

Ratio of Blood Glucose Level Change Measurement for Flap Monitoring

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Background: In a setting of flap congestion, early detection and rapid reexploration are important. Some studies described the efficacy of blood glucose measurement for flap monitoring.¹ However, the sensitivity and specificity of this method were not high enough to determine whether reexploration should be done or not. The purpose of this study was to evaluate and establish a method using the ratio of blood glucose level change (RBGC) measurement for detecting venous thrombosis and to propose an algorithm for flap salvage after congestion.

Methods: Blood glucose level was measured in 36 free tissue transfers over time postoperatively and RBGC was calculated. When flap congestion was suspected, frequent blood glucose measurement and some countermeasures were performed complying with an algorithm. If the venous thrombus was suspected, the reexploration was performed. The RBGCs at the points in time when the venous thrombosis was detected were compared with those at the points in time when the flap demonstrated no venous thrombosis.

Results: Of the 36 flaps, 30 flaps demonstrated no venous thrombosis and 6 flaps demonstrated venous thrombosis. Four flaps demonstrated signs of congestion but improved after the reexploration. The mean RBGCs at the points in time when the venous thrombosis was detected was -7.61 mg/dl h and those at times when the flap demonstrated no venous thrombosis was 0.10 mg/dl h, the former being significantly lower than the latter.

Conclusion: Using the flap monitoring method using RBGC measurement, we could salvage some flaps from the congestion due to the venous thrombosis without unnecessary reexploration. (*Plast Reconstr Surg Glob Open* 2018;6:e1851; doi: 10.1097/GOX.0000000000001851; Published online 16 July 2018.)

INTRODUCTION

The improvement of microsurgical techniques and instruments, the invention of reliable flaps, and the development of flap monitoring method helped improve the success rate of free tissue transfer. Though the success rate is reported to be 95% or higher,² the problem of anastomosed artery or vein remains a major cause of tissue loss. In particular, diagnosis of venous thrombosis is still

difficult. Because salvage of the affected tissue largely depends on the time to reexploration and revascularization,³ early detection and rapid reexploration are exceedingly important, necessitating a reliable monitoring method.

Various methods have been described for monitoring transplanted tissue, including physical assessment of flap color or turgor, capillary refill, temperature, laser Doppler flowmetry,^{4,6} color duplex sonography,^{7,8} noninvasive ultrasound Doppler,⁹ an implantable Doppler system,¹⁰ near-infrared spectroscopy,^{11,12} microdialysis,^{13,14} hydrogen clearance,¹⁵ pH measurement,¹⁶ transcutaneous oxygen tension,¹⁷ photoplethysmography,¹⁸ and so on. An ideal monitoring method should be harmless to the patient and the flap, accurate and reliable, capable of providing rapid response to circulatory change, capable of being used by all personnel, reproducible, inexpensive, and portable.

Veins are susceptible to trauma or pressure because of their thin walls and fragile structures. It is well known that congestion due to venous thrombosis is more common² and more harmful to the flap than ischemia due to ar-

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terial thrombosis.^{19,20} Sakakibara et al.²¹ reported a lower blood glucose level in congestive flaps in clinical cases in 2010. In 2011, Hara et al.¹ described blood glucose measurement for flap monitoring and reported that the blood glucose level of 62mg/dl is the best cutoff value for detecting venous thrombosis, at which the sensitivity and specificity are 88% and 82%, respectively. To obtain more accurate monitoring method for flap congestion, we focused on the ratio of blood glucose change (RBGC). The purpose of this study was to evaluate and establish a simple and accurate method using RBGC measurement for detecting venous thrombosis and to consider an algorithm for flap salvage from congestion.

MATERIALS AND METHODS

Patients

Between 2016 and 2017, a total of 31 patients (36 flaps) underwent free tissue transfer or finger replantation with postoperative blood glucose measurement at the University of Tokyo Hospital. There were 16 male patients and 15 female patients. There were no diabetic patients or the patients receiving insulin. Patients' ages ranged from 9 to 85 years, with a mean age of 52.8 years (Table 1). Flap characteristics (flap indication, flap types) are listed in Table 2. Various types of flap were used thoracodorsal artery perforator (TAP) flap (n = 14), superficial circumflex iliac artery perforator (SCIP) flap (n = 12), rectus abdominis (RA) flap (n = 2), gracilis muscle flap (n = 2), deep inferior epigastric artery perforator (DIEP) flap (n = 1), fibula osteocutaneous flap (n = 1), latissimus dorsi (LD) flap (n = 1), dorsalis pedis flap (n = 1), helical rim flap (n = 1), posterior auricular flap (n = 1).

Table 1. Patient Demographics

Item	n
No. patients	31
No. flaps	36
Age, mean (range)	52.8 (9–85)
Sex, female/male	15/16

Table 2. Flap Characteristics

Flap Indication	No. of Flaps
Lymphedema	16
Cancer	8
Congenital anomaly	4
Vascular malformation	3
Trauma	2
Facial palsy	2
Burn	1
Flap types	No. Flaps
TAP flap	14
SCIP flap	12
RA flap	2
Gracilis flap	2
DIEP flap	1
Fibula osteocutaneous flap	1
LD flap	1
Dorsal pedis flap	1
Helical rim flap	1
Posterior auricular flap	1

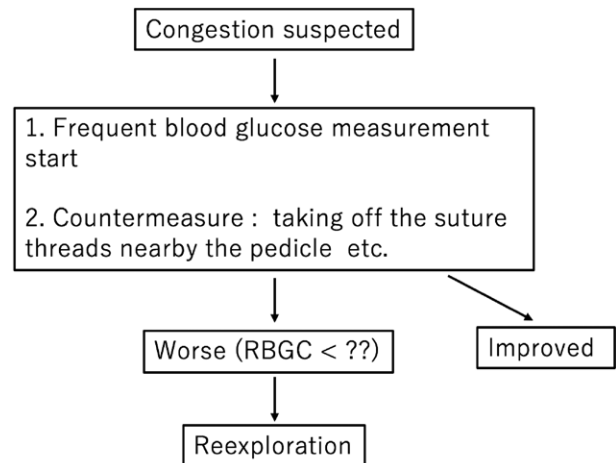


Fig. 1. The algorithm for flap salvage from congestion. RBGC: rate of blood glucose level.

Blood Glucose Measurement

Pinprick tests were performed with a 25G needle. After skin punctures were made, the blood glucose level in the flaps was measured using the Medisafe-Mini (Terumo).¹ This instrument measures the blood glucose level by a colorimetric determination method that requires only 10 μ L of blood.

Blood glucose measurements were performed immediately after the operation, 1 hour after returning to the patient's room, on the first postoperative day, and on the postoperative day 2 in all flaps. When flap congestion was suspected from gross appearance by an experienced doctor, frequent blood glucose measurement was begun and it was measured every hour. At the same time, countermeasures, such as removing the sutures nearby the pedicle, were performed complying with an algorithm (Fig. 1). If the gross appearance or blood glucose level of flaps improved after the countermeasures, hourly blood glucose measurement resumed until the flaps improved. If the gross appearance or blood glucose level of flaps worsened despite such countermeasures, venous thrombus was suspected, and reexploration was performed. And hourly blood glucose measurement resumed until the flaps improved after the reexploration. At the reexploration, we identified the pedicle of the flap and looked for venous thrombosis. If venous thrombosis was detected, thrombectomy, reanastomosis, and in some cases vein graft transfer were performed. When the bleeding after the pinprick test was insufficient for measuring blood glucose, no congestion was suspected.

RBGC

RBGC was measured in each flap. RBGC (mg/dl h) was obtained by dividing the change of blood glucose level (mg/dl) by time (h). We defined "congestion point in time" as a moment when flap congestion was suspected in each flap.

For each flap, RBGC was measured beginning from immediately after the operation until postoperative day 2. If reexploration was performed after flap congestion was suspected, RBGC from the congestion point in time to the

point in time when the reexploration was performed was measured. If congestion improved as time passed with or without any countermeasures, RBGC from the congestion point to the moment when congestion was improved was measured (Fig. 2).

Statistical Analysis

The RBGCs at the points in time when the venous thrombosis was detected were compared with those at the points in time when the flap demonstrated no venous thrombosis. The former RBGCs were calculated between the point in time when the flaps demonstrated signs of congestion and the point in time just before the reexploration. The latter RBGCs were calculated between the point in time when the flaps demonstrated signs of congestion and the point in time when congestion was improved. RBGCs were divided into 2 groups; Group 1 is the set of the congestion point when a venous thrombus developed or the flap eventually is the set of the time point when no venous thrombus was detected became necrotic. Group 2.

Statistical difference was determined using the χ^2 test. A *P* value less than 0.05 was considered significant. Data were queried using Microsoft Excel (Microsoft Corp., Redmond, Wash.). A cutoff score was determined so that the test would have the highest specificity for the prediction of venous thrombosis.

RESULTS

Of the 36 flaps, 27 flaps showed no signs of congestion postoperatively and completely survived (pattern A), 3 flaps demonstrated signs of congestion but improved

without reexploration (pattern B), 4 flaps demonstrated signs of congestion but improved after the reexploration (pattern C), and 2 flaps demonstrated signs of congestion and eventually became necrotic despite the reexploration (pattern D) (Fig. 2). The patients' demographic information is listed in Table 3.

The flaps with Pattern A demonstrated no signs of congestion, so we obtained blood sample 4 times; immediately after the operation, 1 hour after returning to the patient's room, in the morning of the first postoperative day, and in the morning of the postoperative day 2. The flaps with Pattern B, C, and D had "congestion point in time," and we obtained blood sample 3–8 times for each congestion point in time. The number of times we obtained blood sample depends on the case and time to the reexploration.

The flaps with pattern A and B demonstrated no venous thrombosis, whereas those with pattern C and D demonstrated venous thrombosis. The mean RBGCs at the points in time when the venous thrombosis was detected was -7.61 and those at times when the flap demonstrated no venous thrombosis was 0.10, the former being significantly lower than the latter.

Two flaps in pattern D were vascularized lymph node transfers for lower limb lymphedema with using TAP flap. In these flaps, venous thrombus was removed in the reexploration, but the skin paddle remained congested and eventually required debridement.

Seven time points were included in group 1, and 30 time points were included in group 2. The mean RBGC in group 1 was -7.61 and that in group 2 was 0.10, significantly lower than that in group 2 (Fig. 3).

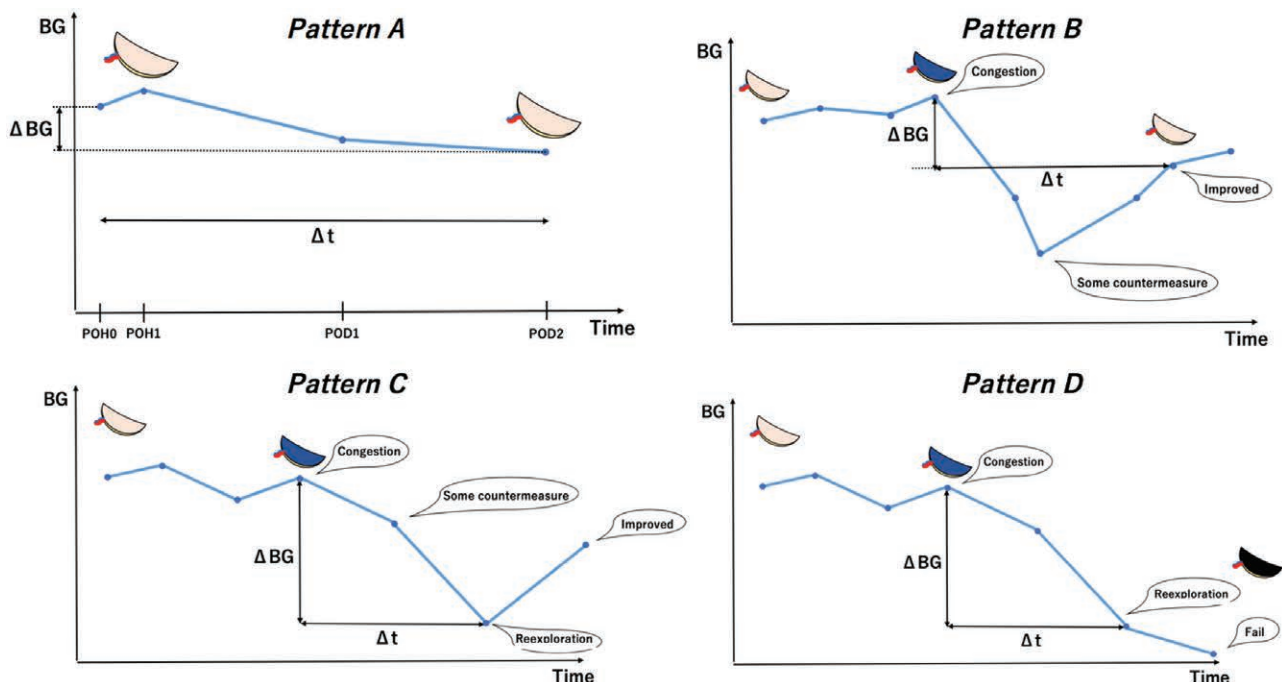


Fig. 2. The flaps of pattern A showed no signs of congestion postoperatively and completely survived. The flaps of pattern B demonstrated signs of congestion but improved without reexploration. The flaps of pattern C demonstrated signs of congestion but improved after the reexploration. The flaps of pattern D demonstrated signs of congestion and eventually became necrotic despite the reexploration. BG, blood glucose; POD, postoperative date; POH, postoperative hour.

Table 3. Patient Demographic Data

Flap No.	Age (y)	Sex	Preoperative Diagnosis	Flap	Pattern
1	85	F	Bilateral secondary lower limb lymphedema	TAP	A
2	85	F	Bilateral secondary lower limb lymphedema	TAP	A
3	12	M	Right microtia	SCIP	A
4	51	M	Bilateral primary lower limb lymphedema	TAP	A
5	44	F	Left breast cancer	DIEP	A
6	74	M	Floor of mouth cancer	LD	A
7	69	M	Right facial paralysis	Gracilis	A
8	14	F	Left microtia	SCIP	A
9	67	F	Bilateral secondary lower limb lymphedema	TAP	A
10	67	F	Bilateral secondary lower limb lymphedema	TAP	A
11	39	M	Left buccal vascular malformation	Dorsal pedis	A
12	83	M	Right facial defect due to burn	SCIP	A
13	38	M	Left hand vascular malformation	SCIP	A
14	69	F	Bilateral secondary lower limb lymphedema	SCIP	A
15	69	F	Bilateral secondary lower limb lymphedema	SCIP	A
16	9	F	Right lower limb vascular malformation	SCIP	A
17	9	F	Left microtia	SCIP	A
18	61	M	Right skull base cancer	RA	A
19	60	F	Bilateral primary lower limb lymphedema	TAP	A
20	60	F	Bilateral primary lower limb lymphedema	TAP	A
21	51	M	Bilateral secondary lower limb lymphedema	TAP	A
22	73	F	Left breast cancer	SCIP	A
23	67	F	Left secondary lower limb lymphedema	TAP	A
24	81	F	Left secondary lower limb lymphedema	TAP	A
25	74	M	Left oropharyngeal cancer	RA	A
26	57	F	Left secondary lower limb lymphedema	TAP	A
27	70	F	Right secondary lower limb lymphedema	TAP	A
28	41	M	Left lateral nasal wall cancer	SCIP	B
29	38	M	Right hand defect due to trauma	SCIP	B
30	13	F	Right microtia	SCIP	B
31	63	F	Right nasal ala cancer	Helical rim	C
32	61	M	Left mandibular cancer	Fibula	C
33	23	M	Nasal defect due to trauma	Posterior auricular	C
34	64	M	Right facial paralysis	Gracilis	C
35	77	M	Bilateral secondary lower limb lymphedema	TAP	D
36	77	M	Bilateral secondary lower limb lymphedema	TAP	D

DIEP, deep inferior epigastric perforator; TAP, thoracodorsal artery perforator.

Ratio of Blood Glucose Level Change (mg/dl·h)

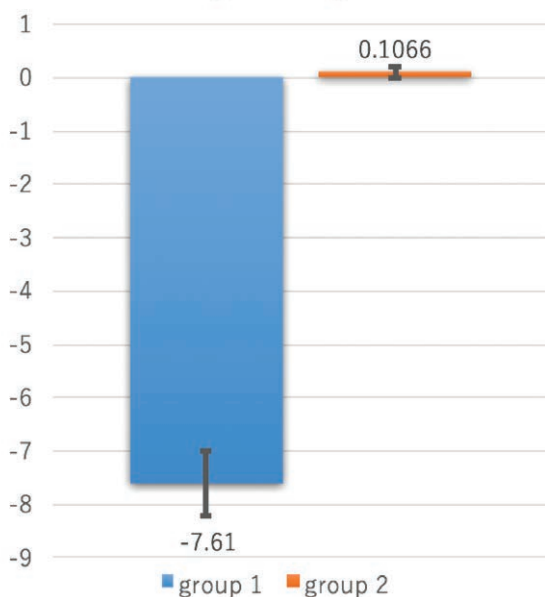


Fig. 3. The mean RBGC in group 1 was -7.61 and that in group 2 was 0.10; significantly lower than that in group 2.

CASE REPORTS

Case 1 (Pattern B)

A 41-year-old male presented with a left lateral nasal wall defect after the adenoid cystic carcinoma resection. Then the secondary reconstructive surgery was performed and the lateral nasal wall defect was reconstructed using a SCIP flap from his left groin.

Although the flap was not congestive and the blood glucose level was 92 immediately after the operation (23:00), the flap became purple and the blood glucose level was 73 in the morning of the first postoperative day (7:00). Because the flap congestion was suspected from the gross appearance and pinprick test, frequent blood glucose measurements were performed every hour, and we took off the suture threads nearby the pedicle to release the pressure on the pedicle. After the countermeasure, the blood glucose level increased hourly, and the color of the flap improved without the reoperation (11:00). At this congestion point in time, RBGC was +2.75 (Fig. 4). The flap survived completely, and the patient was satisfied with the result.

Case 2 (Pattern C)

A 63-year-old female presented with squamous cell carcinoma on the right nasal ala. Following excision of the

tumor, a total defect of the right nasal ala remained. Then the secondary reconstructive surgery was performed, and the right nasal ala defect was reconstructed using a free auricular flap from her left ear.

Although the flap was not congestive and the blood glucose level was 112 immediately after the operation (1:00), the flap became purple with the blood glucose level 80 and congestion was suspected in the morning of the first postoperative day (7:00). After we took off the

suture threads nearby the pedicle, the color of the flap became darker, and the blood glucose level was 71 (8:00) (Fig. 5). At this congestion point in time, RBGC was -9. The flap congestion due to the venous thrombosis was suspected, and the first reexploration was performed. In the operation, venous thrombus was detected and vein reanastomosis was performed. After the reexploration, the bleeding after the pinprick test was insufficient for measuring blood glucose and the color of the flap improved.

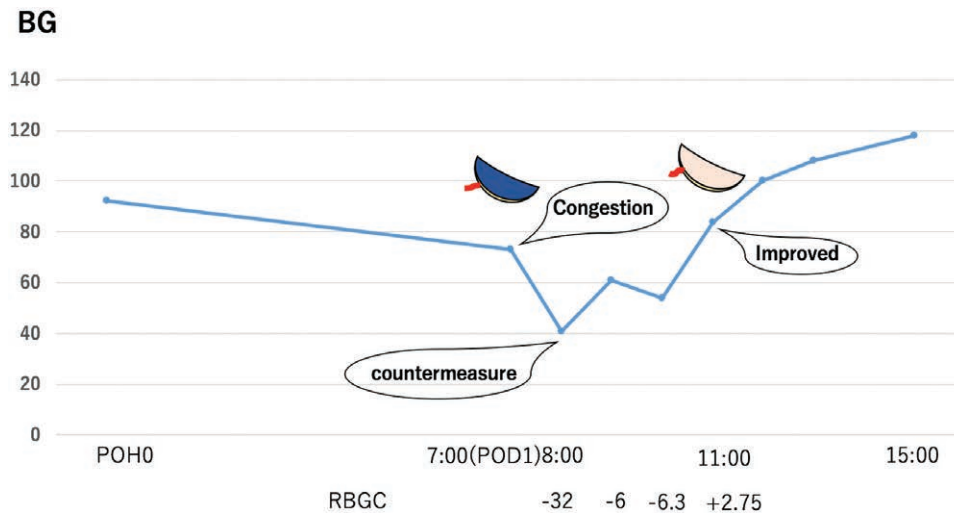


Fig. 4. Although the flap was not congestive and the blood glucose level was 92 immediately after the operation (23:00), the flap became purple and the blood glucose level was 73 in the morning of the first postoperative day (7:00). After the countermeasure, the blood glucose level increased hourly and the color of the flap improved without the reoperation (11:00). At this congestion point in time, RBGC was +2.75.

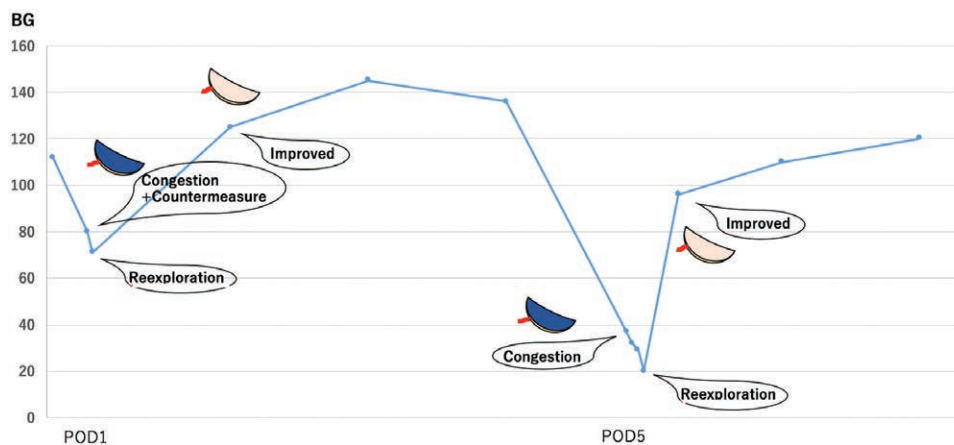


Fig. 5. Although the flap was not congestive and the blood glucose level was 112 immediately after the operation (1:00), the flap became purple with the blood glucose level 80 in the morning of the first postoperative day (7:00). After the countermeasure, the color of the flap became darker, and the blood glucose level was 71 (8:00). At this congestion point in time, RBGC was -9. The flap congestion due to the venous thrombosis was suspected, and the first reexploration was performed. After the thrombectomy, the color of the flap improved. On the postoperative day 5, the flap became purple with the blood glucose level 37, and congestion was suspected. The flap became darker with time, and the blood glucose level went down to 23 two hours after the congestion point in time. The RBGC was -4.6 at this congestion point in time. The flap congestion due to the venous thrombosis was suspected, and the second reexploration and thrombectomy was performed. After the second reexploration, the color of the flap improved with the blood glucose level increasing, and the flap survived completely.

On the postoperative day 5, however, the flap became purple with the blood glucose level 37 and congestion was suspected (Fig. 6). The countermeasure was not taken because there were no threads near the pedicle. The flap became darker with time, and the blood glucose level went down to 23 two hours after the congestion point in time. The RBGC was -4.6 at this congestion point in time. The flap congestion due to the venous thrombosis was suspected, and the second reoperation was performed. In the operation, venous thrombus was detected, and venous reanastomosis and 2 more venous anastomosis were added. After the second reexploration, the color of the flap improved with the blood glucose level increasing and the flap survived completely.

DISCUSSION

Early detection and rapid reexploration is the key success factors in salvage of a congestive flap. However, defining clinical indications for reexploration is challenging. The result of our study showed that the blood glucose level in the congested flap decreased with time; it kept on decreasing despite any countermeasures in congested flaps with venous thrombus. Therefore, the RBGC measurement is useful for monitoring flaps and helpful to determine reexploration. To the best of our knowledge, this article represents the first use of RBGC measurement for detecting venous thrombosis in clinical practice.

Several studies have reported that congestive flaps showed a decrease in the blood glucose level. In 2010, Sakakibara et al.²¹ reported the first use of a blood glucose meter for flap monitoring in diabetic patients and a lower blood glucose level in congestive flaps in clinical case.²⁰ In 2011, Hara et al.¹ described blood glucose measurement for flap monitoring and reported that the blood glucose level of 62 mg/dl is the best cutoff value for detecting venous thrombosis.²¹ However, the sensitivity and specificity are not enough for surgeons to determine whether reexploration should be done or not. Actually, we experienced completely survived flaps in which blood glucose level was less than 62 mg/dl. Some flaps showed a blood glucose level higher than 62 mg/dl at 1 time, but later it decreased rapidly, and the flap became congestive because of venous thrombosis.

What's important is distinguishing temporary congestion due to extrinsic factors such as compression of the pedicle from permanent congestion due to venous thrombus formation. This is because this differentiation directly impinges on surgeons' decision whether reexploration should be performed or not. For the salvage of temporary congestion due to extrinsic factors such as compression of the pedicle, all we need to do is address the extrinsic factor and reexploration is not necessary. For the salvage of flaps with permanent congestion due to venous thrombosis, on the other hand, the reexploration should be performed. Differentiating these 2 congestive flap statuses based on blood glucose measurement at a point in time is unreasonable. Instead, sequential

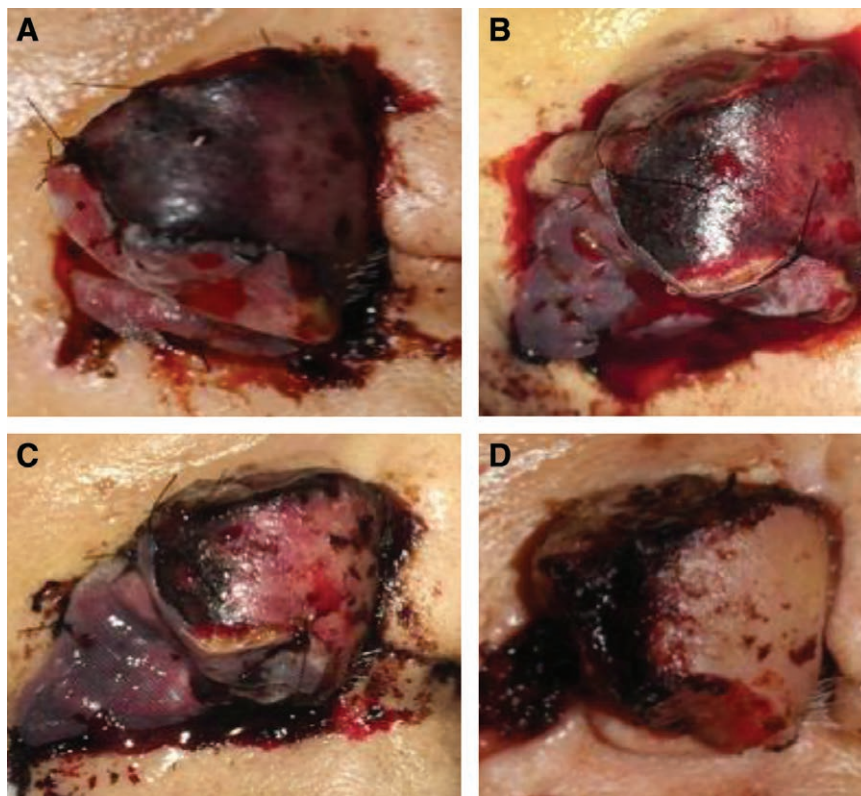


Fig. 6. The appearance of congestive flap. A) On the postoperative day (POD) 5, The flap became darker and the blood glucose level went down to 23. B) After the thrombectomy, the color of the flap improved with time. On POD6, blood glucose level was 98. C) On POD8, blood glucose level was 112. D) On POD13, the flap survived.

blood glucose measurement and RBGC calculation with the intervention such as the release of the extrinsic factors are effective. And we found that RBGC smaller than or equal to -4.5mg/dl per hour was 100% sensitive for venous thrombosis and 100% specific. Thereupon, we propose an algorithm for deciding whether reexploration is necessary in congestive flaps (Fig. 1). Using this algorithm, the salvage rate of congestive flaps due to the venous thrombus would be increased and unnecessary reexploration of flaps could be avoided.

The RBGC method described here has several advantages. First, this method is simple and highly reproducible, which can be performed by residents, nurses, and medical students. Second, it is accurate and reliable. In our study, setting the RBGC cutoff value as -4.5mg/dl per hour, 100% sensitivity and specificity could be obtained. Third, this method is inexpensive.

On the other hand, this study has several limitations. First, the patients who suffered from diabetics or received insulin were not included. It is uncertain if RBGC method can be used in diabetic patients, since the blood glucose level often fluctuates more than that of nondiabetic patients. Therefore, it may be essential to modify the blood glucose level obtained from the flap of diabetic patients, and further investigations on this study will be needed. Second, various types of flaps were included in this study. It is sure that the patterns of drainage and the tolerance to congestion varies depending on the types of flaps. For example, it is well known that free jejunal flaps are more susceptible to congestion when compared with adipocutaneous flaps. However, with regard to the change of blood glucose level, which is affected by hemodynamics, the diversity of flaps is thought to be acceptable. The paucity of cases is also a limitation of this study, but we believe the statistical significance demonstrates that the RBGC method is useful for detecting venous thrombosis. Further investigations are needed for more precise analysis.

In our study, the rate of flap failure was 5.5% (2 flaps), which was higher than that of previous study.² The 2 flaps were vascularized lymph node transfers for lower limb lymphedema using TAP flaps. The 2 flaps became necrotic despite the thrombectomy because the diameter of the recipient vein was extremely small. The technique of the vascularized lymph node transfer with TAP flap has not yet been established, and this may be the reason for higher rate of flap failure. However, using this RBGC method, venous thrombosis of these necrotic flaps could be predicted before reexploration. To put it differently, RBGC method can be helpful in detecting congestion in flaps that are still at an early stage in a learning curve.

CONCLUSIONS

The RBGC measurement of free tissue transfers provides detection of venous thrombosis with outstanding sensitivity and specificity in clinical cases. RBGC smaller than or equal to -4.5mg/dl per hour was 100% specific for venous thrombosis. RBGC method is simple, highly reproducible, accurate, reliable, and inexpensive.

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