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ORIGINAL ARTICLE
Reconstructive

Equivalence in Color-coded Duplex Sonography Parameters before Complex Microsurgery

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Background: Color-coded duplex sonography (CCDS) is a widely proposed noninvasive diagnostic tool in microsurgery. CCDS has been applied to lower extremity salvage cases to define appropriate blood flow velocity criteria for achieving arterial success in diabetic foot and complex microsurgery cases. This study aimed to compare the success ratio of free flaps when using CCDS versus cases where CCDS was not used.

Methods: We included complex microsurgery cases from 2019 to 2021. These cases were subsequently categorized into two groups: group A consisted of cases where CCDS parameters were applied, whereas group B comprised cases where CCDS was not performed at all.

Results: The study encompassed 14 cases (11 men and three women). The age range varied from 23 to 62 years, with an average age of 42. Using CCDS analysis and planning demonstrated improved outcomes in comparison with cases where CCDS was not performed, albeit without statistical significance ($P = 0.064$).

Conclusions: The application of CCDS proves to be beneficial in the realm of microsurgery. Although not achieving statistical significance, our data imply that CCDS utilization holds promise for enhancing microsurgical procedures. *(Plast Reconstr Surg Glob Open 2023; 11:e5399; doi: 10.1097/GOX.0000000000005399; Published online 15 November 2023.)*

INTRODUCTION

Imagine an electric current flowing through a light bulb. If the current surpasses the bulb's capacity, the bulb bursts, and if the current falls short, the bulb remains off. However, with the right amount of electricity, the bulb functions properly. In this comparison, the electric current signifies arterial circulation, and the light bulb represents a free flap. Nevertheless, this analogy lacks a crucial component: venous drainage. In microsurgery, emphasizing both arterial and venous circulation is essential for success.

Color-coded duplex sonography (CCDS) serves as a widely used noninvasive diagnostic tool in the field of microsurgery. Hong et al[1,2] extensively detailed the utilization of CCDS in cases involving limb salvage, establishing appropriate blood flow velocity (BFV) thresholds for achieving arterial success in scenarios like diabetic foot and complex microsurgery. Time-average flow velocity acts as an indirect parameter for estimating endothelial function.[3] Moreover, it serves as a physiological indicator, with the potential to forecast the success of free flaps in intricate microsurgery.[2] When the BFV in the recipient artery surpasses 15 cm per second, it ensures successful blood flow to the flap.[2] The implementation of CCDS takes place preoperatively a few days before reconstruction, during which all pertinent values (which are described later) are recorded. Subsequently, the flap and recipient vessels are chosen based on these registered values.

Numerous instances in microsurgery present complexity, and we classify such instances as those in which alterations in BFV of the recipient artery or vein occur. Additionally, cases where the recipient vessels have inadequate diameters that do not align with flap vessels are also deemed complex. In our context, intricate reconstructive cases often arrive at the emergency room, and our operations take place within the constraints of limited resources in a developing country.

The challenge lies in conducting reconstruction under the pressure of directives to achieve optimal outcomes with minimal procedures for patients. This study aimed to juxtapose the success ratio of free flaps when using CCDS against cases where CCDS was not used.

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Takeaways

Question: Could color-coded duplex sonography (CCDS) help prevent making incorrect decisions in complex microsurgery cases?

Findings: Sometimes, recipient vessels exhibit compromised blood flow, or the recipient vein might not be the optimal choice. In such scenarios, using CCDS can greatly assist in accurately identifying vascular anatomy. This precise identification serves to prevent erroneous decisions in intricate microsurgery cases.

Meaning: Using CCDS as a diagnostic adjunct provides valuable data and enhances precision of microsurgical planning.

PATIENTS AND METHODS

The study was conducted in accordance with the stipulations of the Declaration of Helsinki 1964 and the requirements outlined in the General Law of Health of Mexico City, and was approved by the institutional ethical committee. Furthermore, all patients involved in the study provided their informed consent, both for undergoing procedures and for the utilization of their data in subsequent publications.

For inclusion criteria, we specifically opted for cases involving complex microsurgery, excluding more commonplace instances of microsurgical reconstruction. The selection encompassed complex microsurgery cases from the period spanning 2019–2021. Subsequently, these cases were categorized into two distinct groups: group A consisted of cases where CCDS parameters were implemented, whereas group B included cases where CCDS was not used at all.

The considered variables encompassed age, gender, localization of wound defect, reconstruction type, chosen flap, implementation of CCDS planning, heart rate frequency, instances of re-operation, surgery duration, flap ischemia duration, various preoperative and postoperative blood parameters, estimated blood loss, average patient temperature, mean arterial pressure, average oximetry levels, whole blood viscosity, urinary outflow, utilization of vasopressors (ephedrine or adrenaline), and ultimately, the outcome, characterized as positive for flap success (including partial loss <20%) and negative for flap loss.

STATISTICAL ANALYSIS

Data collection was electronically executed through Microsoft Excel within the Microsoft Office suite (Microsoft Corp., Redmond, Wash.), and statistical analysis was conducted using R-Studio. Descriptive statistics were used to portray measures such as mean and SD, among others. These statistics are accompanied by 95% confidence intervals (CIs) with a 5% margin of error. Numerical comparisons between groups were assessed using the *t* test, whereas categorical variables were subjected to the chi-square test. Moreover, an odds ratio for an additional outcome was computed to ascertain whether any other confounding factors might contribute to potential bias.

CCDS PARAMETERS EXPLAINED

A. *Blood Vessel Diameter*: Blood vessel diameter, both arterial and venous, can be estimated in either one or two dimensions, observed longitudinally or in an axial view. In our protocol, we strive to achieve a recipient arterial candidate diameter ratio of less than 2:1. In situations where venous recipient candidates are not viable, we aimed to maintain at least three potential options. The primary choice is the comitant venous vessel, followed by an adjacent venous vessel as the second option. The third option involves a superficial vein, which typically possesses a diameter larger than that of the comitant donor vein. In specific cases, an anastomosis with a considerable discrepancy, such as 4:1, has been conducted, always ensuring the recipient vessel's diameter surpasses that of the donor vessel. Notably, an anastomosis involving a recipient vein smaller than the donor vein is never performed (Fig. 1).

B. *Blood Vessel Wall Thickness*: This parameter holds significance, particularly for patients with a history of diabetes or hypertension, as they might have peripheral arterial disease marked by vessels exhibiting endothelial damage. Arterial wall thickness serves as a valuable indicator, potentially revealing the presence of arteriosclerosis or endothelial inflammation within the vessel. Hence, when encountering an acoustic shadow that indicates calcification or arteriosclerosis, an alternative recipient vessel is chosen.

C. *Vein or Arterial Thrombosis*: Blood thrombosis can be suspected based on variations in BFV (whether an increase or decrease). For instance, envision a scenario with a water hose being partially obstructed; this causes an elevation in water pressure, subsequently accelerating the water's speed upon exit. In microsurgery, this hydrodynamic parameter proves valuable. At times, a thrombus can be visibly present within the vessel, whereas in other cases, its visibility is obscured. In instances where the thrombus is not observable,

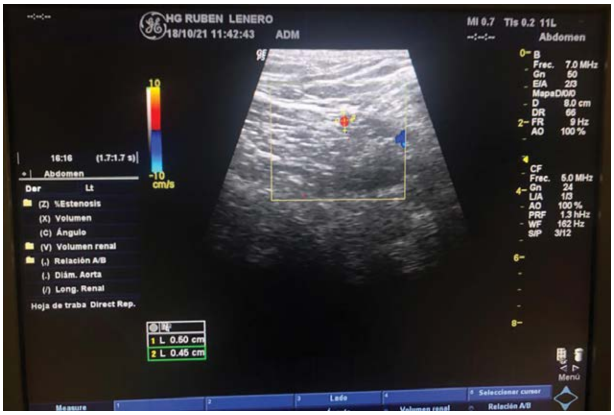

Fig. 1. Dimensional aspects of a blood vessel's diameter. Our measurements encompass both the inner and outer diameters, providing a reference for assessing wall thickness.

fluctuations in flow velocity become evident, indicating that the vessel might not be the most suitable option.

D. *Blood Flow Velocity*: An optimal BFV measures above 15 cm per second,[2] aiming to establish equivalence between the recipient and donor vessels. Equivalence is pivotal because larger flaps or composite flaps necessitate increased oxygen and ATP delivery (Fig. 2). Consistency in flow velocity measurement is maintained through uniform methodology. If the linear transducer is oriented at 90 degrees to the recipient vessel, the same approach is followed for the donor vessel. Uniform ultrasound placement parameters are maintained to mitigate operator errors. We strive to identify closely aligned values between the flap and recipient vessels.[3–5] Patient-specific factors such as heart rate and blood pressure must be factored in; individuals with bradycardia or hypotension may exhibit distinct flow velocity values. Similarly, fever in a patient may manifest systemic inflammatory responses that could introduce bias during ultrasound assessment.[6–11]

E. *Theoretical Pedicle Length*: This is determined by measuring the distance from the wound center to the selected recipient vessels.[12–14] Following the flap pedicle to the main vessel allows us to assess its adequacy. In intricate cases, achieving equivalence among these values might be challenging, prompting us to incorporate solutions like venous grafts into the plan. This comprehensive approach helps prevent unexpected complications during surgery. Our primary goal is meticulous preoperative planning to minimize improvisation and reduce the number of decisions required in the operating room. This strategy aims to curtail surgical duration, alleviate stress, and prevent surgeon fatigue (Fig. 3).

Fig. 2. Display of the data representing an illustrative example of BFV.

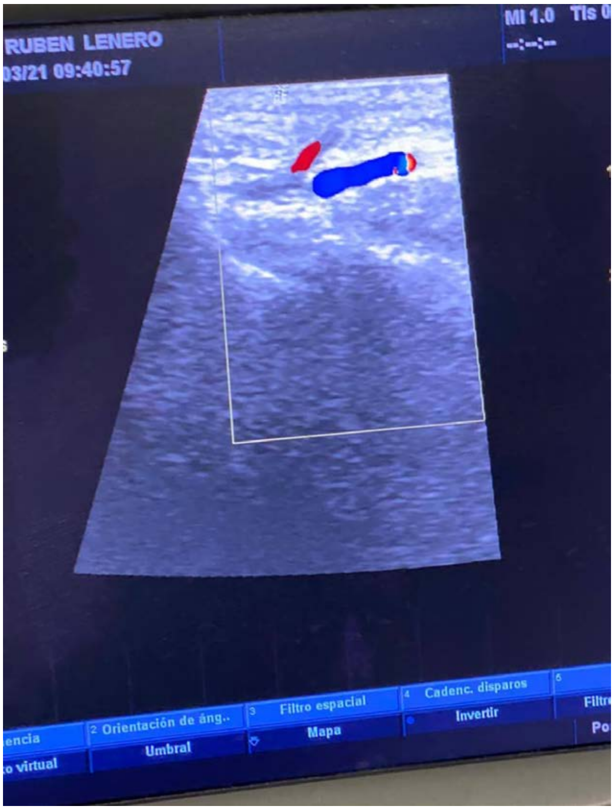

Fig. 3. Elucidation of our process of tracing the trajectory of perforators to assess anatomical placement (muscular or septal) and highlight various potential anatomic variations encountered during perforator dissection.

RESULTS

A total of 22 cases were assessed during the specified period, of which eight were excluded for not meeting the inclusion criteria. The final study encompassed 14 cases, comprising 11 men and three women (Table 1). Patient ages ranged from 23 to 62 years, with an average of 42. Among the performed flaps, the anterolateral thigh flap (ALT) was the most prevalent, accounting for five cases. Additionally, three latissimus dorsi free flaps were executed, whereas the remaining cases involved different flap types.

Recipient artery diameters had an average of 2.65 mm (range 1.2–3.4 mm), whereas venous diameters averaged 3.12 mm (range 1–4.4 mm). The donor artery diameter had an average of 1.12 mm (range 1.6–4 mm), and the venous diameter measured 3.23 mm (range 3–6.3 mm). Mean BFV for donor arteries was 15 cm per second, and for recipient arteries, it averaged 18 cm per second. Reintervention was required in six cases. Whole blood viscosity[15–20] exceeded normal levels in seven cases. Ephedrine was administered in two instances due to hypotension, and epinephrine was used once for the same reason. Six cases resulted in total free flap loss, necessitating additional reinterventions. Importantly, no flap losses were observed within the CCDS group (Table 2).

Table 1. Sample of Flaps Used for This Study

No.	Age	Sex	Diagnostic	Mechanism of Injury	Wound Region	Gustilo-Anderson	Flap Performed	CCDS	Outcome
1	27	M	Wound	Crush injury	Left foot	IIIB	ALT	No	Flap success
2	56	M	Wound	Electric burn	Scalp	Not apply	Free radial forearm flap	No	Flap success
3	27	F	Wound	Bullet wound	Right hand	Not apply	SCIP & ALT	No	Flap loss
4	23	F	Wound	Scald burn	Left shoulder	Not apply	ALT	No	Flap success
5	47	M	Wound	Motorcycle accident	Left hand	IIIB	Free latissimus dorsi flap	No	Flap loss
6	62	M	Wound	Electric burn	Left foot	Not apply	ALT	No	Flap loss
7	47	F	Wound	Mucromicosis	Upper third face	Not apply	Free latissimus dorsi flap	No	Flap loss
8	48	M	Wound	Motorcycle accident	Left leg	IIIB	ALT	No	Flap loss
9	59	M	Wound	Car accident	Right ear	Not apply	Free radial forearm flap	Yes	Flap success
10	50	M	Wound	Electric burn	Right leg	Not apply	ALT	Yes	Flap success
11	49	M	Wound	Car accident	Left leg	IIIB	Free latissimus dorsi flap	Yes	Flap success
12	38	M	Wound	Car accident	Oral cavity	IIIB	Free fibula flap	No	Flap loss
13	30	M	Wound	Dog bite wound	Scalp	Not apply	Free latissimus dorsi flap	Yes	Flap success
14	25	M	Wound	Motrcylce accident	Right hand	IIIB	Lateral arm flap	Yes	Flap success

SCIP, superficial circumflex iliac artery perforator.

Table 2. Variables of the Study

Age	Minimum	23	
	Maximum	62	
	Median	47	
	Mean	42	
Sex	Male	11	
	Female	3	
Flap used	ALT	5	
	Latissimus dorsi	2	
	Lateral arm	1	
	Fibula	1	
	Other	5	
Vessel diameter (in mm)			
Receptor artery	2.65		
Recipient vein	3.12		
Donor artery	1.12		
Recipient vein	3.23		
CCDS performed	Group 1	Yes	5
	Group 2	No	9
Equilibrium in blood flow velocity		Yes	5
		No	9
Blood flow velocity (in cm/s)			
	Receptor artery	18	
	Recipient vein	15	
Re-interventions		Yes	6
		No	8
Whole blood viscosity (in 0.5 s^{-1})		>5	7
		<5	7
Ephedrine		Yes	2
		No	12
Adrenaline		Yes	1
		No	13
Successful flaps	8		
Failed flaps	6		

Implementation of CCDS analysis and planning yielded a notably improved outcome compared with cases where it was not used, although this difference lacked statistical significance ($P = 0.064$). Worth noting are the potential confounding factors: elevated whole blood viscosity (>5) increased failure risk, with an odds ratio of 3.33 and a relative risk of 1.78 ($P = 0.28$; confidence interval CI, 0.032–2.76).[2,21–30] Furthermore, the odds ratio for using adrenaline was 1.94, with a relative risk of 0.38 ($P = 0.70$; CI, 0.0005–0.46), whereas for ephedrine, the odds ratio was 0.71, with a relative risk of 0.22 ($P = 0.82$; CI, 0.069–28.12).

DISCUSSION

The application of CCDS has previously been recognized as pioneering in the field of microsurgery, as effectively detailed by Hong et al.[1,2] However, it is crucial to acknowledge that ultrasound's utility remains reliant on the observer's expertise, and its adoption necessitates a learning curve.[1,2] Not all medical centers have radiologists well versed in microsurgery, potentially leading to extended presurgical planning times. Notably, within this series, surgical and CCDS planning durations were not measured. It is conceivable that assessing these time parameters in the future could enhance the value of CCDS application.

Certainly, working with a sample size of 14 cases does represent a limitation in terms of statistical robustness. Conducting a larger, double-blind study could serve to either validate or challenge our current findings. The significance of CCDS as a crucial tool for surgical planning is affirmed by our data, underscoring its favorable utility within microsurgery. Given the constraints of our current sample size, the lack of statistical significance may be attributed to this limitation. Moving forward, we plan to gather a larger sample size and, in due course, disseminate our expanded findings.

Certainly, an apparent confounding factor stems from the fact that the initial patients did not undergo CCDS due to a lack of awareness about its potential application. As we assessed the clinic's outcomes and identified the suboptimal results, we instituted changes to enhance them. It is noteworthy that the introduction of CCDS was proposed by the first author, leading to a potential limitation in the study's methodology. Despite this, there was a notable improvement in results upon the implementation of CCDS. This underscores the potential efficacy of CCDS in influencing positive outcomes, even though the study's design may be weakened by the initial variability in patient selection.

CONCLUSIONS

CCDS emerges as a potent planning tool within the realm of microsurgery, mitigating the risk of failure in intricate scenarios. Our data strongly indicate enhanced outcomes through the utilization of ultrasound-guided CCDS in complex microsurgery cases when compared with cases where it was not used. It is noteworthy that our ability to attain statistical significance was potentially constrained by our sample size. CCDS parameters align with the principles of medical homeostasis. Moving forward, a larger, double-blinded study is imperative to provide robust support for our findings.

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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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