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Steal Syndrome in Microsurgery

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Abstract...

The Steal Phenomenon (SP), or micro vascular steal syndrome, is a rare clinical complication described in the reconstruction of lower limbs using free flaps. It occurs secondary to a decrease in the velocity of the donor vessel's blood flow, which compromises the distal perfusion of the lower extremity. It is associated with hematic and vascular pathologies as well as the use of local anesthetics. Clinical manifestations can be local or systemic, but the vast majority go unnoticed. As such, close postoperative monitoring is essential since most complications occur in the first 24 hours of the postoperative period.

Key words: Microsurgery; Steal Syndrome; Free Flaps; Vascular Insufficiency.

Introduction

The microvascular free flap technique, by definition, is a surgical procedure in which a unit of tissue (skin, muscle, bone, or fascia) is transferred to a remote recipient area, carrying a vascular pedicle with it to perform the micro vascular anastomosis with the pedicle of the receiving bed. Currently, to treat coverage defects in the reconstructive elevator, free flaps are the treatment option with highest cutaneous stability, a high success rate, and a low percentage of complications [1].

Vascular steal is a well-documented phenomenon in multiple clinical scenarios, such as Arterio Venous Fistulas (AVFs), complications in vascular accesses designed for hemodialysis patients [2,3], or vascular shunts in the limbs [4]. AVFs and arterial shunts form a low-resistance circuit that can create a high-flow siphon, which results in the displacement of the blood supply and a high probability of subsequent distal ischemia. Siphoning occurs when there is greater resistance in the outflow of the free flap, which leads to reduced blood volume and ischemia in the distal segment of the anastomosis. The same happens in an AVF, where there is a damming of blood flow due to low resistance [5].

Conceptually, this phenomenon could also be expected at a micro vascular level in microsurgical free flaps in extremities, since a low-resistance parallel circuit which is connected to the already existing distal vascular circuits-is created. If there is significant vascular disease, the free flap low-resistance circuit can act as a siphon, generate a fistula, and increase distal ischemia in the limb [6].

The success rate of free flaps has reached 98.8% [7]. The surgeon's expertise and experience are the factors that determine this small margin of error. In relation to the remaining percentage, which constitutes the failure rate, various etiologies are derived from the patient's existing conditions such as: nutritional status, diabetes, trauma, peripheral vascular disease, and tobacco or other substance use. Another potential risk factor is the use of anesthetics and sympathetic blocks that could trigger micro vascular complications such as blood flow deviation and inadequate flap perfusion-especially in the lower extremities. This alteration of the normal blood flow, following the transfer of microsurgical free flaps (either to the flap orto adjacent regions), has been called microvascular Steal Phenomenon (SP).

In 1960, Contorni reported that a stenotic lesion in the subclavian artery proximal to the origin of the vertebral artery resulted in reverse vertebral arterial flow [8] and vertebrobasilar insufficiency [9] and called this syndrome "subclavian steal syndrome" [10]. Because this form of cerebrovascular insufficiency is amenable to treatment-and after being described, it became diagnosed more frequently-numerous publications [11-13] have given it different designations, including:"vertebral grand larceny" [14], "bilateral steals" [15], "double steal" [16], "triple steal" [17], "intracranial steal" [18], "Robinhood syndrome" [19], "occipital vertebral steal" [20],"the ophthalmic steal" [21] and "asymptomatic steal" [22]. Its main characteristic is the blood shunt in a "siphon circuit," and it has been detected in other vascular beds such as the aorto-iliac [23], celiac [24], hepatic [25], mesenteric [26,27], spinal [28], renal splenic [29], upper extremity [30], and even cardiac-if part of the coronary circulation is supplied by a coronary bridge [31]. It has been reported that splenic steal syndrome can occur after a liver transplant. It represents an undetected cause of ischemia of the transplanted organ [32-35] and it is diagnosed by angiography. This splenic steal is characterized by decreased flow in the transplanted hepatic artery, a significant deviated flow to the splenic parenchyma via the splenic artery [36,37], histopathological changes of central necrosis, cholestas is, and changes of the ductal epithelium, which lead to functional ischemia of the transplanted organ [38-40].

Perhaps where SP has been most researched is in femoro-femoral bypass procedures, where it occurs in more than 80% of the operated limbs [41] due to decreased distal blood pressure. In these cases, a significant increase in complications is seen when there is concurrent vascular disease [42]. It is necessary to consider the subclinical presentation which, in addition to being more frequent, may precede the SP itself [43].

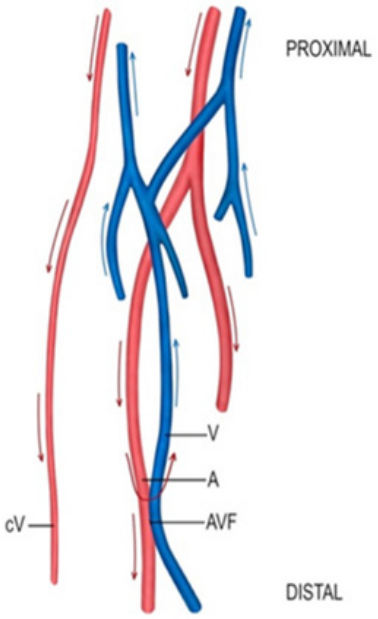

Figure 1: Components of arteriovenous fistula with direction of flows (arrows) and collateral vessels that contribute to the perfusion of tissues distal to the fistula. (A) Artery, (V) Vein, (AVF) Arteriovenous Fistula, (cV) collateral Vessel.

Physiopathology

SP has normally been described when performing an AVF via arterio-venous anastomosis, which provides reliable vascular access for long-term hemodialysis [44], or when performing a venous graft of arterial interposition, when there are vascular lesions or stenosis in extremities [45-47]. Essential components of the AVF circuit include proximal and distal arteries and veins, the fistula itself, the distal vascular bed, and the collateral arteries and veins [48]. The proximal artery provides the main blood flow to the AVF, while the collateral vessels provide an alternative route for blood to reach the distal vascular bed (Figure 1).

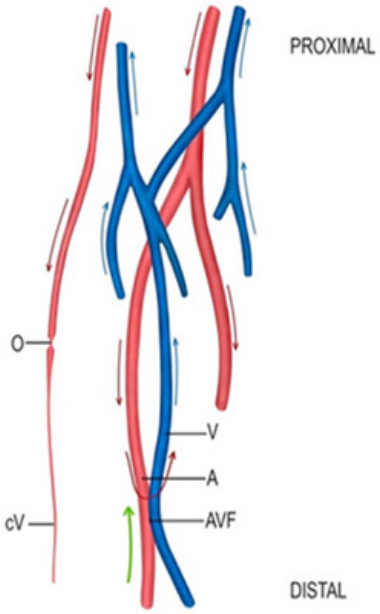

Figure 2: Obstruction of the collateral vessels that generate reverse flow (green arrow) to the arteriovenous fistula and compromise the perfusion of distal tissues. (O) Obstruction, (A) Artery, (V) Vein, (AVF) Arteriovenous Fistula, (cV) collateral vessel.

In scenarios where the collateral vessels are not functioning adequately-and depending on the size of the fistula-an SP may occur in the distal segment of the AVF, which might lead to a reverse flow at this level and thus decrease blood flow at the distal level [49]. This produces transient ischemia, as shown in Figure 2.

SP can also happen when significant stenosis occurs at the entrance artery or at the AVF's own venous graft. This generates vascular steal by reverse flow in the same vascular circuit of the fistula [50] (Figure 3).

In the field of microsurgery, when transferring free flaps to reconstruct coverage defects in lower extremities, a low-resistance parallel circuit is added to the main vascular axis of the limb [51,52]. This leads to a displacement of blood flow from the area of greater resistance (distal segmental vessels) to the vascular bed of lower resistance (vascular anastomosis) that will act as a siphon [53]. This can subsequently produce ischemia at the distal level that progresses to necrosis of the surrounding tissues (Figure 4).

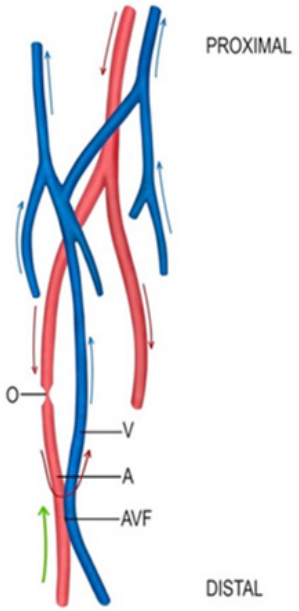

Figure 3: Obstruction at the level of the source artery of the AVF that generates reverse flow (green arrow) from the distal tissues and compromises the infusion. (O) Obstruction, (A) artery, (V) vein, (AVF) arteriovenous fistula.

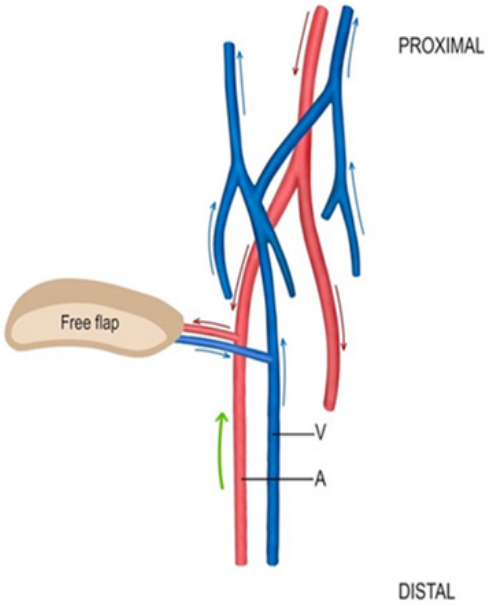

Figure 4: Free flap transfer with termino-lateral anastomosis that creates a low resistance circuit and can act as a siphon by diverting flow to the flap (green arrow) and affecting the perfusion of distal tissues. (A) artery, (V) vein.

Normally, micro anastomosis performed in free flaps does not carry a risk of necrosis of distal tissues. In diabetic patients, orin patients with severe vascular disease who have undergone microsurgical reconstructions, progressive ischemic necrosis has been seen in the fingers and toes after the transfer, while the transferred flaps remain viable [54,55].

To explain this parallel circuit's effect on the transfer of free flaps, some authors have cited the Hagen-Poiseuille law of fluid dynamics, which models laminar flow in incompetent blood vessels. It is also compared with the principle of resistance in electrical circuits, attempting to explain the expected resistance in the flow of fluids in the vessels [56] (Figure 5). One factor that can cause reduced distal flow in an organ or tissue is the change in blood volume due to directional change in a new vascular circuit. This reduces the amount of pressure that was originally going to irrigate the distal part of the organ or limb [57].

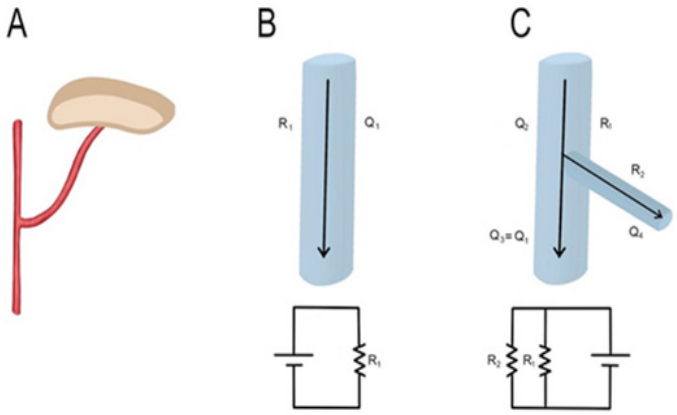

Figure 5: Microvascular anastomosis and flows. **(A)** Diagram of the termino-lateral anastomosis of a free flap to its receiving artery. **(B)** A blood vessel segment where the direction of flow is shown. R1 and Q1 represent the resistance and the flow rate, respectively, with a diagram of the electrical circuit analogous to the duct with a given resistance. **(C)** A blood vessel with a termino-lateral anastomosis showing the direction of the flows. Q2 represents the flow rate proximal to the anastomosis. Q3 represents the flow rate distal to the anastomosis. R2 and Q4 represent the resistance and the flow rate of the free flap vessel. The electrical circuit illustrates the new vessel in parallel, represented by the resistors R1 and R2.

Furthermore, since the vessel's radius is inversely proportional to the resistance and directly proportional to the velocity of the flow, increasing the vessel's radius (for example, with a vascular anastomosis) results in a greater loss of pressure and, therefore, distal flow to the anastomosis [58,59]. It is important to note this when performing free flaps on limbs with vascular compromise, especially if the receiving artery is the only one perfusing the distal part of the limb [60,61].

Another type of SP can take place in random skin flaps when a perfusion steal from its fatty tissue occurs. Significant blood sequestration occurs in the distal fat portion of the flap due to the rich subcutaneous vascular network, which causes deterioration of the flap skin's blood vessels by perfusion steal, and it directly affects its survival [62].

Epidural anesthesia in extremities during microsurgical procedures has been mentioned as a possible cause of SP. This is secondary to the vasodilation produced and the loss of sympathetic innervations of the flap vessels, which can divert the flow to the flap with the consequent acute effect on the transferred flap [63,64]. The combination of general anesthesia and epidural anesthesia has also been discussed as a factor of SP, especially in extremities [65]. As previously mentioned, regional anesthesia increases blood flow in free flaps, which prevents the vasospasm of microvascular anastomoses [66]. However, at the same time, due to the vasodilation produced, it could lead to a significant decrease in blood flow, which is in addition to the approximate 20% decrease in flow during flap dissection [67]. In a study by Scott *et al.* on the use of epidural anesthesia supplementation for free flaps in lower extremities, no difference was found in the success of free flaps when compared with those performed with single general anesthesia. Postoperative pain management and decreased at electas is were the only advantages in the concomitant use of epidural anesthesia, despite the chemical sympathectomy it produces [68]. On the contrary, by

means of free flap flow monitoring with flowmetry and Doppler laser, Twisk *et al.* demonstrated that the administration of epidural bupivacaine produces a drop in the perfusion rates of the transferred tissues. This drop is explained by sympathectomy that leads to vasodilation of the skin, an increase in temperature in the limb, and superficial circulation "stealing" blood from deep structures. Likewise, they found two other effects of epidural anesthesia: the increase in intraoperative bleeding and postoperative hematomas due to vasodilation, and the drop in blood pressure (effect seen in 80% of patients) that negatively impacts the perfusion of flap tissues [69]. A study that aimed to evaluate the anesthetic effects on microvascular flow in free flaps (dorsal width) in pigs showed that hypovolemia-defined as a volumetric loss greater than or equal to 10% of total volume-decreases between 20% and 25% the flap's local blood flow [70]. Erni *et al.* studied 21 patients undergoing reconstructive surgery of a lower extremity with free muscle (n=8), fasciocutaneous (n=6), or musculocutaneous (n=7) flaps. The microcirculatory flow was continuously measured with Doppler laser, which did not support the hypothesis that epidural anesthesia improves this condition but rather causes its decrease by 20% to 30% in the three types of free flaps examined. Subsequently, they concluded that an epidural block does not cause changes in microcirculatory flow in unprocessed tissues, but results in a marked decrease in free flaps [71].This condition is evidenced in Figure 6, a clinical case of the authors, a patient with a severe soft tissue injury due to a high-energy open fracture of the tibia and fibula, reconstructed with a Latissimus dorsi muscle free flap under general anesthesia combined with epidural anesthesia, having adequate evolution the first 3 days postoperatively, suffering in the subsequent days rapid deterioration of its perfusion until its total loss, for which it was necessary to perform a new ALT microsurgical flap under general anesthesia only, with no evidence of alteration of the receptor vessels or another factor that has influenced the loss of the first flap, attributing this late complication to the vasodilation that occurs in the limb due to epidural anesthesia and that robs flow to the flap, until its vascular collapse, without affecting perfusion of the involved limb. This is another type of steal phenomenon, where it is the limb that affects the transferred tissues.

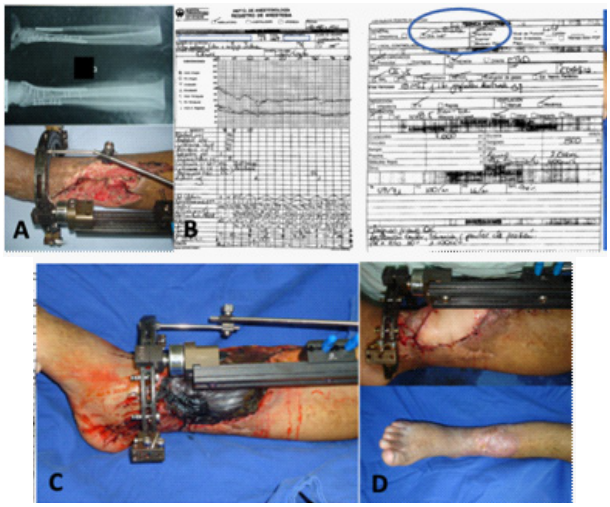

Figure 6: Clinical case of the authors. (A) Open fracture of tibia and fibula with severe soft tissue injury. (B) Combined, general, and epidural anesthesia reports. (C) Loss of Latissimus dorsi free muscle flap. (D) Second reconstructive procedure with ALT free flap (general anesthesia) and an adequate result.

Diagnostic aids

Many publications on diagnostic techniques are dedicated to hemodynamic evaluation and the state of circulating tissues [72] for different types of SP. Ultrasound studies evaluate arterial flow velocity and venous flow volumetry is used to detect hypo-or hyper-perfusion of the tissue or organ involved [73]. Duplex ultrasound is frequently performed to evaluate the presence and severity of arteriosclerotic disease in individuals with vascular risk, as it makes it possible to determine hemodynamic alterations that could be corrected by endovascular surgery. Multi detector tomography and resonance angiography assess the anatomy and type of alteration of vessels and their ramifications [74]. Angiography with perfusion imaging demonstrates the degree to which the vessels fill and allows for a postoperative evaluation after revascularization or selective ligations [75].

To assess collateral vessels, photon emission tomography (SPECT) can be used to detect arterial steal in patients with chronic vascular diseases as well as angiographic ally document the tissues that the collateral vessels are supplying and the degree of tissue perfusion [76]. When conventional morphological and angiographic images do not make it possible to confirm SP, which is clinically evident, F-Fluorodeoxyglucose- Positron Emission Tomography Imaging (F-FDG PET-MRI) monitors metabolic modifications related to hemodynamic changes [77].

In some cases, there are signs or intraoperative findings in different types of surgical procedures that may indicate a possible SP. Therefore, it is necessary to have a real-time diagnostic method that can predict the risk of postoperative necrosis, which increases tissue defects and increases morbidity in the patient. One objective and practical method-with numerous clinical studies in reconstructive surgery [78,79] is Indocyanine-Green (ICG) fluorescence angiography. This method helps to detect alterations in vessels in the involved body segment, the vessels' perforators, and the state of the tissues from a perfusion perspective (80), as well as the irrigation of the tissues to be transferred as a reconstructive option [81,82] (Figure 7). This technology helps in real time to detect and correct early any perfusion alteration not only of the transferred tissues but also of possible changes in the irrigation of the limb or the compromised body segment, which can lead to major complications, by being able to directly see the quality of perfusion of the affected tissues.

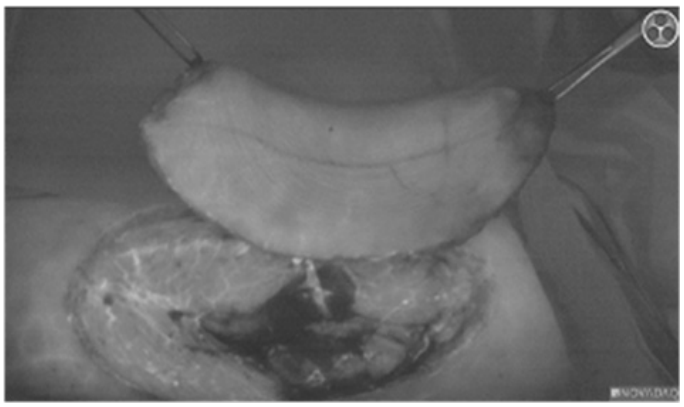

Figure 7: Evidence of adequate free flap perfusion in reconstructive surgery with Intraoperative Indocyanine-Green (ICG) fluorescence angiography.

Discussion

SP is a clinical condition that must be detected or prevented to lessen the effects it may trigger. As such, it is important to consider the risk factors involved, which can be categorized into three phases: before, during, or after the surgical procedure. For example, preoperative risk factors include vascular disease, states of hypercoagulability, and diabetes mellitus. Perioperative factors include atherosclerosis, hypovolemia, anemia, type of microvascular anastomosis, vasodilator, and anesthetic agents. Finally, postoperative factors include anticoagulation schemes, medium arterial pressure, low urinary output, bleeding, and hematomas. All these factors must be considered to avoid failures in the chosen reconstructive method, mainly when free flaps are used, regardless of what type of flap is chosen, since this choice depends on the tissues that are required depending on the tissues. Affected and the reconstructive plan in place. It is vitally important that adequate preoperative evaluation and careful postoperative surveillance can detect changes in perfusion of both the affected body segments and the affected tissues, one of them being PS, which, when detected early, have a high chance of being corrected and avoid major complications, such as those described in previous sections.

It is important to properly plan each procedure to be performed and carefully evaluate each patient-especially from the vascular perspective-to identify patients who can develop SP. Pre surgical examinations such as arteriography, arterial and venous duplex, central pressure measurement, and ankle-brachial index are indicated depending on the pathology and underlying conditions of each case.

Likewise, patients with vascular diseases, blood alterations, or a history of intensive smoking or obesity, among others, should be kept under close surveillance in the immediate postoperative period to promptly detect the presence of SP. This monitoring should be carried out clinically (local flap changes and pain modulation), hemodynamically (blood pressure, heart rate, respiratory rate, temperature, and oxygen saturation),and through imaging (arterial and venous Doppler) if necessary [83].

As for regional anesthetics, it is important to carry out a proper evaluation and identify risk factors before determining their use. The use of single epidural opioids or combined with diluted local anesthetics may be more appropriate in microsurgical procedures if the main purpose is postoperative pain therapy rather than the disruption of the painful stimulus during surgery. The use of regional anesthesia for microsurgical procedures should be previously discussed with the surgical team involved, considering the patient's risk factors, the type of reconstruction to be performed and possible consequences, as well as therapeutic actions if any type of complication occurs, such as SP.

Several different diagnostic imaging techniques make it possible to diagnose anatomical alterations or concomitant diseases that can predict the appearance of this phenomenon. This evaluation is important in patients with potential risk factors, that help to decide the form and type of reconstruction to carry out. The possibility of determining the degree of perfusion of the different tissues in real time, helps in the early detection of alterations that can be corrected effectively.

Knowledge of the different types of SP helps all personnel involved in the reconstruction of different injuries, to consider this condition, diagnose it in a timely manner and take the necessary measures to avoid major complications or put the lives of patients at risk.

Conclusion

The description of SP in free flaps or microvascular surgery is relatively new, and there is still very little information about it. It is defined as the flap's theft of blood flow from tissues adjacent and distal to the anastomos is site or altered perfusion in the transferred flap caused by a flow's diversion to adjacent vascular circuits or surrounding tissues. It occurs more frequently in patients with vascular alterations, AVF, bypass, or altered blood conditions, as well as in cases where regional anesthetics were used.

The most frequently occurring type is subclinical; in most cases, there are not major repercussions. However, it can be more severe and cause significant changes at the level of the tissues involved, so its detection requires strict clinical and hemodynamic monitoring.

It is important to consider the risk factors that can cause this condition and to detect it early on to avoid severe injuries or catastrophic consequences, such as the amputation of a limb.

Declarations

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