right* shows the donor foot. **a** The shape of the big toe of the donor foot with scar tissue and calluses in a patient who received the classic operation method. **b** No scar tissue or callus in the donor foot in a patient who received the modified operation method. **c** The full length of the big toe of the donor foot in a patient who received the modified operation method without scar tissue and callus forming

walking fast or running and none showed obvious pain in the donor foot. The average walking speed was 1.3 m/s for the first 100 m; the walking speed showed no obvious decrease when the walking distance increased, and the average walking speed was 1.2 m/s for the last 100 m. When running and jumping in situ, all patients touched the ground using both feet during jumping; after 10 min, the donor foot showed no obvious pain and the skin color of the donor foot did not show obvious change. Overall, the patient did not feel obvious discomfort. The patients could stand fairly steadily using the donor foot only. Direct footprints showed comparable marks for both the healthy unaffected foot and the donor foot. No changes in the weight-bearing points were observed (Fig. 2b).

Further analysis on plantar pressure distribution (Fig. 2c) showed that when standing naturally on both feet, significant differences occurred between the donor foot and the healthy unaffected foot in patients who received the classic operation method (Table 1). Compared with the healthy unaffected foot, no significant differences in weight-bearing were found under the heel and the fourth and the fifth metatarsal heads; while at the front half of the foot, significant changes in pressure distribution were seen. Weight-bearing decreased significantly under the first metatarsal head and increased significantly

under the second and the third metatarsal heads. This increase in pressure distribution under the second and the third metatarsal heads was consistent with the occurrence of calluses in this area. For patients who received the modified operation method, there were no significant differences in plantar pressure distribution between the healthy unaffected foot and the donor foot (Table 1).

Pressure distribution was also analyzed when patients were walking (Table 2). It was found that during walking, for patients who received the classic method of operation, pressure distributed evenly under the first to the fifth metatarsal heads for the healthy unaffected foot, with more weight-bearing under the first and the fifth metatarsal heads, and less weight-bearing under the second to the fourth metatarsal heads. During walking, the donor foot however showed a lack of pushing power under the first metatarsal head and weight-bearing increased under the second and the third metatarsal heads. Stress transfer occurred as weight-bearing under the first metatarsal head was redistributed. For patients who received the modified method of operation, weight-bearing distributed evenly under the first to the fifth metatarsal heads in both the donor foot and the healthy unaffected foot. Weight-bearing under the first metatarsal head was not redistributed, and no signs of stress transfer were found (Table 2).

Fig. 2 Footprints of the donor foot in patients who received thumb reconstruction using big toe wrap-around flap in two different operation methods. The *left* shows the healthy unaffected foot; the *right* shows the donor foot. **a** With the classic operation method. **b** With the modified operation method. **c** Computerized foot pressure distribution of the donor foot in the 2 different operation methods. Different color indicates different plantar pressure; blue, green, light yellow, dark yellow, and red represent plantar pressure from low to high

Discussion

Using big toe transplant for thumb reconstruction has become the standard treatment for traumatic thumb defects. The effects of this surgical procedure on the donor foot have increasingly attracted attention [3]. Plantar pressure analysis and gait analysis are techniques developed based on the understanding of

biomechanics to investigate the structure and function of human lower extremities. Both techniques are used to assess and predict podiatry disorders and to provide guidance for rehabilitation training. Since these analyses are easy to carry out and the data gathered are specific and objective, they are widely used in orthopedics [4].

The weight-bearing regions of the human foot are in both the forefoot and the rearfoot. The forefoot consists of 5 toes, the first to the fifth metatarsal bones, and part of the tarsal bones; the rearfoot is the heel. Fifty percent of the weight is carried by the heel and the other 50 % is distributed to the 5 metatarsal heads. The weight under the first metatarsal head is two times of the weight carried by each of the other 4 metatarsal heads. Slight changes in the structure of the forefoot can result in changes in plantar pressure distribution [5].

In recent years, besides the traditional clinical observations and summaries of findings during the follow-up, there have been reports on applying plantar pressure analysis in the assessment of the donor foot after thumb reconstruction surgery [6, 7]. However, only limited studies reported the findings of comparison analysis based on long-term follow-up on large group of cases [8, 9].

In the current analysis, aiming to acquire detailed knowledge of the damage to the donor foot after thumb reconstruction, we used a computerized plantar pressure measuring device to assess the function of the donor foot in patients who received different operation procedures for thumb reconstruction. Previously, Chen et al. showed that after the classic wrap-around flap thumb reconstruction, the differences in plantar pressure distribution between the donor foot and the healthy unaffected foot were significant during standing and walking [8]. Zhang et al. conducted a follow-up study including 62 patients who had lost part or all of the first distal phalange of the toe; 32.3 % of the patients had pain at the stump and recurring ulcers, and in some cases the patients had difficulty in walking [10]. Stupka et al. found that obstructed weight-bearing ability occurred in 33 % of the patients in standing position and in 67 % while walking; 83 % of the patients had problems caused by scar tissue, among whom 50 % were classified as having unstable scars [3]. For the 21 patients included in our study who received the classic operation method, plantar pressure analysis showed altered weight-bearing due to the flap taken from the big toe, the points of weight-bearing had shifted outwards, and calluses were formed on the donor foot. The peak pressure under the thick calluses of the donor toe showed abnormal increase, while no pressure distribution was detected under the skin damages and ulcers of the scarred tissue of the donor foot. The peak pressure under the second, third, fourth, and fifth metatarsal head of the donor foot was significantly higher than that of the healthy unaffected foot. Following these changes in plantar pressure of the donor foot, callus formation under the second metatarsal head increased, which caused pain. Weight-

Table 1 Plantar pressure distribution in standing position

	Peak value of pressure, kPa					
	Heal	M1	M2	M3	M4	M5
Classic operation method						
Healthy unaffected foot	68.3±1.74	42.5±4.55	7.5±1.66	4.2±1.47	2.4±1.14	9.4±2.57
<i>N</i> =21						
Donor foot	67.9±1.36	39.6±2.12	8.4±1.21	5.0±1.14	2.7±1.57	8.8±2.10
<i>N</i> =21						
<i>t</i> statistic	0.889	2.830	1.908	2.138	1.913	1.384
<i>P</i> value	>0.05	<0.01	<0.05	<0.05	>0.05	>0.05
Modified operation method						
Healthy unaffected foot	67.8±1.34	43.2±4.40	7.8±1.73	4.2±1.55	2.3±1.35	9.1±2.45
<i>N</i> =24						
Donor foot	67.2±1.56	42.9±3.42	8.1±1.88	4.0±1.14	2.4±1.67	9.9±2.52
<i>N</i> =24						
<i>t</i> statistic	1.430	0.264	0.576	0.509	0.229	1.115
<i>P</i> value	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

M1 to M5, the first to the fifth metatarsal heads

bearing shifted from under the first metatarsal head to under the second metatarsal head, and the difference between the third and the fourth metatarsal heads was significant. These findings indicated that the pressure center in the forefoot had obviously shifted outwards. It was also found that the distance of the forward shifting of the pressure center was obviously shortened in the donor foot suggesting a pressure concentration in the forefoot as the result of the damaged weight-bearing ability due to a much shortened big toe. All these changes caused pain in the plantar surface and the discomfort after long distance walking, which led to limping and slowed walking speed in patients who received the classic operation method.

Since Morrison et al. reported the use of wrap-around flap for thumb reconstruction in 1980 [1], it has been widely used for the treatment of thumb defects. Using this method, the shape of the reconstructed thumb is nearly the same as a normal thumb, and the shape of the hand is esthetically appealing after surgery. Later, it has been found that the usage of wrap-around flap has considerably affected the donor foot [11]. The big toe of the donor foot has a shortened length with scar tissues covering the stump, causing problems at the weight-bearing points. Since the nerve of the big toe has been severed, neuroma forms at the proximal end and adhesion with the scar tissue occurs, and this causes pain when the donor foot bears weight. The operation also causes damage to the structure of

Table 2 Plantar pressure distribution while walking

	Peak value of pressure, kPa				
	M1	M2	M3	M4	M5
Classic operation method					
Healthy unaffected foot	245.70±4.19	66.80±5.74	27.80±2.14	16.53±6.45	60.68±2.24
<i>N</i> =21					
Donor foot	157.30±4.16	132.70±4.44	55.20±4.17	21.78±6.86	73.30±3.45
<i>N</i> =21					
<i>t</i> statistic	3.459	4.332	2.684	1.225	1.654
<i>P</i> value	<0.01	<0.01	<0.05	>0.05	>0.05
Modified operation method					
Healthy unaffected foot	253.23±4.19	67.80±5.23	28.80±3.14	16.70±5.28	57.90±5.14
<i>N</i> =24					
Donor foot	256.9±4.46	66.6±4.42	28.1±4.13	15.1±5.14	56.3±5.54
<i>N</i> =24					
<i>t</i> statistic	1.004	0.307	1.102	1.018	0.384
<i>P</i> value	>0.05	>0.05	>0.05	>0.05	>0.05

M1 to M5, the first to the fifth metatarsal heads

the toes resulting in the weight-bearing point being shifted outwards, movement of the metatarsophalangeal joints is limited, and the pushing forwards function of the foot is hindered. The main blood vessel in the big toe of the donor foot is severed for the operation. Circulation has been affected and the venous return is obstructed. In our study, similar problems in the donor foot were identified. After using the wrap-around flap for thumb reconstruction, the plantar weight-bearing points shifted outwards, weight-bearing under the first metatarsal head decreased significantly than that of the healthy unaffected foot ($P < 0.05$), while weight-bearing under the second and the third metatarsal heads increased considerably with callus formation. During walking test, it was found that the donor foot showed lack of pushing forwards power than the healthy unaffected foot and the difference was significant.

In order to reduce the high rate of complications in the donor foot after the classic wrap-around flap operation method for thumb reconstruction, Hu et al. reported a modified operation method with satisfactory short-term post-operation outcomes, in which the distal phalange under the big toe is partially removed for thumb reconstruction and the plantar weight-bearing region remains [12]. In this study, we carried out a long-term (range 4–10 years, mean 6.5 years) follow-up for the 24 patients who received this modified operation method. In the foot kinematics test, compared with healthy unaffected foot, the donor foot showed no significant changes in the plantar pressure measurements either in standing position or during walking, which indicated that the modified wrap-around flap transplant did not have obvious effects on the walking and standing of the donor foot. For the kinetic measurements, among the 6 measured anatomical sites of the donor foot, 5 sites (except for the big toe) showed similar peak pressure values when compared with the corresponding site in the healthy unaffected foot. The center of pressure in the plantar aspect is fairly symmetrical in both feet, and the peak pressure of the forefoot appeared under the second metatarsal head in both feet.

Based on the findings of this study, we concluded that after the operation of using the wrap-around flap of the big toe for thumb reconstruction, for the donor foot, the plantar pressure distribution remained normal, no obvious pressure concentration occurred, and the rate of pain in the phalanges was low. However, significantly lower peak pressure under the big toe and significant shorter pressure–time were seen in the donor foot than in the healthy unaffected foot, and the differences were statistically significant. These results showed that after the flap was taken, the normal anatomical structure of the big toe was damaged, and the pressure distribution in the plantar aspect changed accordingly. A possible explanation is that the weight-bearing region of the donor foot became narrower after

the operation, which reduced the area for weight-bearing, therefore the plantar peak pressure under the donor foot decreased. Meanwhile, the peak pressure under each metatarsal head showed no significant difference between the donor foot and the healthy unaffected foot, which indicated that the weight-bearing of the plantar surface was not affected after the flap was used for thumb reconstruction, and no clinical complications were found in the big toe of the donor foot.

Overall, this long-term follow-up study showed that using the classic method, the appearance of the donor foot was not very satisfying and the plantar pressure distribution was considerably damaged; while using the modified method, the appearance of the donor foot was nearly normal and the plantar pressure distribution was less affected. Therefore, it can be deduced that the modified wrap-around flap thumb reconstruction operation procedure has less damage to the donor foot than the classic operation method.

Compliance with Ethical Standards

Conflict of Interest The authors have nothing to disclose.

All procedures performed in the current study were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards and were approved by the ethics committee of the hospital.

All patients provided written informed consent before taking part in the current study.

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