Int J Clin Exp Med 2019;12(6):7623-7629
www.ijcem.com /ISSN:1940-5901/IJCEM0091253

Original Article

Establishment of a three-dimensional digital model database of inguinal compound tissue flaps with multiple perforating artery branches and its pilot application

Yiheng Chen, Zhijie Li, Peng Luo, Shi Li, Tinggang Chu, Weiyang Gao

Department of Hand and Plastic Surgery, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, Wenzhou, Zhejiang Province, China

Received January 13, 2019; Accepted March 11, 2019; Epub June 15, 2019; Published June 30, 2019

Abstract: Objective: The aim of the current study was to investigate the efficacy of three-dimensional digital model-assisted inguinal compound tissue flaps with multiple perforating artery branch (TDMA-ICTFMP) transplantation on traumatic wound plastic surgery in the upper limbs of patients. Methods: Sixty-eight patients with upper limb trauma were divided into the control group and observation group, according to a random number table, with 34 patients in each group. Patients in the control group were treated with inguinal compound tissue flap (ICTF) transplantation, while patients in the observation group received TDMA-ICTFMP transplantation. Results: There were 33 patients with effective treatment and 29 patients with excellent and good cosmetic results in the observation group, significantly higher than those in the control group. Perforating vessel-related data collected in the observation group was basically consistent with relevant data found during the operation. Levels of accuracy of collected data and degrees of damage in the donor site were better than those in the control group. Operation times and flap healing times in the observation group were significantly less than those in the control group. Eleven patients had complications in the observation group, significantly lower than that in the control group. Conclusion: TDMA-ICTFMP transplantation improves treatment effects for patients with upper limb trauma, providing better upper limb function and improved cosmetic results.

Keywords: Inguinal compound tissues flaps, three-dimensional digital model-assisted transplantation, upper limb trauma, treatment efficacy

Introduction

Upper limbs are featured by strong mobility. Due to the requirements of life and work, some people are exposed to dangerous environments, such as high-temperature solids, as well as liquids and gases, adding risk of trauma to the upper limbs [1]. Trauma in the upper limbs has a great impact on the health and lives of patients. If untreated, it may cause severe infections, leading to amputation [2]. Inguinal flap transplantation is a common technique for clinical treatment of bone and soft tissue injuries [3]. Some studies have found that, in the treatment of trauma in the upper limbs, it is necessary not only to repair the wounds, but also to repair defective blood vessels. Current inguinal flap transplantation practices have certain deficiencies, leading to treatment failure for upper limb trauma [4]. A recent study showed that establishment of a three-dimensional model database of targeted tissues is helpful for surgical design and improvement of therapeutic effects of burn tissues [5]. However, the establishment of a three-dimensional model database is complicated. It has not been clinically applied on a large scale. Design parameters of some databases require further improvements to meet the requirements of clinical surgery.

In the current study, the practicability and operability of a three-dimensional model database were further improved by optimizing databases, with an aim of enhancing treatment efficacy. Through patient image data of skin soft tissue defects, a three-dimensional digital model of inguinal compound tissue flaps with multiple perforating artery branches was constructed. Based on this three-dimensional digital model, a system dedicated to three-dimensional model management and data extraction, analyses and comparisons of each patient were established. Results provide strong support for guidance of personalized surgical design of inguinal tissue flaps in the future.

Materials and methods

General data

Sixty-eight patients with trauma in the upper limbs, treated in The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, from February 2017 to February 2018, were selected. They were divided into two groups according to a random number table. Thirty-four patients in the control group, including 19 males and 15 females, aged 27-41 years, were treated with inguinal flap transplantation. Thirty-four patients in the observation group, including 16 males and 18 females, aged 23-48 years, were treated with three-dimensional digital model-assisted inguinal flap transplantation.

Inclusion criteria: Patients without a history of inguinal surgery; Patients with complete clinical data. Exclusion criteria: Patients with liver and kidney failure; Patients receiving treatment for the first time in other hospitals; Patients with poor compliance. This study was conducted in compliance with the Declaration of Helsinki and approved by the Ethics Committee of The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University. Informed consent was obtained from all enrolled patients and their families.

Establishment of a three-dimensional digital model database of inguinal compound tissue flaps with multiple perforating artery branches

Methods for establishing a three-dimensional digital model database of inguinal compound tissue flaps with multiple perforating artery branches were as follows [6]. First, continuous enhanced computed tomography (CT) images of the upper limbs were imported into Amira software (Visage Imaging CO.). The threshold was adjusted through the threshold slider on an isosurface and inguinal compound tissue flaps were reconstructed on an isosurface. Directions and locations of perforating vessels of the compound tissue flaps were observed and recorded. Next, pixel allocation, noise reduction, and smoothness levels of the material image were sequentially performed. Image color was then adjusted. Image data was partitioned and connected with existing data. Data sets were input into the software for compound tissue flap reconstruction, observing the anatomic relationship between compound tissue flaps and perforating vessels in multi-directional and stereoscopic ways. Relevant data was applied to surface or volume reconstruction of hyalinized skin and subcutaneous tissues. Cutting was performed according to the direction of the perforating vessels and the general shape of soft tissue defects. At the same time, the software was written in C++ language. Database establishment adopted the embedded database Vista DB 2.1. SQL 92 compatible v-SQL was used to develop the custom search engine, meeting the requirements of expansion to T-SQL in the future. After the database was established, each module was debugged. Application testing included the stability of the running database, whether the items of database design meet the requirements of clinical data of surgical treatment of inguinal compound tissue flaps with multiple perforating artery branches, and the flexibility of custom fields. According to application testing, each module and the overall database worked smoothly, indicating that database establishment was completed (**Figure 1**).

Therapeutic methods

Patients in the control group were treated with inguinal flap transplantation [6]. Primary debridement of damaged tissues was carried out after local anesthesia. According to patient tissue wounds, the wound area of skin soft tissue was assessed. Incisions were performed from the inguinal skin to deep fascia. The flap was cut off in the midline of the rectus abdominis. The flap area was slightly larger than the wound area. Attention was paid to reduce nervous system injuries. Postoperative inflammation and infections were controlled. Patients in the observation group were treated with three-dimensional digital model-assisted inguinal flap transplantation. After each patient was in-

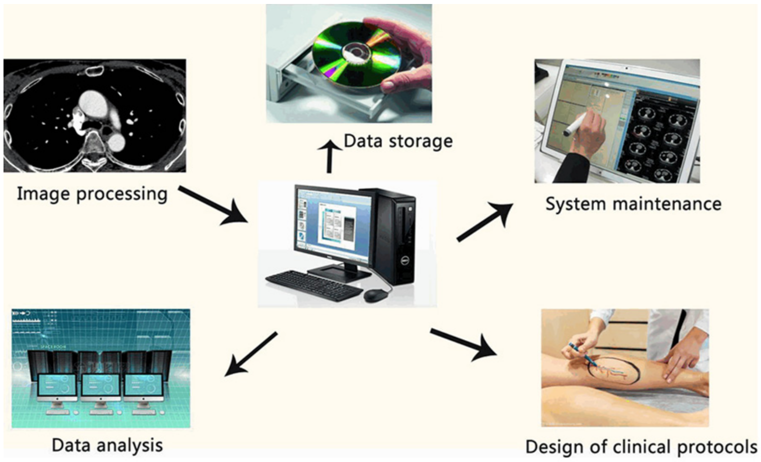

Figure 1. Establishment of a three-dimensional digital model of inguinal compound tissue flaps with multiple perforating artery branches and database development.

Table 1. Analysis of general clinical data

Group	Control (n=34)	Observation (n=34)	t/χ^2	P
Gender (male/female)	19/15	16/18	2.146	0.085
Age (years)	35.3±6.9	36.8±7.4	1.592	0.097
Weight (kg)	62.6±5.3	64.1±4.7	3.146	0.072
Flap area (cm^2)	78.4±5.8	85.6±6.2	2.459	0.086
Long-term smoking (Yes/No)	15/19	13/21	2.715	0.081
Long-term drinking (Yes/No)	11/23	10/24	1.739	0.092
Average follow-up time (months)	15.1	14.8	3.267	0.069

jected with 80 mL of iohexol, as as low-osmolar contrast agent, CT scans were performed. CT scan data was imported into the database management system. Vascular routes and mutual relationships were confirmed through CT film analysis. After the three-dimensional model database of inguinal compound tissue flaps was debugged and verified, the most relevant data points and characteristics of a three-dimensional model in the database were extracted automatically with the combination of patient CT image features. This was done to fit out a most suitable perforating vessel model for patients. The model optimized surgical plans to improve success rates of transplantation of tissue flaps. Suitable room temperatures were maintained in the operating room to prevent patients from spasming during surgery. Dezocine or propofol was administered to control pain and maintain sedation. Patients were prohibited from exercising to avoid injury at the surgical site. If the patient felt intense pain after surgery, analgesics were administered.

Outcome measurements and therapeutic effect evaluation

Main outcome measurements were flap area and flap healing times. Treatment effects were classified into three degrees, including excellence, improvement, and failure. Criteria of excellence: Transplanted flaps survived and limb flexion and extension function were normal [6]; Criteria of improvement: Part of the transplanted flaps survived and limb flexion and extension function recovered, to some degree; Criteria of failure: Treatment failed. Total effective rate = (the number of excellence + the number of improvement)/total number of patients * 100%. Evaluation of cosmetic results was as follows: 1) Excellent: Patients had smooth skin without pigmentation and scar hyperplasia after surgery; 2) Good: Patients had little scars, scar hyperplasia in local skin, and a little pigmentation; 3) General: Patients had scar reduction by about a half and mild pigmentation; 4) Poor: Patients had many scars and obvious pigmentation [7]. The excellent and good rate of cosmetic results = (the number of excellent rate + the number of good rate)/total number of patients * 100%.

Statistical analysis

SPSS 21.0 was used to analyze data. Measurement data are expressed as mean ± standard deviation. Student's t-test was applied to detect between-group differences. Enumeration data are shown as percentages. Chi-squared test was also applied. Comparison of enumeration data for less than 40 patients was performed using Fisher's exact probability. $P<0.05$ indicates statistically significant differences.

Table 2. Comparison of clinical efficacy between the two groups (n, %)

Group	Excellence	Improvement	Failure	Total effective rate
Control (n=34)	12 (35.3)	15 (44.1)	7 (20.6)	27 (79.4)
Observation (n=34)	27 (79.5)	6 (17.6)	1 (2.9)	33 (97.1)
χ^2	6.237			6.428
P	0.034	0.017	0.027	0.031

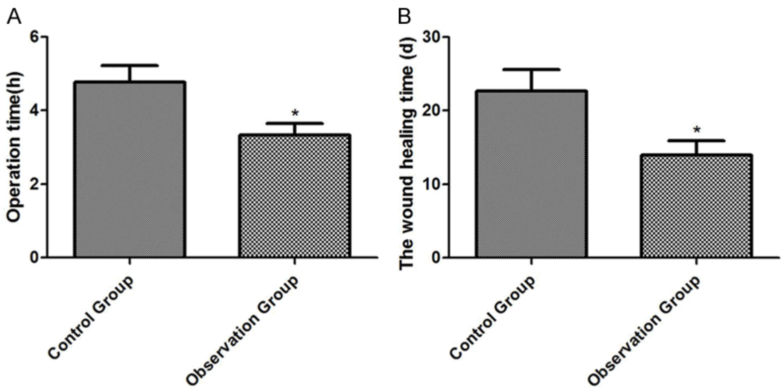

Figure 2. Operation times and wound healing times. Compared with the control group, *P<0.05.

Table 3. Cosmetic results of wounds (n, %)

Group	Excellent	Good	General	Poor	Excellent and good rate
Control (n=34)	4 (11.8)	14 (41.2)	10 (29.4)	6 (17.6)	18 (53.0)
Observation (n=34)	13 (38.2)	16 (47.1)	3 (8.8)	2 (5.9)	29 (85.3)
χ^2					5.647
P	0.012	0.404	0.031	0.042	0.026

Results

General data

There were no significant differences in gender, age, weight, flap area, long-term smoking, long-term drinking, and average follow-up times between the two groups (all P>0.05, **Table 1**).

Treatment effects

In the observation group, there were 27 patients (79.5%) with excellent effects, significantly more than those in the control group (P<0.05). There were 6 patients (17.6%) with improved effects and 1 patient (2.9%) with failed treatment, significantly less than those in the control group (both P<0.05). In the observation group, there were 33 patients (97.1%) with effective treatment, significantly more than those in the control group (P< 0.05, **Table 2**).

Surgery related indicators

Perforating vessel-related information collected in the observation group (including the number of perforating vessels, diameter, and starting location and direction of the vessel) was basically consistent with relevant data found during the operation. Accuracy levels of the collected data were significantly better than those in the control group. Degrees of damage in the donor site in the observation group were lower than those in the control group. Operation times (3.4±0.2 h) and flap healing times (14.7±2.6 days) in the observation group were significantly less than those in the control group (all P< 0.05, **Figure 2**).

Cosmetic results of wounds

In the observation group, there were 13 patients (38.2%) with excellent cosmetic results, significantly more than those in the control group (P<0.05). There were 16 patients (47.1%) with good cosmetic results, showing no significant differences between the two groups (P>0.05). There were 3 patients (8.8%) with general cosmetic results and 2 patients (5.9%) with poor cosmetic results, significantly less than those in the control group (both P<0.05). In the observation group, there were 29 patients (85.3%) with excellent and good cosmetic results, significantly more than those in the control group (P<0.05, **Table 3**).

Complications

There were 3 (8.8%) patients with hematomas, 2 (5.9%) patients with wound dehiscence, 4 (11.8%) patients with flap infections, and 2 (5.9%) patients with partial necrosis in the

Table 4. Complications (n, %)

Group	Hematoma	Wound dehiscence	Flap infection	Partial necrosis	Cumulative occurrences
Control (n=34)	7 (20.6)	5 (14.7)	8 (23.5)	6 (17.6)	26 (76.5)
Observation (n=34)	3 (8.8)	2 (5.9)	4 (11.8)	2 (5.9)	11 (32.4)
χ^2					4.216
P	0.013	0.021	0.024	0.035	0.029

observation group, significantly less than those in the control group (all P<0.05). A total of 11 patients (32.4%) had complications, significantly less than those in the control group (P<0.05, **Table 4**).

Discussion

Compound tissue flaps with multiple perforating artery branch transplantation has been a focus of plastic surgery [6]. Anatomy-related problems have also been proposed. Perforating flaps and compound tissue flaps are new developments in microsurgery. They are in conformity with the principle of tissue transplantation, "effective repair and reconstruction on the recipient area leads to little damage on the donor site" [7, 8]. Clinical studies have found that the distribution of blood vessels in different humans may be extremely different. Although distribution has a certain regularity, it is not suitable for all patients. During the operation, it is necessary to change the operation plan or abandon the operation for some patients due to different blood vessel distribution. Thus, many operations will fail due to insufficient preparation [9, 10]. Therefore, it is of great value to explore the application of three-dimensional digital model-assisted inguinal flap transplantation for upper limb trauma.

In this study, a database of three-dimensional digital model of inguinal compound tissue flaps with multiple perforating artery branches was established with the combination of modern medical imaging, computer graphics and image processing, computational medicine, modern clinical anatomy, and osteology. Some studies have suggested that the introduction of digital medical technology into treatment of upper limb traumas can enhance the reliability, reproducibility, and traceability of surgery, improving clinical treatment effects [11, 12]. Some studies have found that database technology can realize systematic and standardized management of the three-dimensional digital model of inguinal compound tissue flaps with multiple perforating artery branches, providing convenient operations for clinical individualized treatment meeting the needs of clinical work and research [13-15]. In the development process, programmers were assisted by application personnel in completing a series work of design, development, debugging, and improvement. Component-based software development was adopted, improving the speed and quality of database development, due to the large work quantity and short construction period for the database [16, 17].

In the observation group, there were a total of 33 patients (97.1%) with effective treatment. Operation time was 3.4±0.2 h and flap healing time was 14.7±2.6 days. These values are significantly better than those in the control group, indicating that three-dimensional digital model-assisted inguinal flap transplantation has good therapeutic effects and significantly improves postoperative upper limb function. Due to the complex structure of muscles, blood vessels, and nerves of the human body, some patients with severe skin and muscle tissue damage are difficult to treat. Three-dimensional digital model-assisted inguinal flap transplantation can effectively assist physicians in assessing traumatic wound features. This will help in developing individualized surgical plans for patients, significantly improving clinical treatment effects [18]. One study, examining 52 upper limb trauma patients with inguinal flap transplantation, found that patients had large flap areas, long wound healing times, and poor treatment effects of upper limb trauma. Results suggested that using inguinal flap transplantation, alone, could not accurately grasp the characteristics of damaged tissue, affecting patient treatment [19, 20]. Other studies have found that inguinal compound tissue flaps with multiple perforating artery branches after three-dimensional reconstruction can be displayed transparently or in any combination. The three-dimensional tissue structure shows a clear overall structure with strong perception of solidity from different angles. The relationship between tissues is clear, at a glance, which is conducive to clinical treatment [21, 22].

In this study, there were 29 patients (85.3%) with excellent and good cosmetic results in the observation group. This number was significantly larger than that in the control group, indicating that three-dimensional digital model-assisted inguinal flap transplantation could improve cosmetic results of patients and have great effects on quality of life. A study found that 58 patients with upper limb trauma, after three-dimensional digital model-assisted inguinal flap transplantation, had up to 81.4% of excellent and good rate of cosmetic results. This was significantly higher than that after inguinal flap transplantation [23]. This is consistent with present findings. In the current study, a total of 11 patients (32.4%) had complications in the observation group, significantly less than those in the control group. This indicates that three-dimensional digital model-assisted inguinal flap transplantation could effectively improve treatment and reduce incidence of complications. However, the three-dimensional digital model database of inguinal compound tissue flaps with multiple perforating artery branches established in this study has a short clinical application time. It is necessary to further improve and standardize operation standards and procedures of the database to meet the requirements for clinical treatment.

In summary, three-dimensional digital model-assisted inguinal flap transplantation shows a three-dimensional dynamic anatomic structure of normal anterolateral thigh flaps, vividly, providing a visualized digital anatomic basis for preoperative flap design. It effectively improves treatment effects for patients with upper limb trauma. It also improves cosmetic results, showing good clinical application value.

Acknowledgements

This work was supported by the Medical Health Science and Technology Project of Zhejiang Provincial Health Commission (No. 2015-KYA160).

Disclosure of conflict of interest

None.

Address correspondence to: Yiheng Chen, Department of Hand and Plastic Surgery, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, No. 109 Xueyuan West Road, Wenzhou 325027, Zhejiang Province, China. Tel: +86-0577-88879012; Fax: +86-0577-88879-012; E-mail: chenyiheng09@163.com

References

[1] Kotick JD, Sandelin RS and Klein RD. Deep inferior epigastric perforator free flaps for use in complicated groin wound repair: a case report of severe groin scar contracture and review of pedicled and free flaps in groin wound repair. J Hand Microsurg 2017; 9: 101-106.

[2] Seo BF, Choi JY, Han HH, Oh DH, Rhie JW, Ahn ST and Moon SH. Perforators as recipients for free flap reconstruction of the inguinal and perineal region. Microsurgery 2015; 35: 627-633.

[3] Ray MD, Garg PK, Jakhetiya A, Kumar S and Pandey D. Modified skin bridge technique for ilio-inguinal lymph node dissection: a forgotten technique revisited. World J Methodol 2016; 6: 187-189.

[4] Westerman ME, Tausch TJ, Zhao LC, Siegel JA, Starke N, Klein AK and Morey AF. Ventral slit scrotal flap: a new outpatient surgical option for reconstruction of adult buried penis syndrome. Urology 2015; 85: 1501-1504.

[5] Zeltzer AA, Anzarut A, Braeckmans D, Seidenstuecker K, Hendrickx B, Van Hedent E and Hamdi M. The vascularized groin lymph node flap (VGLN): anatomical study and flap planning using multi-detector CT scanner. The golden triangle for flap harvesting. J Surg Oncol 2017; 116: 378-383.

[6] Feng S, Xi W, Zhang Z, Tremp M, Schaefer DJ, Sadigh PL, Zhang W and Zhang YX. A reappraisal of the surgical planning of the superficial circumflex iliac artery perforator flap. J Plast Reconstr Aesthet Surg 2017; 70: 469-477.

[7] Scaglioni MF, Enrique Carrillo Jimenez L, Kuo YR and Chen YC. Pedicled posteromedial thigh (PMT) flap: a new alternative for groin defect reconstruction. Microsurgery 2017; 37: 339-343.

[8] Chao WN, Wang PH, Chen BR and Chen SC. Chimeric groin free flaps: design and clinical application. Microsurgery 2016; 36: 206-215.

[9] Scaglioni MF and Suami H. Lymphatic anatomy of the inguinal region in aid of vascularized lymph node flap harvesting. J Plast Reconstr Aesthet Surg 2015; 68: 419-427.

[10] Wormald JC, Balzano A, Clibbon JJ and Figus A. Surgical treatment of severe hidradenitis suppurativa of the axilla: thoracodorsal artery per-

forator (TDAP) flap versus split skin graft. J Plast Reconstr Aesthet Surg 2014; 67: 1118-1124.
[11] Ding J, Su Y, Liu S, Yang Y, Zhou B, Yu Z, Xiao B and Guo S. A mouse model of vascularized skin transplantation. Ann Plast Surg 2017; 78: 576-581.
[12] Miyamoto S, Fujiki M, Nakatani F, Kobayashi E, Sakisaka M and Sakuraba M. Reconstruction of complex groin defects after sarcoma resection. Ann Plast Surg 2017; 78: 443-447.
[13] Hummelink S, Schultze Kool LJ and Ulrich DJ. Displaying inguinal lymph nodes before transplantation in a deep inferior epigastric perforator flap breast reconstruction using an innovative projection method. J Plast Reconstr Aesthet Surg 2016; 69: 376-380.
[14] Jia Y, Xu J, Kang Q, Zhang C and Chai Y. Reverse-flow lateral tarsal island flap for covering the great toe donor site of wraparound flap. Ann Plast Surg 2016; 77: 445-449.
[15] Liu HL, Pang SY, Lee CC, Wong MM, Chung HP and Chan YW. Orthotopic transfer of vascularized groin lymph node flap in the treatment of breast cancer-related lymphedema: clinical results, lymphoscintigraphy findings, and proposed mechanism. J Plast Reconstr Aesthet Surg 2018; 71: 1033-1040.
[16] Gupta MK, Patel AP and Master VA. Technical considerations to minimize complications of inguinal lymph node dissection. Transl Androl Urol 2017; 6: 820-825.
[17] Mukai Y, Watanabe T, Sugimoto M, Kimata Y and Namba Y. Vaginoplasty with a pudendal-groin flap in male-to-female transsexuals. Acta Med Okayama 2017; 71: 399-405.
[18] Chatterjee A, Kosowski T, Pyfer B, Fisher CS, Tchou JC and Maddali S. A cost-utility analysis comparing the sartorius versus the rectus femoris flap in the treatment of the infected vascular groin graft wound. Plast Reconstr Surg 2015; 135: 1707-1714.
[19] Al-Qattan MM and Al-Qattan AM. Defining the indications of pedicled groin and abdominal flaps in hand reconstruction in the current microsurgery Era. J Hand Surg Am 2016; 41: 917-927.
[20] Tong D, Liu Y, Wu LW, Zhu S, Zhu J and Chen S. Free groin flap for aesthetic and functional donor-site closure of the anterolateral thigh flap. J Plast Reconstr Aesthet Surg 2016; 69: 1116-1120.
[21] Zelken JA, AlDeek NF, Hsu CC, Chang NJ, Lin CH and Lin CH. Algorithmic approach to lower abdominal, perineal, and groin reconstruction using anterolateral thigh flaps. Microsurgery 2016; 36: 104-114.
[22] Sato S, Nakamura Y, Teramoto Y, Yeh YW, Maruyama H, Nakamura Y, Fujisawa Y, Fujimoto M and Yamamoto A. A novel approach for inguinal lymph node dissection without inguinal skin incision for invasive extramammary paget disease. Dermatol Ther 2015; 28: 351-354.
[23] Nicoli F, Orfaniotis G, Lazzeri D, Lim SY, Kiranantawat K, Chen PY, Ciudad P, Chilgar RM, Sapountzis S, Sacak B and Chen HC. The latissimus dorsi-groin-lymph node compound flap: a comprehensive technique with three features including skin coverage, restoration of motor function, and prevention of upper limb lymphedema. Microsurgery 2016; 36: 689-694.