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Reconstructive

DIY Flap Monitoring: The Glucose Index

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Background: Flap loss is reduced by monitoring, which detects vascular compromise. Glucose levels vary in suffering flaps; therefore, we aimed to show that monitoring flaps with glucose pinprick test is a cheap, reliable, ubiquitous, and easy method.
Methods: We reviewed a prospectively kept database. A pinprick test was performed to measure systemic and flap glucose levels. A glucose index (GI; flap glucose/systemic glucose) was calculated. Comparison between the groups (with occlusive event, and without occlusive event) was done.
Results: In total, 32 flaps in 29 consecutive patients were included. Eleven (34%) were free flaps. Of these, one (9%) was explored twice. Initially, salvage was achieved. However, 36 hours later, a second exploration was needed but was unsuccessful. Of the 21 pedicled flaps (66%), one (5%) needed exploration (suture release), and three (14%) had partial losses that were not clinically relevant. On the ROC curve, we found a cut-off value for a GI of 0.49 or less with a sensitivity of 95% [95% confidence interval (CI): 75.1 to 99.9%] and a specificity of 100% (95% CI: 98.5 to 100%), with a positive predictive value of 100% (95% CI: 81.5 to 100%) and a negative predictive value of 99.6% (95% CI: 97.8 to 100%) for flap suffering.
Conclusions: The GI, as a complement, assists in defining treatment approach. It is an easy, reliable, accessible method that can be performed by nonmedical personnel. Its main drawback is the inability to monitor buried or hard to reach flaps.
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INTRODUCTION

Reconstructive surgery uses flaps as means to cover defects.[1–3] Tissue vitality is dependent on blood flow.[4] Occlusive events (OEs) may occur due to thrombosis, kinking, or external compression, and early detection of these clinical scenarios is critical to ensure flap survival, as flap loss can be reduced if blood flow is rapidly restored.[5–8] Flap monitoring is essential to achieve this objective.[9,10]

The ideal monitoring method should allow early and precise detection of ischemia in a simple, intuitive, reproducible, and objective manner; it should be noninvasive or minimally invasive, and preferably, provide continuous monitoring of flap metabolism. As well, it should be low cost, ubiquitous and, ideally, distinguish arterial from venous occlusion, even though this may not be clinically relevant given that both arterial and venous occlusions should prompt exploration.[11]

Different monitoring techniques exist.[10,12] Clinical monitoring by evaluating skin color, turgor, temperature, and capillary refill is the most widely used.[9] This can be complemented with flap puncture to evaluate bleeding, and the use of a hand-held Doppler. Other available techniques include the implantable Doppler,[13] thermography,[14,15] and microdialysis, among others. However, these implements increase cost and are not widely distributed.

Delgado et al[16] in 1972 were the first to describe glucose level variations as one of the metabolic changes in suffering flaps. Other studies followed studying glucose fluctuation.[17–19] Di Lorenzo determined that a glucose ratio of 1.8–2.5 was associated with flap suffering,[20] and Hara established that a flap glucose value of less than 62 mg per dL predicts venous thrombosis, and a ratio of 0.38 or less predicts blood flow disorder.[21]

We propose that measuring systemic and flap glucose concentration with a pinprick test is a simple, ubiquitous, and low-cost method for flap monitoring. Its inexpensive cost, compared with other methods, would be a great asset in low-income countries. Our aim was to describe the relationship between systemic and flap glucose levels, measured through a pinprick test, in different clinical scenarios.

Disclosure statements are at the end of this article, following the correspondence information.

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METHODS

A retrospective analysis of a prospectively kept database was conducted. We included all patients who underwent reconstruction with a pedicled or a free flap from August 2020 to September 2021, performed by the senior author (CFS) at Hospital Universitario Austral, Hospital Británico de Buenos Aires and Hospital de Clínicas (Argentina).

Flaps with a surface area of less than 16 cm^2, those with no cutaneous paddle, or those for which the position presented a difficulty to puncture were excluded from analysis (Fig. 1). Patient characteristics and relevant medical history are summarized in Table 1. Flap characteristics, types, and indications are presented in Table 2.

Systemic and flap blood glucose were simultaneously measured by means of a pinprick test at the patient's arrival at the ward, every 6 hours the first day, every 12 hours the second day, and every 24 hours thereafter, following an internal protocol. Hourly controls were performed if flap compromise was suspected and after exploration. The registered values for flap blood glucose measurement (BGM) were analyzed. As well, a ratio was calculated between the flap BGM and the systemic glucose measurement by dividing blood glucose level in the flap by the systemic levels as performed by Hara et al[19] to obtain the glucose index (GI).

Patients were grouped by presence or absence of an OE, defined as vascular compromise resulting from thrombosis, kinking, or compression of the flap's artery or vein. Continuous variables are described as media and SD, and qualitative variables as percentage. Mann-Whitney

Takeaways

Question: Can flaps be monitored in a reliable way by comparing the glucose level in the flap and the systemic glucose level measured by a pinprick test?

Findings: In this study, we simultaneously measured glucose levels in the flap and capillary systemic glucose via a pinprick test, and calculated the glucose index (GI; flap glucose/systemic glucose). Flaps with an occlusive event were found to have a statistically significant lower GI value. If the GI is less than 0.49, an occlusive event is very likely.

Meaning: The GI is a reliable adjunct to flap monitoring. It is ubiquitous; cheap; and easy to learn, do, and interpret.

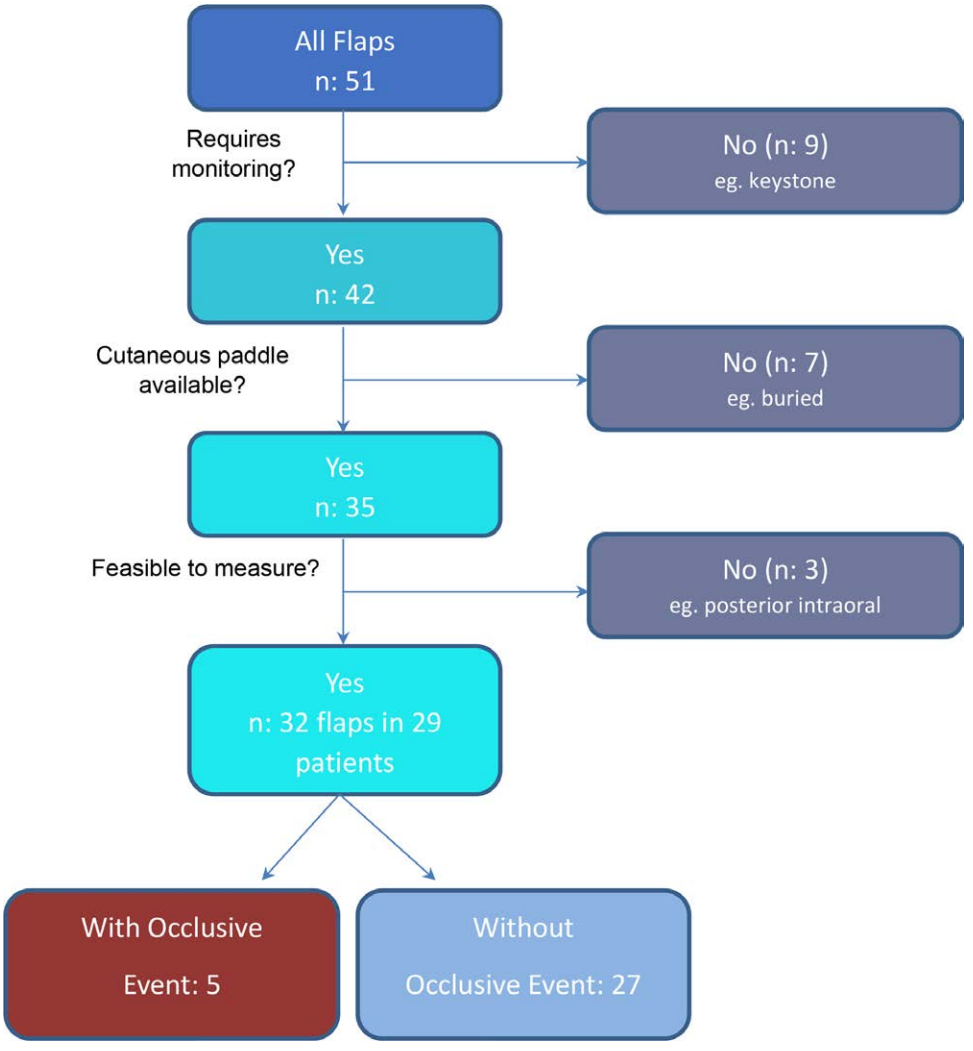

Fig. 1. Flow chart: patients included and excluded.

Table 1. Patient Demographics

	All	With OE	Without OE	*P*
No. flaps (n)	32	5	27	
Age (mean) ± 1SD	47.1 years	48.6 ± 25.1 years	46.8 ± 22.7 years	0.88
Gender				
Male (%)	12 (37.5%)	3 (60%)	17 (63%)	0.99
Female (%)	20 (62.5%)	2 (40%)	10 (27%)	
BMI (mean) ± 1SD	25.7	26.7 ± 5.9	25.5 ± 5.1	0.62
Chemotherapy				
No (%)	23 (72%)	5 (100%)	18 (67%)	0.29
Yes (%)	9 (28%)	0 (0%)	9 (33%)	
Radiotherapy				
No	25 (78%)	5 (100%)	20 (74%)	0.56
Yes	7 (22%)	0 (0%)	7 (26%)	
Hypertension				
No	24 (75%)	3 (60%)	20 (74%)	0.60
Yes	8 (25%)	2 (40%)	7 (26%)	
Diabetes				
No	24 (75%)	4 (80%)	20 (74%)	0.99
Yes	8 (25%)	1 (20%)	7 (26%)	
Smoking				
Never	22 (68.75%)	3 (60%)	19 (70.4%)	0.90
Current	4 (12.5%)	0 (0%)	4 (14.8%)	
Former	6 (18.75%)	2 (40%)	4 (14.8%)	

Both chemotherapy and radiotherapy are previous to surgery. *P* value calculated comparing group with OE versus without OE. *P* value calculated for: (1) age and BMI: Aspin-Welch *t* test; (2) sex, radiotherapy, chemotherapy, hypertension, diabetes: Fischer exact test; (3) Smoking: chi square for a 2×3 table.

Table 2. Flap Characteristics

Characteristic	No. (%)	With OE	Without OE	*P*
No. flaps	32	5	27	
Flap indication				
Trauma	2 (6.3%)	1 (20%)	1 (3.7%)	0.29
Cancer	19 (59.3%)	3 (60%)	16 (59.3%)	0.99
Infectious	4 (12.5%)	1 (20%)	3 (11.1%)	0.51
Other	7 (21.9%)	0 (0%)	7 (25.9%)	0.56
Procedures				
Free flaps	11 (34%)	1 (20%)	10 (37%)	0.63
Pedicled flaps	21 (66%)	4 (80%)	17 (63%)	0.63
Flap type				
Anterolateral thigh flap	4 (12.5%)	0 (0%)	4 (14.8%)	0.99
Latissimus dorsi flap	5 (15.6%)	0 (0%)	5 (18.5%)	0.56
RFFF	3 (9.4%)	0 (0%)	3 (11.1%)	0.99
Fibula flap	5 (15.6%)	1 (20%)	4 (14.8%)	0.99
Other	15 (46.9%)	4 (80%)	11 (40.8%)	0.16

U and Fischer exact tests were used to compare both groups. ROC curve was used to calculate the cut-off value for the GI and for the net BGM in the flap, to predict an OE. Statistical significance was considered if *P* was less than 0.05. GraphPad Prism 8.2 was used to perform this analysis.

RESULTS

Fifty-one flaps were performed in 47 patients during this period. In total, 19 flaps were excluded according to our exclusion criteria (Fig. 1). Thirty-two flaps in 29 patients were included for analysis. Of these, 21 (66%) were pedicled, and 11 (34%) were free flaps. In total, five flaps suffered an OE (15.6%). Regarding pedicled flaps, one (5%) needed exploration, three (14%) had partial loss (not clinically relevant), and no complete losses were registered. From the free flaps, one (9%) was revised twice (Fig. 5). Tables 1 and 2 summarize patient and flap characteristics. There were no statistically significant differences in patient demographics or flap characteristics when comparing the group with OE with the group without OE.

The independent variables we analyzed were the net BGM of the flap and the GI value, as a relationship between the flap and systemic glucose. Flaps were assigned to either the OE group or non-OE group depending on their clinical development.

To compare the GI levels between the groups, we used a Mann-Whitney *U* test, and established that there is a statistically significant difference ($P < 0.0001$) (Fig. 2). ROC analysis determined, with an area under the curve

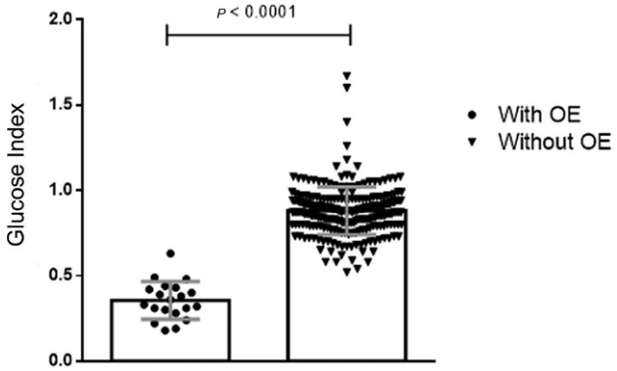

Fig. 2. Mann Whitney test. There is a statistically significant difference in the glucose ratio values of flaps with OEs compared with those without OEs.

Table 3. Analysis for Two Different Cut-off Values: Their Sensitivity, Specificity, and Positive and Negative Predictive Values

	Cut-off Value ≤ 0.49	Cut-off Value ≤ 0.63
Positive predictive value (%)	100	71.5
95% CI	81.5–100	50.6–87.3
Negative predictive value (%)	99.6	100
95% CI	97.8–100	98.5–100
Sensitivity (%)	95	100
95% CI	75.1–99.9	83.2–100
Specificity (%)	100	97.2
95% CI	98.5–100	94.3–98.9

Analysis for two different cut-off values: their sensitivity, specificity, and positive and negative predictive values.

(AUC) of 0.999 [95% confidence interval (CI) = 0.996–1.000], that a GI of 0.63 or less could predict flap suffering with 95% sensitivity and 100% specificity. As shown in Table 3, we also analyzed GI of 0.49 or less as a cut-off value with excellent values, increasing the specificity to 100% (95% CI = 100%–98.5%) and positive predictive value to 100% (95% CI = 100%–81.5%) without significantly altering the sensitivity, making a GI of less than 0.5 (same as GI ≤ 0.49, but simpler to remember) our value of choice.

Regarding the net BGM, the mean value in the OE group was 56 mg per dL, whereas in the noncompromised flap group, the mean net BGM was 111 mg per dL. A *t* test showed a statistically significant difference ($P < 0.00001$). In the ROC analysis (Fig. 3), a cut-off value for net BGM of 0.54 mg per dL or less was found to predict flap suffering regardless of

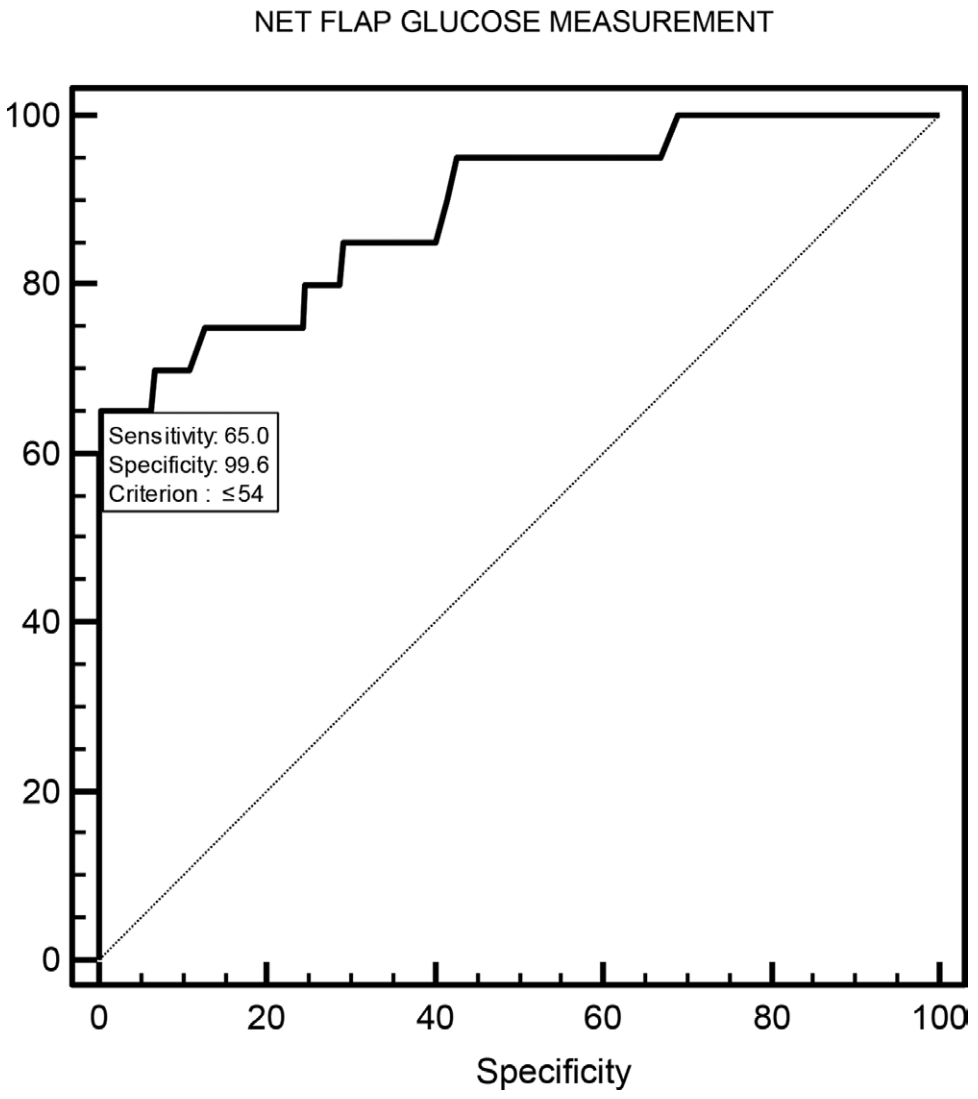

Fig. 3. ROC curve analysis for the net value of flap glucose measurements. A cut-off value of 54 mg per dL has a sensitivity of 65% (95% CI: 40.8%–84.6%) and a specificity of 99.6% (95% CI: 97.8%–100%) to detect flap compromise, with an AUC of 0.889 (95% CI: 0.802–0.975) with a significance level of *P* less than 0.0001.

the index, with an AUC of 0.889 (95% CI = 0.802–0.975), a sensitivity of 65%, and specificity of 99.6% (Fig. 3).

We present three different clinical scenarios we encountered throughout this initial experience, which show how the variations in the GI relate to vascular compromise and our approach to each case. (Figs. 4–6).

DISCUSSION

Flaps require a patent vascular supply to survive. Events that compromise blood flow like thrombosis, kinking of the pedicle, or external compression (ie, hematoma) are considered occlusive. To ensure flap survival, adequate planning, management of patient comorbidities, meticulous flap dissection, and strict postoperative monitoring of the flap are required.[9,10]

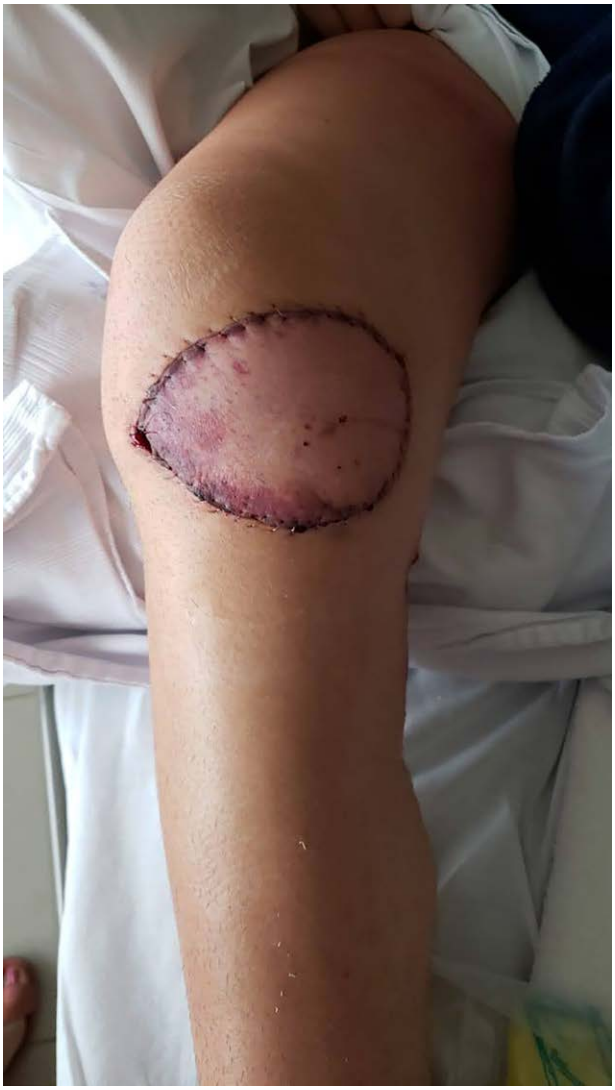

Fig. 4. Clinical scenario #1: Solving the issue. Patient with liposarcoma of the knee, who underwent resection and was reconstructed using a medial sural artery perforator (mSAP) flap. On the 18-hour monitor: flap glucose level, 26 mg per dL; systemic glucose, 109 mg per dL; GI, 0.24. The flap had normal color, temperature and turgor with a slightly fast capillary refill indicating a probable venous compromise. Two stitches were removed from the overlying closure of the pedicle's tunnel. After 30 minutes, flap glucose was 38 mg per dL, and at 60 minutes, 52 mg per dL. Capillary refill improved.

In an OE, time is of the essence, given that flap survival is inversely proportional to ischemia time.[4–8] Strict monitoring of flaps reduces flap loss through early detection of vascular compromise.[9,10] The ideal monitoring method should allow early and precise detection of ischemia in a simple, intuitive, reproducible, and objective manner; it should be non- or minimally invasive and, preferably, provide continuous monitoring of flap metabolism. As well, it should be low cost; ubiquitous; and, ideally, capable of distinguishing arterial from venous occlusion. This latter requirement may not be clinically relevant given that both types of occlusions should prompt exploration.[11]

When blood flow is altered, tissues change to an anaerobic metabolism. In 1972, Delgado et al[16] demonstrated the metabolic changes that occur in suffering flaps using microdialysis. After this experience, other studies on flap metabolic changes followed.[22,23] In 1989, Heden et al[24] showed that glucose uptake was increased in pig skin flaps in venous and arterial occlusions. In 2010, Sitzman et al[17] published that glucose levels descended 15 minutes after occluding flap pedicles on rats. That same year, Sakakibara et al[18] reported low glucose levels in patients with congestive flaps.

In this study, we analyzed two variables: GI and net flap BGM. Measurements were done on the flap and patient's finger (systemic) using a One Touch Ultra Mini glucometer (or similar device), available in hospital wards. These need 10 µL of blood, obtained by puncturing the skin with a 25G needle, to determine glucose levels by means of a colorimetric method.

We compared two groups: the OE group and non-OE group, which in this study share similar characteristics, including diabetes, allowing us to say that the difference found in the GI and BGM is due to the OE and not due to other factors (Tables 1 and 2). However, we are aware that the sample is small.

Glucose Index

The GI, being a ratio, accounts for the influence of the systemic glucose level; thus, it is more reliable compared with solely taking the net BGM of the flap, as proposed by Hara et al[21] and Henault et al,[25] especially for patients who are diabetic or are not fasting. This is particularly helpful because it can be used ad hoc.

In accordance with Hara et al,[19] the GI shows a significant descent in patients with suffering flaps. Hara et al reported a cut-off GI value of 0.38 or less, with a sensitivity of 87% and a specificity of 93%. In this study, a higher cut-off value has been established at GI less than 0.5 (as shown in Table 3 under ≤0.49), with 95% sensitivity and 100% specificity, better than that reported by Hara et al.

Di Lorenzo and Corradino[20] calculated the index inverting dividend and divisor, so their ratio ranges from 1.8 to 2.5, which is comparable to our findings. To further explain, a GI less than 0.5 implies that the flap's glucose is

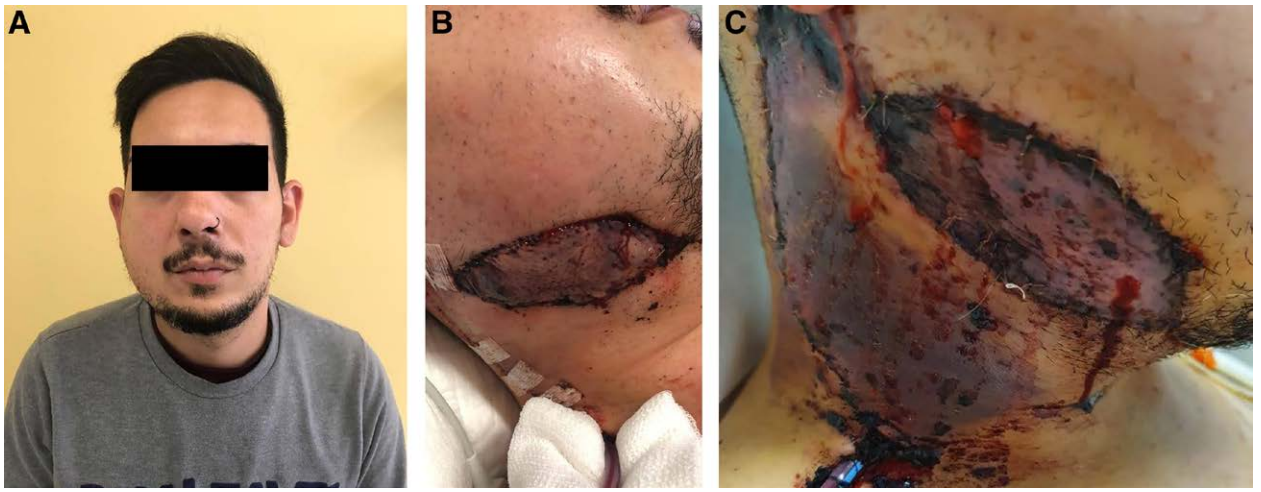

Fig. 5. Clinical scenario #2: Monitoring a suffering paddle. Patient presents with an exposed and infected mandibular reconstruction titanium plate from a prior ameloblastoma resection (A). Reconstruction with free fibula flap. At 36-hour monitor the flap looked congested and the measurements were as follows: flap glucose level, 24 mg per dL; a systemic glucose, 133 mg of dL; GI, 0.18. Exploration showed extensive venous thrombosis, which was treated. The skin paddle was bluish, and with hematoma due to the thrombosis and clinically, the paddle could not be used for monitoring (B). BGM and increasing GI reassured us that the flap was viable. At 60 hours after exploration, BGM and GI descended once again. C, A second exploration was performed, but flap salvage was not possible.

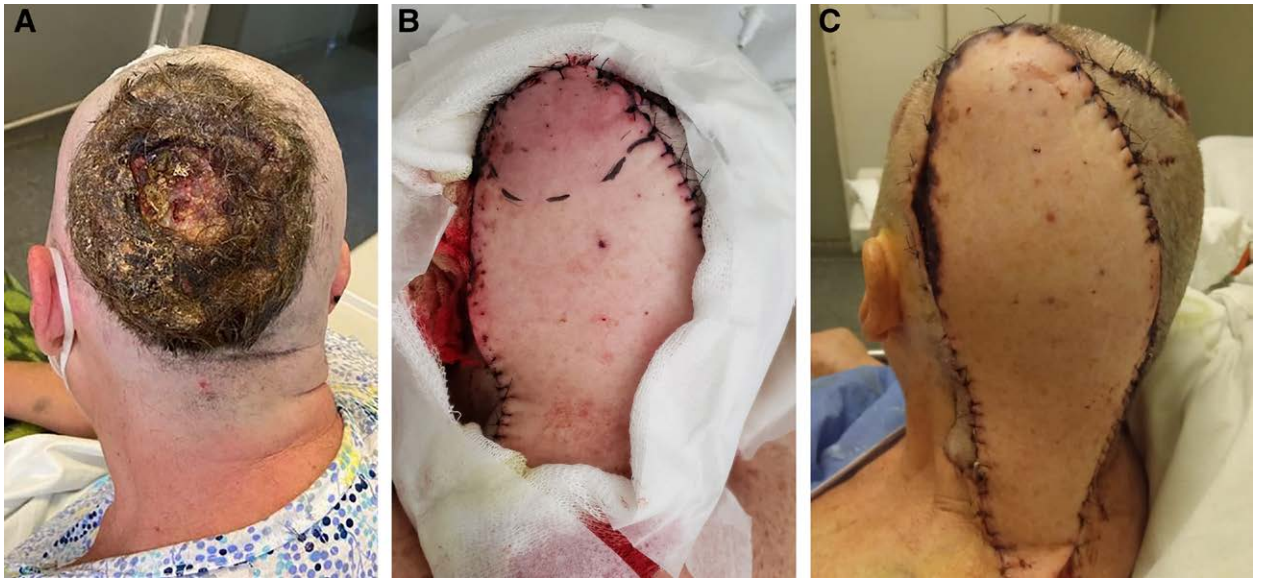

Fig. 6. Clinical scenario #3: Half & half. Patient with symptomatic scalp squamous cell carcinoma that invaded skull and dura, that she did not treat due to the pandemic (A). A wide resection was performed, and the defect was reconstructed using a large trapezius flap. During the first 24 hours, a clear line developed in the flap (B). It was divided into two zones: the proximal area looked vital and had a GI above 0.65 and the distal area had a fast capillary refill and a GI of 0.49, which trended down. Stitches were released in the periphery and pedicle tunnel. The area that suffered was reduced and circumscribed to the edges (C).

half the value of systemic glucose, and a value of 2 for Di Lorenzo and Corradino would imply that the systemic glucose is twice the value of the flap's glucose. This finding also correlates with the finding by Hara et al of 0.4 (40% of systemic value), meaning that the systemic glucose is 2.5 times higher than the flap's value. Thus, the range reported by Di Lorenzo and Corradino includes our cut-off value and the cut-off value reported by Hara et al. In correlation to the findings of Karakawa et al, a downward trend in the GI should prompt an alarm.[26]

Sakakibara et al state that a high sensitivity should be given priority in establishing the cut-off value, over a high specificity.[18] This would incline us to use a GI of 0.63 or less as a cut-off value (which has a sensitivity of 100%) instead of 0.49 or less (which has a sensitivity of 95%). However, using a higher sensitivity would imply detecting all of the OEs, but some of those detected would not actually be an OE, and a highly specific test would be needed to confirm. On the other hand, a GI of 0.49 or less has a very good sensitivity, combined with an excellent positive predictive

value of 100%. Given that the flap salvage rates are generally low,[27] we suggest using a GI of 0.63 or less as an initial alarm to prompt stricter monitoring, and a GI of 0.49 or less as a strong factor to consider exploration despite no other sign of suffering being present. To our knowledge, this is the first study to compare GIs between suffering and viable flaps.

Flap Glucose Measurement

In regard to the net BGM in the flap, Hara et al[21] established that BGM less than 62 mg per dL in the flap predicts venous thrombosis with a sensitivity of 88% and specificity of 82%. In this cohort, ROC analysis established a value of 54 mg per dL to predict an OE with specificity of 99.6% but with a low sensitivity at 65%. To improve sensitivity up to 90%, the cut-off value should be 102 mg per dL, which could not be used in clinical practice because that value lies within the normal range of a fasting glucose. Thus, we do not recommend using the net BGM as a stand-alone value.

Karakawa et al[26] measured BGM in flaps in a manner similar to that of Hara et al but calculated that a rate of decrease of -7.61mg per dL per hour in the values of BGM predicted flap suffering. It is worth mentioning that no diabetic patients were included. In correlation, we also evidenced a downward trend in the BGM. The ratio of decrease reported by Karakawa et al could be used instead of the net BGM.

Clinical Scenarios: Lessons Learned

In scenario #1, the GI aided in the detection of suffering when the only clinical evidence was a slightly faster capillary refill. Compression was suspected, and bedside suture release was performed. The GI was an objective parameter in the immediate follow-up, showing an upward trend. This flap may have been lost otherwise. We propose that further studies should be done with more frequent controls to establish if the GI is reliable in predicting suffering earlier than other methods.

In case #2, the GI fell before the appearance of clinical manifestations of suffering. A critical GI value and the appearance of a bluish color determined the exploration. After flap salvage, the skin paddle was altered (patchy bruises; Fig. 5), so clinical monitoring was rendered impossible. GI measurements were vital to flap monitoring, with an upward trending curve in the immediate postoperative period. However, trends descended 36 hours later, prompting a new exploration, which was not successful. The GI is useful to monitor a flap with an altered cutaneous paddle.

Clinical scenario #3 showed us that GI and BGM may vary within the flap, and these variations match with areas of clinical suffering. As a result, those areas with low GI represent partial loss regions. This is more applicable to pedicled flaps and supports the decision-making.

Further studies with a larger number of patients are needed; also, considering flap volume and increasing the frequency of flap monitoring would be beneficial. New technology, like continuous glucose monitoring sensors, could be contemplated for more inaccessible flaps.[28] The GI is a good complement to existing monitoring techniques; however, it cannot be used in buried flaps.

CONCLUSIONS

Early detection and rapid exploration are the key success factors in salvage of a congestive flap. Defining clinical indications for exploration is challenging, whereas measuring blood glucose is a simple, low-cost technique that can be performed bedside in a repeated way, using equipment that is available in any hospital ward by any healthcare worker. For these reasons, it is a remarkable method to detect flap compromise, to prompt an earlier exploration and, thus, attain higher flap salvage rates. We have included it as a standard in our daily practice and recommend its use, particularly in low-income countries where other methods may not be available.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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This study has been approved by the hospital's institutional review board.

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