Université de Montréal

Les bases anatomiques
du lambeau perforant ostéocutané
de l'artère iliaque circonflexe profonde

par
Léonard Bergeron, MD

Département de chirurgie
Faculté de médecine

Mémoire présenté à la Faculté des études supérieures
en vue de l'obtention du grade de Maître ès sciences (M.Sc.)
en sciences biomédicales

novembre, 2006

Université de Montréal

Direction des bibliothèques

AVIS

L'auteur a autorisé l'Université de Montréal à reproduire et diffuser, en totalité ou en partie, par quelque moyen que ce soit et sur quelque support que ce soit, et exclusivement à des fins non lucratives d'enseignement et de recherche, des copies de ce mémoire ou de cette thèse.

L'auteur et les coauteurs le cas échéant conservent la propriété du droit d'auteur et des droits moraux qui protègent ce document. Ni la thèse ou le mémoire, ni des extraits substantiels de ce document, ne doivent être imprimés ou autrement reproduits sans l'autorisation de l'auteur.

Afin de se conformer à la Loi canadienne sur la protection des renseignements personnels, quelques formulaires secondaires, coordonnées ou signatures intégrées au texte ont pu être enlevés de ce document. Bien que cela ait pu affecter la pagination, il n'y a aucun contenu manquant.

NOTICE

The author of this thesis or dissertation has granted a nonexclusive license allowing Université de Montréal to reproduce and publish the document, in part or in whole, and in any format, solely for noncommercial educational and research purposes.

The author and co-authors if applicable retain copyright ownership and moral rights in this document. Neither the whole thesis or dissertation, nor substantial extracts from it, may be printed or otherwise reproduced without the author's permission.

In compliance with the Canadian Privacy Act some supporting forms, contact information or signatures may have been removed from the document. While this may affect the document page count, it does not represent any loss of content from the document.

Université de Montréal
Faculté des études supérieures

Ce mémoire intitulé :

Les bases anatomiques
du lambeau perforant ostéocutané
de l'artère iliaque circonflexe profonde.

présenté par :
Léonard Bergeron

a été évalué par un jury composé des personnes suivantes :

Julio Fernandez, MD, MSc
président-rapporteur

Hubert Labelle, MD
directeur de recherche

Louise Caouette-Laberge, MD
codirectrice

Steven Morris, MD
codirecteur

Andreas Nikolis, MD, MSc
membre du jury

Mémoire accepté le :

Summary

Background: Perforator flaps are increasingly utilized due to advantages including reduced flap bulk, less donor site morbidity and more donor site options. The deep circumflex iliac artery (DCIA) osteomusculocutaneous flap with iliac crest has been one of the most useful flaps used for mandibular reconstruction. However, its use has been limited by its bulkiness and added donor-site morbidity due to the inclusion of an "obligatory muscle cuff" of abdominal muscle. Early results at designing a DCIA perforator (DCIAP) flap to circumvent this problem have been varied. Details regarding the location, number, and reliability of DCIA musculocutaneous perforators have been conflicting. The purpose of this thesis is to comprehensively document the anatomical basis of the DCIAP flap.

Methods: Six fresh bodies underwent whole body lead oxide injection (n=12 specimens). Landmarks were identified with radiopaque markers. Dissection, angiography and photography were used to document the precise course of individual perforators in the flank region. Angiograms were assembled with Adobe Photoshop and analyzed with Scion Image Beta.

Results: An average of 1.6 DCIA perforators with a diameter of 0.7mm were present in 92% of specimens. Perforators were located 5-11 cm posterior to the anterior superior iliac spine, 1-35mm superior to the iliac crest, with a perforator zone of 31 cm^2. The DCIA perfused the medial aspect of the iliac crest.

Keywords: Perforator flap, osteocutaneous flaps, deep circumflex iliac artery, DCIA, cadaveric study, lead oxide.

Résumé en français

Introduction : Les lambeaux perforants sont de plus en plus utilisés dû aux avantages qu'ils offrent : lambeau plus minces, réduction de la morbidité du site donneur et nombre accru de sites donneurs. Les lambeau ostéomusculocutané « classique » de l'artère iliaque circonflexe profonde a été l'un des lambeaux les plus utilisés pour la reconstruction mandibulaire. Toutefois, son usage a diminué à cause de son large volume et à la morbidité abdominale causée par l'inclusion d'une « frange musculaire obligatoire ». Les résultats préliminaires sur l'utilisation d'un lambeau perforant ont été variés. Les détails concernant la localisation, le nombre et la fiabilité des perforantes musculocutanées sont conflictuels. Le but de ce mémoire est de documenter en détails les bases anatomiques du lambeau perforant de l'artère iliaque circonflexe profonde.

Méthode: Six cadavres frais ont été injectés systémiquement avec une solution radio-opaque d'oxide de plomb et de gélatine (n=12 spécimens). Les repères anatomiques de surface ont étés identifiés. La localisation et l'origine exacte de chaque perforante rencontrée dans la région du flanc a été documentée à l'aide de la dissection, l'angiographie et la photographie. Les angiographies ont été aasemblées avec Adobe Photoshop et analysées avec Scion Image Beta.

Résultats: En moyenne, 1,6 perforantes de l'artère iliaque circonflexe profonde étaient présentes chez 92% des spécimens. Le diamètre moyen était de 0,7mm. Elles étaient localisées 5-11 cm postérieures à l'épine iliaque antérosupérieure et de 1 à 35 mm supérieures à la crête iliaque. L'artère iliaque profonde perfusait la face médiale de la crête iliaque.

Mots-clés: lambeau perforant, lambeau ostéo-cutané, artère iliaque circonflexe profonde, études cadavériques, oxyde de plomb

Table of contents

List of tables

List of figures

List of abbreviations

ASIS	Anterior superior iliac spine
DCIA	Deep circumflex iliac artery
DCIAP	Deep circumflex iliac artery perforator
SCIA	Superficial circumflex iliac artery

Remerciements

Merci à Dr Steven Morris pour m'avoir aidé dans le cheminement intellectuel nécessaire à la réalisation de ce projet. Merci de m'avoir accueilli et supporté si gracieusement.

Merci à Dr Louise Caouette-Laberge pour la planification de ce projet, sa logistique et son encouragment continuel.

Merci à Dr Maolin Tang pour sa précieuse aide avec ses connaissances anatomiques étendues et pour l'aide apportée durant les centaines d'heures de méticuleuses dissections.

Merci à Dr Hubert Labelle pour l'encadrement académique et ses précieux conseils.

Merci à Dr Amélie Bourget pour le support apporté tout au long de ce processus.

Funding provided by:

Capital District Health Authority Research Foundation, Halifax, Nova Scotia, Canada

Department of Surgery, Dalhousie University, Halifax, Nova Scotia, Canada

IRSC. Programme MENTOR, Microprogramme en mobilité et posture

1 Introduction

Perforator flaps are revolutionizing plastic surgery. Refinements in vascular anatomy knowledge allow more precise isolation of blood vessels supplying the skin and sparing of unnecessary tissue components. Musculocutaneous flaps[1-4] are currently the most widely used flap type when skin is needed. The perforator flap concept allows the exclusion of muscle – a passive vessel carrier – in the flap design. This has contributed to diminish donor site morbidity as well as decreasing flap bulk. One of the areas in which this concept could be applied is mandibular reconstruction.

The deep circumflex iliac artery (DCIA) osteocutaneous flap with iliac crest has been one of the major flaps used for mandibular reconstruction since its description in 1979[5,6]. It is known for the large amount of vascularized bone available, the similarity in shape between the iliac crest and the mandible[7], and its vascular pedicle length and size[5,6].

Anatomical research has allowed precise characterisation of various flap components and improvements over the original flap design have been achieved. The inner cortex of the iliac crest is mainly supplied by the DCIA through periosteal circulation[6]. This allows the longitudinal splitting of the crest[8,9] to reduce flap bulk and diminish donor site morbidity. The iliac crest can also be osteotomized to better fit the jaw contour as long as the periosteum along the medial aspect of the iliac crest is left intact[10]. Others have characterized the contribution of the DCIA to the internal oblique muscle[11], which has been used to facilitate closure of through and through oromandibular osteomucocutaneous defects[12].

Despite the numerous advantages of using the iliac crest, the widespread use of the DCIA flap has been limited by the unnecessary bulk of the "obligatory muscle cuff" and the tethering of the skin to the bone which renders soft tissue placement problematic in complex oromandibular reconstructions.[13-15] Pioneering efforts by Safak[13] and Kimata[14,15] at designing a DCIA perforator (DCIAP)[16] flap to reduce the soft-tissue bulk of the flap have had limited success. There are only 7 cases reported in the literature[13-15].

The purpose of this thesis is to establish the anatomical basis of a reliable DCIAP flap for mandibular reconstruction. A critical review of the literature is conducted first. It is then followed by a description of the methods used, which includes a review article on vascular investigation techniques. A second article on the anatomical basis of the DCIAP flap constitutes the core of this thesis. An expanded discussion is included in this document, along with a conclusion.

2 Critical review of the literature

This section reviews the history of perforator flaps, mandibular reconstruction, and development of the iliac crest free flap as the reconstructive method of choice. The objectives of the pioneering efforts to develop a DCIA perforator flap were to reduce donor site morbidity and to diminish the soft-tissue bulk of the classic DCIA osteomyocutaneous flap. The development and clinical use of different DCIA flaps is discussed herein. Finally, methods for investigating tissue vascularity and perforator flaps are reviewed.

2.1 The development of perforator flaps

2.1.1 Plastic surgery and the difficult wound

Historically, Plastic Surgery has been concerned with the closure of difficult wounds which can be the consequences of disease, trauma or oncologic surgery. The plastic surgeon's arsenal consists of different grafting or tissue transfer techniques. A graft is a piece of tissue which relies entirely on its recipient bed to meet its metabolic demands as it does not have its own blood supply. A flap, is a mass of tissue(s) which is supplied by its own artery and vein: the pedicle. Free tissue transfers involve either a graft or a flap that is taken from a donor site and "transplanted" to a recipient. The artery and vein of the flap are anastomosed to an artery and vein at the recipient site using special microsurgical instruments and a microscope, a technique called microsurgery. Grafts and flaps can be made of one or many constituents: skin, muscle, bone, tendon, nerve, adipose tissue, etc. As a general rule, grafts are usually smaller and thinner as they rely on donor site diffusion to meet their metabolic requirements. Larger and more complex grafts are less reliable as blood and nutrients fails to reach cells away from the recipient site. Flaps are not restricted by such size limits as they have their own circulatory system.

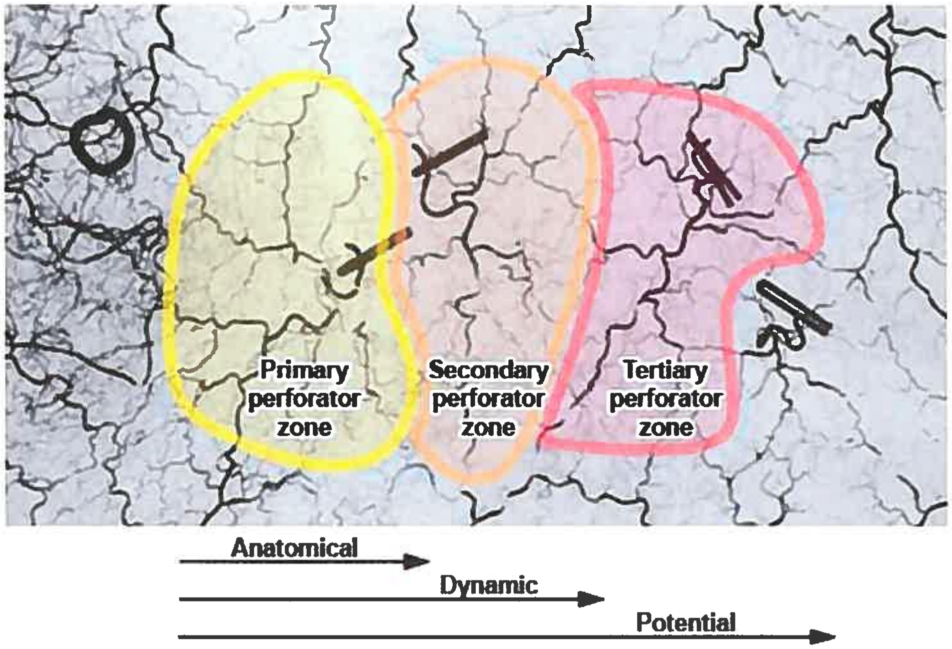
The required tissue constituents for closure of a wound are dictated by the wound characteristics. A cutaneous deficit requires skin for closure, a bone deficit requires bone for closure, a tendon deficit requires tendon, etc. In the same way, a multi-layered deficit ideally requires a multi-component flap for closure. The ultimate goal is the restoration of both form and function.

2.1.2 Angiosomes and perforator zones

An angiosome[17] is a bloc of tissue(s) or territory perfused by a named artery. An angiosome is to blood vessels what a dermatome is to cutaneous nerves. The human body has many angiosomes and they are relatively consistent between individuals. For simplicity in this document, an angiosome will only refer to the cutaneous contribution of a named artery. To reach the skin, a named artery gives off smaller branches called "perforators" because these vessels are "perforating" the deep fascia. One (cutaneous) angiosome, or vascular territory, is therefore the cutaneous territory supplied by one or many perforators.

There is no anatomical term to define the integument territory perfused by one single perforator. Cormack and Lamberty in their book on fasciocutaneous flaps[18] used the terms anatomical, dynamic, and potential territories to describe how blood flows from one vascular unit (the anatomical territory) to a second vascular unit (dynamic territory) and even possibly to a third vascular unit (potential territory) through the rich network of choke vessels interconnecting these systems. However, this vocabulary is derived from physiological studies. Anatomy is a static, descriptive science and we preferred devising a more accurate vocabulary for the purpose of our study. Therefore, the vascular territories are described as primary, secondary and tertiary zones (Figure 1).

Figure 1. Anatomical and physiological definitions of vascular territories.



Perforator zones.psd

2.1.3 Vascular anatomy and flap design

To design a flap for a particular reconstruction, one must know the precise vascular anatomy of the donor area. Surgical incisions in flap design are guided by the angiosomes principle so as to preserve the blood supply to the piece of tissue of interest. Failure to respect this vascular organisation will likely result in flap failure, or necrosis. Sir Harold Gillies made the comment[19]: “Plastic surgery is a constant battle between blood supply and beauty.”

2.1.4 Free flaps in reconstructive surgery

A free flap involves the distant transfer of tissues. It also requires re-establishing its intrinsic circulation by anastomosing an artery and a vein under the operating microscope. Current microsurgery techniques currently allow for suturing of vessels as small as 0,5mm[20].

A successful microsurgical transfer requires a precise knowledge of the vascular anatomy of both the donor site and recipient areas[21]. A bloc of tissues, the flap, can then be safely dissected to its pedicle, knowing that it will receive a sufficient vascular supply and outflow to meet its metabolic demands and allow for its complete survival. The pedicle can then be severed and re-anastomosed at a distant site to re-establish its blood circulation[21,22].

The first successful skin free flap was performed in 1973 by Daniel and Taylor[21,22], who demonstrated that a solid anatomical knowledge of cutaneous vascularization could allow the isolation of a bloc of tissues on its pedicle and remain viable after anastomosis at a distant site. Further research demonstrated a consistency in cutaneous vascularization territories known as angiosomes[17], and this provided the anatomical basis for several free flap donor sites[23]. A consistency in muscle vascularization was also described[1]. This led to a multitude of musculocutaneous flaps being used and described in the late 1970s and 1980s[16].

The arrangement of blood vessels within bone has been disputed for many years and the most widely accepted description was made by Brookes[24,25]. However, anatomical dissections[6] and clinical experience[5] of surgeons with bone flaps have been more useful to identify reliable blood supply to bone for tissue transfer[25], than the use of a general bone vascularization classification.

2.1.5 Perforator flaps: a revolution in reconstructive surgery

Flap design is based on vascular anatomy. During the past decade or two, most flap designs were modified to fit these vascular territories in an effort to improve tissue vascularity and survival. Musculocutaneous flaps[1-4] in particular, were found to have a very reliable anatomy and were therefore some of the earliest flaps used in reconstructive surgery[26]. A muscle supplied by a large artery and vein supplies musculocutaneous perforators to the overlying skin. When a skin flap was used for reconstruction, the musculocutaneous composite flap was therefore raised en bloc, using the underlying muscle as a passive carrier for vessels supplying the overlying skin. Perforators had been identified, but were overlooked as their anatomy was judged unreliable. Thus, initial flaps were quite bulky, and donor site morbidity was an issue. But this compromise was necessary to maintain the integrity of skin vascularization with current knowledge of vascular anatomy.

Perforator flaps have revolutionized reconstructive surgery[16]. Pioneer work by Koshima[27] and Kroll[28] has shown that the passive muscle carrier was not necessary to protect the course of perforators. Reappraisal of skin vascular anatomy[29] and refinement of investigative methods[30,31] have clearly established that perforators and perforator zones are a clinically useful entity. This new level of vascular knowledge has led to an explosion of improvements in current surgical practices[32-38]. However, our ability to perform successfully free tissue transfer has improved much more than our knowledge of anatomy. New perforator flaps potential donor sites are still to be found and vascular anatomy principles[6,17,23,39-46] need to be revisited.

2.1.6 Advantages and disadvantages of perforator flaps

The advantages of perforator flaps are numerous. The isolation of the vascular pedicle and sparing of unnecessary tissue components decreases donor site morbidity, provides more versatile flap designs, and improves postoperative recovery[16]. It is also thought that the long-term shape of the flap is more stable as there is not atrophy of included muscle.

The main disadvantages of perforator flaps over musculocutaneous flaps include a longer dissection to isolate the musculocutaneous perforators and variability in the size and position of perforators necessitating a preoperative Doppler examination[47,48] to locate those vessels.[16] Moreover, the main factor limiting the development of new perforator flaps has been the lack of anatomical characterization and location of these perforating vessels, which would allow more reliable perforator isolation and surgical flap design.

2.2 Mandibular reconstruction

In this section, we will review the history of mandibular reconstruction, one of the most challenging procedures in plastic surgery[49]. The evolution from bone grafting to vascularized bone flaps as the method of choice to restore mandibular continuity is discussed, as well as current problems particular to oromandibular reconstruction.

2.2.1 History

Early mandibular reconstruction techniques were developed at the beginning of the 20th century[50]. In 1916, Delangeniere discussed mandibular reconstruction with a tibial bone graft[51,52]. The iliac crest for mandibular reconstruction was described the same year by Lindman[51]. Early efforts at improving reconstruction included delaying mandibular reconstruction, the use of internal wire fixation, and the introduction of antibiotics during World War II[50]. A multitude of conventional bone grafts and alloplastic material were subsequently used to restore mandibular continuity[49].

Attempts at mandibular reconstruction were complicated in the 1960s. Aggressive resection were performed and followed by radiotherapy which caused bone graft resorption and infection[50]. Poorly vascularized beds with dysfunctional wound healing were suboptimal and reconstructive efforts were disappointing[49,51]. Attempts were made to reduce graft infection rates by pediculing local osteomyocutaneous flaps[9,52,53], which brought their own blood supply to the irradiated wound bed. Initial success rates of 35%, dropping to 15% at one year, were disappointing. Other pedicled osteomyocutaneous flaps described have had mitigated results[9,50,54,55]. Bone resorption was less than with grafts but available local bone sources were suboptimal[50]. This led to the conclusion that pedicled flaps were unacceptable for primary mandibular reconstruction[9].

2.2.2 Osteocutaneous free flaps as the reconstructive method of choice

Microsurgery and the ability to transfer vascularized tissues[22,56,57] from a distant donor site has revolutionized mandibular reconstruction[5,6,9,49,51], one of the most difficult problems in head and neck reconstruction[49,58]. The surgeon was no more limited by anatomical proximity of the donor and recipient sites. Microvascular composite tissue transfer has since become the method of choice for primary reconstruction of the mandible[51,59-61].

Four osteocutaneous flaps are now commonly used for mandibular reconstruction[60]: the iliac crest, the fibula, the radius (radial forearm flap), and the scapula (Table 1). Of these, the fibula and deep circumflex iliac artery (DCIA) flaps are the two flaps of choice[60] when large bone deficits are present. The DCIA osteomusculocutaneous flap offers numerous advantages[15]. A substantial amount of vascularized bone is supplied by the deep circumflex iliac artery, which is of large diameter. The shape of the iliac crest with its anterior superior iliac spine is similar to the body of the mandible with its angle. A reliable cutaneous paddle if perfused by the DCIA. Multiple tissue components, such as the internal oblique muscle[11,62], can be raised on the DCIA pedicle to accommodate complex deficits[12,63,64].

Table 1. Osteocutaneous free flaps.

Flap name	**Flap type**	**Vascular pedicle**	**Bone**	**Bone flap size**	**Cutaneous island size**	**Described by**
Iliac crest osteo-cutaneous free flap	Osteo-musculocutaneous	Deep circumflex iliac artery and vein	Iliac crest	14-16cm [10]	10x7cm to 30x15 cm[6]	Taylor[6]
Fibular osteocutaneous flap	Osteo-fasciocutaneous flap.	Peroneal artery and vein	Fibula	26 cm[65]	14x9cm to 15x30cm[65]	Chen[66]
Scapular osteo-cutaneous flap	Osteo-fasciocutaneous	Circumflex scapular artery and 2 venae comitantes	Scapula	1,5 (t) x 3 (w) x 10-14 (l) cm[67]	10x15cm[67]	Swartz[67]
Radial osteo-fasciocutaneous forearm flap	Osteo-fasciocutaneous	Radial artery and cephalic vein	Radius	1-1,5 (w) x 8-10 (l) cm [65]	2-8 (w)x 2-10 (l) cm[65]	Foucher[68]

2.3 Deep circumflex iliac artery osteomyocutaneous flap with iliac crest

The iliac crest with its overlying skin was readily identified as a potential donor site for an osteocutaneous composite flap in 1978 by Taylor and Watson[69]. They concluded initially after their preliminary ink injection and dissection studies in 25 cadavers, that a segment of the iliac crest could be raised in continuity with its overlying skin, based on the superficial circumflex iliac artery (SCIA) pedicle. Two clinical cases were reported.

Clinical observations while raising the SCIA osteocutaneous flap prompted Taylor et *al.* to investigate the contribution of the DCIA to the area[6]. The authors performed bilateral ink injection studies in 20 cadavers. They documented stained cutaneous territories and examined 30 of the iliac crests microscopically for ink staining. DCIA perforators were counted bilaterally in 10 abdominoplasty cases. Thirty clinical angiograms were also used to confirm the course of the DCIA. They found that the DCIA is a large vessel (2mm diameter) originating from the external iliac artery, proximal and deep to the inguinal ligament. It then ascends along the inner aspect of the iliac crest towards to the anterior superior iliac spine where it gives off a nutrient branch to the bone and an ascending branch which supplies exclusively the muscular components of the abdominal wall. The DCIA then pierces the *transversalis* fascia and *transversus abdominis* as it travels posteriorly along the iliac crest. The venous drainage of the DCIA system is via *venea* *comitantes* that parallels the arterial system[5,6]. They unite and form a single vein near the inguinal ligament, before draining into the external iliac vein [5,6,62,70].

The DCIA was found clinically to give an average of 6 cutaneous perforators in a 2,5cm wide area extending anteriorly from the ASIS, to 6cm posteriorly, and bordered by the iliac crest inferiorly. A dominant perforator was found in all cases. A stained skin area, ranging from 10x7cm to 30x15cm, was always present. The skin ellipse was centered on a point 4 to 8 cm posterior to the ASIS.

The authors successfully demonstrated the anatomical basis for the superiority of the DCIA as the main blood supply to the iliac crest osteomusculocutaneous flap. They supported their findings by performing 11 clinical cases[5]. Multiple authors subsequently studied the DCIA and its contribution to different tissue components[11,13,62,71-75].

2.3.1 Iliac crest vascularization

The iliac crest is known as a reliable source of both cortical and cancellous bone of endochondral origin[76,77]. Long term follow-up studies indicate that vascularized bone flaps are superior to bone grafting, as bone grafts undergo a larger and unpredictable volume loss due to resorption[78-83]. The vascularized iliac crest free flap has therefore been the preferred method of iliac crest transfer for mandibular reconstruction[50].

Anatomical[6,72,74] and clinical studies[5] have shown that the DCIA is the main blood supply to the anterior iliac crest. It has been recognized that the periosteum of the inner table of the iliac crest provides sufficient vascularization to the iliac crest bone flap, and this property has been used to design a thinner bone flap that includes only the inner cortex of iliac crest flaps[8,9]. Other vessels contributing directly or indirectly to the vascularization of the iliac crest described in the literature include: the iliolumbar[84,85], the lumbar[86], the superior gluteal[87-89], the superficial circumflex iliac[69], and lateral femoral circumflex[90-92] arteries.

2.3.2 Refining the bony component

In 1981, Taylor and Daniel reported the feasibility of raising only the inner cortex of the iliac crest, along with a portion of the epiphysis, to promote flap growth in a 13 year-old patient[8]. Shenaq then applied this flap modification routinely to decrease donor site morbidity and contour deformity in adult patients[9,51,93].

2.3.3 Adding the internal oblique muscle for intra-oral lining

Ramasastry recognized the contribution of the DCIA to the internal oblique muscle[11,62]. Based on this information[9], Urken proposed a triple tissue component flap (iliac crest, internal oblique muscle, and skin) based on the DCIA for mandibular reconstruction[12,63,64]. The skin paddle was used to reconstruct the cheek, the iliac crest to replace the mandible, and the denervated internal oblique muscle was used for intra-oral lining and skin grafted. The subsequent muscle atrophy and retraction would help obtain a better definition of underlying head and neck structures[10,12] to ease fitting of dentures.

2.3.4 Adding peritoneum for intra-oral lining

To reduce the need for a second flap for intra-oral lining in compound mandibular defects, Karcher evaluated the possibility of including peritoneum to the DCIA flap for intra-oral lining [73]. He performed ink and barium studies of the DCIA in 32 dissections from 26 cadavers. He found an area of peritoneum that stained with ink, measuring in average 6x14cm. One case involved two flap components pedicled on the DCIA: a first classic osseomusculocutaneous DCIA flap was designed and a second musculoperitoneal component was made based on the ascending branch of the DCIA artery. It included the internal oblique muscle, transversus abdominis muscle and underlying peritoneum. A second case involved only the transfer of the *transversus abdominis* muscle and underlying peritoneum based on the ascending branch of the DCIA. A third osteomusculoperitoneal flap (without mention of the exact tissue components) was also reported. The authors reported excellent flap vascularization. No hernias were reported at 9 months.

2.3.5 Bulk problems

Factors limiting the use of the DCIA iliac crest osteocutaneous flap oromandibular reconstruction include the bulk[10] associated with the inclusion of the "obligatory muscle cuff"[5,6], a full-thickness fringe of abdominal muscles raised in continuity with the iliac crest[5,6]. According to the musculocutaneous flap concept[1-4], a sufficiently large mass of muscle must be included with the flap to incorporate a significant number of musculocutaneous perforators to supply adequately the overlying skin[10]. This extra mass can complicate intra-oral reconstruction[13-15].

2.3.6 Strategies to reduce soft-tissue bulk

To address the extra bulk associated with the obligatory muscle cuff, some authors recommended raising two different flaps: one from the iliac crest and a second thin cutaneous one which would replace the thick musculocutaneous component of the DCIA flap. This would also facilitate three-dimensional placement of the soft-tissue component as the integument is usually tethered to the underlying muscle. Flaps that have been combined with the DCIA bone flap include: SCIA/DCIA[58,94,95], DCIA/radial forearm[96], DCIA/ulnar forearm flap[61], DCIA/tensor fascia lata[96] flaps. Such procedures are complex and lengthy as they require elevation of two separate flaps, two sets of microvascular anastomosis, and closure of two donor sites.

2.4 Deep circumflex iliac artery osteocutaneous perforator flap

The classical iliac crest musculocutaneous flap[5], with its "obligatory muscle cuff", is quite bulky and complicates oral reconstruction[13-15]. It is recommended that a 3x8 cm fringe of full thickness abdominal wall musculature be kept in continuity with the iliac crest, even extending anterior to the anterior superior iliac spine (ASIS), to protect the DCIA musculocutaneous perforators. The mobility of the skin component is restricted by its attachments to this muscular component and this further complicates reconstructive efforts. With the recent advent of perforator flaps, where the vessels are isolated from their passive muscle carrier to diminish donor site morbidity[16], several authors have questioned the utility of this "obligatory muscle-cuff" to improve the original design of the flap by reducing this bulk and increasing its component mobility[13-15].

Safak *et al.*[13], in 1997, challenged the "obligatory muscle cuff" concept and reported the two first cases of DCIA osteocutaneous flap without this obligatory muscle cuff. He had previously performed bilateral DCIA dissections in 10 non-injected cadavers. Three vascular patterns were identified by the authors. In 40% of cases, the DCIA travelled deep the *transversus abdominis* and liberated a series of small musculocutaneous perforators (0,3-0,5mm). In 30% of dissections, the DCIA penetrated the *transversus abdominis* 3-4cm posterior to the ASIS and travelled between the *transversus abdominis* and the internal oblique muscle and provided a similar pattern of small musculocutaneous perforators. In the last 30% of dissections, a dominant musculocutaneous branch was found 5-6 cm posterior to the ASIS and 1-2cm above the iliac crest. It averaged 1,5mm in diameter and 6cm in length. His findings contrasted with Taylor's[6] in that he did not find a consistent "dominant perforator" pattern during his dissections.

2.5 Clinical outcomes

In this section, we will review the functional outcomes of the classic iliac crest flap and the DCIA perforator flap, as well as donor site morbidity. Surprisingly, donor site morbidity following iliac crest harvest is low. A split iliac crest flap design can decrease donor site morbidity. Besides reducing flap bulk and facilitating soft-tissue placement, the DCIA perforator flap design is thought to reduce the incidence of abdominal hernia by sparing the "obligatory muscle cuff".

2.5.1 Outcome of the DCIA osteomusculocutaneous flap

Shpitzer and Neligan[97] present a retrospective analysis of 117 patients who underwent mandibular reconstruction. Fifty-nine percent of flaps used were iliac crests. Three iliac crest flaps were lost. A total of 31 patients in the iliac crest group were available for follow-up. When compared to fibula flap reconstructions, the iliac group demonstrated no statistically significant difference in functional and cosmetic outcome for oral competence, speech, and contour.

David[61] reported his ten-year experience with 32 iliac crest flaps for mandibular reconstruction. One bone flap's pedicle thrombosed, but survived as a graft. The authors did not note any donor-site complications.

Forrest [98] studied 78 patients who had 82 iliac crest free flaps. The most frequently encountered problem at the donor site was sensory change. Femoral neuropathies and femoral hernias were infrequent. Functional loss resulting from free iliac crest transfer was found to be acceptable.

2.5.2 Outcome of the DCIA osteocutaneous perforator flap

Safak first described two successful cases of a DCIA osteocutaneous perforator flap[13]. Based on previously published anatomical data on the DCIA perforators, Kimata then intended to raise a DCIA osteocutaneous perforator flap in

10 consecutive patients[14,15]. In 3 patients, a DCIA perforator could not be found preoperatively with Doppler examination, so the DCIA perforator flap design was rejected. Of the 7 cases were a perforator was identified, only five were raised as a perforator flap. The perforating vessels were judged too small in the other 2 cases (0,5mm). One hundred percent flap survival was obtained in the DCIA osteocutaneous perforator flap group. Preservation of the abdominal wall muscle integrity is thought to reduce the incidence of abdominal hernias[13-15].

2.6 *Methods for investigating tissue vascularity*

The gold standard for studying skin perforators is the lead oxide-gelatine technique[30], which allows reliable visualisation of very fine vascular networks.

2.6.1 Presentation of article 1

A review of the methods of vascular injection studies for the study of perforator flaps is presented. Our laboratory has improved the lead oxide-gelatine technique[30] to allow constant and reliable visualisation of fine vessels, a prerequisite for the study of perforator flaps. This information was not previously available in a summarized form. A section of the article expands on our methods.

The role of Dr Bergeron was to find and summarize historical and current investigation techniques for the study of perforator flaps, as well as writing the current article.

2.6.2 Article 1: A review of vascular injection techniques for the study of perforator flaps

Bergeron L, Tang M and Morris S F. A review of vascular injection techniques for the study of perforator flaps. *Plast Reconstr Surg* 2006;117:2050-2057. Reproduced under permission by the Editor.

A Review of Vascular Injection Techniques for the Study of Perforator Flaps

Leonard Bergeron, M.D., C.M.
Maolin Tang, M.D.
Steven F. Morris, M.D., M.Sc.

Halifax, Nova Scotia, Canada

Background: With a new era of flap surgery, additional anatomical information is required. The relatively recent interest in musculocutaneous perforator flaps has once again sparked interest in the vascular anatomy of surgical flaps. There are a variety of anatomical techniques available to define the vascular anatomy of tissues of interest. In this article, the authors review vascular injection techniques available and describe the technique currently used in their laboratory.
Methods: A comprehensive review of vascular injection techniques is summarized. Barium sulfate and lead oxide in particular are reviewed in detail.
Results: This article reviews the historical development of vascular injection techniques, outlines current investigative methods, and expands on a radiopaque lead oxide and gelatin injection method that provides high-quality angiograms.
Conclusions: The standard method for the study of perforator flap is the lead oxide–gelatin technique. However, other methods can provide complementary information on vascular anatomy. (*Plast. Reconstr. Surg.* 117: 2050, 2006.)

Surgeons require detailed, accurate information regarding the anatomy of cutaneous perforating vessels before using specific surgical flaps. With the rapid development and application of perforator flaps in plastic surgery, there has been renewed interest in the vascular anatomical basis of current and potential perforator flaps. Traditional injection techniques used for the study of tissue vascularity are often confusing and produce variable results. This has led to the refinement and validation of the radiopaque lead oxide injection technique for the study of microcirculation.[1] Other nonradiopaque techniques can potentially be useful. Unfortunately, there is no updated account of injection techniques in recent publications. The goals of this article are therefore to (1) review the history of arterial injection techniques; (2) review the modern techniques used for studying surgical flaps; and (3) describe in detail the injection technique used in our laboratory that provides consistently high-quality angiograms of the vasculature of skin, bone, tendons, muscle, nerves, peritoneum, and viscera.

From the Department of Anatomy and Neurobiology and Surgery, Dalhousie University.
Received for publication December 8, 2004.

DOI: 10.1097/01.prs.0000218321.36450.9b

HISTORY OF THE STUDY OF VASCULAR ANATOMY

Early knowledge of vascular anatomy was first obtained from the dissections of anatomists including Herophilus (circa 340 BC), who coined the term "artery"[2]; Galen (circa 129 to 200 AD), who established the basis of modern anatomy after his animal dissections; and Vesalius (1514 to 1564), who performed extensive human dissections. The discovery of capillaries was made independently by Marchello Malpighi (1628 to 1694) and Antoni van Leeuwenhoek (1632 to 1723) in 1661 and 1668, respectively.[2]

Nonradiopaque Injection Studies

Jean Riolan (1580 to 1657) was the first anatomist to inject colored dyes to demonstrate the branching of the vascular tree.[2] Whitten[3] summarized the various dyes used historically in the study of vascular anatomy. These included saffron, carmine, Prussian blue, India ink, and silver nitrate in aqueous or gelatin suspension.

India ink injections have since been extensively used for the study of skin vascular territories to plan surgical flaps.[4–8] Ink can be used to stain blood vessels to facilitate their dissection. It can also be used to identify the skin territory perfused by a given artery or perforator. Gelatin can be mixed with the ink[9–12] to facilitate dissection. As with other methods of selective vessel injection, overfilling of the studied angiosome is a frequent problem. Any ink exceeding the "intraangiosomal" volume overflows to adjacent angiosomes by means of choke anastomotic vessels. There is no way of predicting the exact amount of dye necessary to fill an anatomical territory. Dye studies are useful for locating cutaneous paddles of flaps, but information regarding the exact size and borders of the territory perfused should be regarded as imprecise.

Injection Masses

Various "injection masses" have also been used to fill blood vessels to facilitate dissection. Swammerdam (1637 to 1680) injected colored wax in arteries and veins. He then dissected the specimen and covered it with resin. Substances such as starch, plaster of Paris, glue, glazier's putty, asphalt, latex or rubber, gum Arabic, sodium silicate, oil of sesame, shellac, thymol, and mercury were injected for this purpose.[3]

Latex is still widely used as a visual guide during gross dissections[8,13,14] and as a suspending medium for various radiocontrast media.[6,15] Its color makes it easier to identify vessels during dissection and its elasticity helps preserve vessel integrity. Latex is supplied in a liquid form and solidifies quickly in the presence of formalin. The standard injection technique takes advantage of this property. After flushing out blood, latex is injected in the arterial system and is allowed to distribute for a few minutes. Formalin is then injected in the venous system and slowly diffuses throughout the tissues and microvasculature. This speeds the hardening process of the latex necessary for dissection. Another, less reliable method consists of first injecting the formalin intraarterially and then injecting the latex. In contrast to ink, latex only allows visualization of blood vessels and does not allow gross visual assessment of the skin territory perfused by a given vessel.

Diaphanization (Spalteholz Method and Derivatives)

This process involves rendering cadaveric tissues transparent by a series of chemical reactions according to a method developed by Spalteholz.[16] The basic steps consist of (1) injection of India ink or latex to allow later visualization of vessels, (2) fixation of the specimen with formalin, (3) optional decalcification, (4) bleaching, (5) dehydration with alcohol, and (6) rendering the specimen transparent with a combination of methyl salicylate and other products. Diaphanization has been mainly used for studying the vascular anatomy of bone,[17–19] tendons,[20–22] and joints.[23] It has also been used for study of surgical procedures[24] and for the study of the vascularization of the skin and subcutaneous tissues.[11,25] This method allows visualization of vascularization in situ with proper intravascular staining. However, the procedure is time consuming and can only be applied to relatively small and thin specimens. It is not ideal for studying soft tissues, as shrinkage occurs,[24,26,27] preventing accurate measurements.

Tissue Corrosion

Tissue injection followed by corrosion has also been used extensively to define vascular anatomy. Most techniques involve the use of a medium with a low melting point that is injected at a higher temperature and allowed to solidify. Bidloo (1685) used Rose's metal (alloy of bismuth, lead, and tin) as an injectant and boiled the specimen to remove connective tissues. Ruysch (1704) injected metal in coronary vessels and used maggots and larvae to decompose the tissues and obtain a vascular cast. Lieberkuhn (1711 to 1746) was the first to use acid to corrode tissues. Since then, various mixtures of injectants have been used, and tissues surrounding the casts have been corroded with various agents such as hydrochloric acid or potassium hydroxide.[3] Corrosion casts are still in use today to study surgical anatomy.[28–30] Various resins have been used: epoxies,[31] methymethacrylate,[30,32] and acrylic.[33] Some of them, such as acrylic, do not penetrate the capillary bed of human organs.[34] Such studies must often be combined with other types of investigation, as the relationship of the vasculature with its surrounding tissues is lost.

Radiopaque Injection Techniques

In 1895, Roentgen discovered x-rays, and within a few weeks of this discovery, the first angiogram was produced by Haschek[35] in 1896 after injecting chalk into the arteries of a cadaveric hand. Other early contrast media include[3,36] calcium sulfate,[37,38] mercury,[39] barium,[40] bismuth,[41] colloidal silver,[42] lead oxide,[43] lead chromate,[44] vermilion (mercuric sulfide),[36] sodium bromide,[45] and iodized oils.[46] In 1923, Berberich performed femoral angiography on a living subject for the first time with strontium bromide.[47] Table 1 presents the historical development of contrast media.[7,35–56] The most useful of these methods have been barium sulfate and lead oxide injection techniques.

Table 1. The Development of Contrast Media for Anatomical Vascular Studies

Year	Investigators	Radiopaque Medium	Suspending Medium
1896	Haschek and Linderthal, 1896[35]	Chalk	N/A
1896	Dutto, 1896[37,38]	Calcium sulphate	N/A
1896	Braus, 1896[39]	Mercury	N/A
1899	Baumgarten, 1899[41]	Bismuth	N/A
1907	Jamin and Merkel, 1907[43]	Lead oxide	Gelatin
1910	Frank and Alwens, 1910[42]	Colloidal silver	N/A
1913	Parker, 1913[44]	Lead chromate	N/A
1920	Gough, 1920[40]	Barium	N/A
1923	Hinman et al., 1923[45]	Barium and sodium bromide	Gelatin
1923	Berberich and Hirsch, 1923[47]	Strontium bromide	N/A
1924	Ferguson, 1924–25[36]	Vermilion	N/A
1924	Cadenat, 1924[46]	Iodized oils	N/A
1936	Salmon, 1936[48,49]	Lead oxide	Oil, phenol, colophony, ether
1938	Schlesinger, 1938 and 1957[50,51]	Lead phosphate	Agar or gelatin
1941	Olovson, 1941[52]	White lead	Acacia
1950	Lindbom, 1950[53]	Barium	Acacia and gelatin
1953	Trueta and Harrison, 1953[54]	Barium, silver iodide	Latex
1974	Shehata, 1974[55]	Barium	Starch
1986	Rees and Taylor, 1986[56]	Lead oxide	Gelatin
1987	Taylor and Palmer, 1987[7]	Lead oxide	Gelatin

N/A, not applicable.

MODERN RADIOPAQUE INJECTION TECHNIQUES AND SURGICAL FLAPS

Barium Sulfate

Barium sulfate is a well-known radiographic contrast agent. Its use was first described in 1920.[3,40] The technique involves flushing out intravascular blood and injection of barium sulfate mixed with gelatin or latex to facilitate subsequent dissection. It has been used with moderate success in the early investigation of cutaneous vascular anatomy. Barium was soon replaced by lead oxide as the standard contrast agent for the study of very fine vascular networks such as those found in the integument.[48,49,56] However, the barium sulfate technique has been reappraised lately. Some authors have improved the technique and obtained angiograms of very high quality by using mammography techniques.[57] This technique, however, is limited to small tissue samples, as the specimen has to fit in a conventional mammography machine.[58]

Lead Oxides

Lead oxide is the standard for visualization of blood vessels required for the planning of surgical flaps. It is not expensive, is simple to prepare, and reliable results are obtained. Lead oxide in gelatin was first used by Jamin and Merkel in 1907.[43,59] Salmon, in 1936, perfected the technique to study muscle and skin vascular anatomy.[48,49] In 1986, Rees and Taylor rediscovered Salmon's work and proposed their simplified lead-oxide injection technique.[56] They used lead oxide in its litharge form (PbO) instead of red lead (Pb_3O_4), and gelatin was reintroduced in the mixture to facilitate dissection. However, Taylor has gone back to Pb_3O_4.[7,60,61] The bright orange-red color of the lead is very easy to identify and facilitates dissection of fine structures.

Different forms of lead oxide used for injection studies are often confused. Red lead, litharge, and massicot are degradation products of PbO_2, which degrades following the pathway PbO_2 (plattnerite) → Pb_3O_4 (red lead) → PbO (litharge) → PbO (massicot).[62] Table 2 compares these chemicals.[62] Red lead oxide is the most frequently used form of lead oxide for injection studies.

Technique

Our laboratory has refined the lead oxide injection technique[1] outlined by Rees and Taylor.[56] Fresh bodies are obtained within 48 hours of death through the Dalhousie University Donor Programme. All projects are approved by the Dalhousie University Ethics Committee. Exclusion criteria include evidence of severe peripheral vascular

Table 2. Comparison of Various Forms of Lead Oxide Used for Injection Studies

	Red Lead (minimum)	Litharge	Massicot
Formula	Pb_3O_4	Tetragonal PbO	Orthorhombic PbO
Color	Bright orange-red	Ranging from yellow to red	Yellow

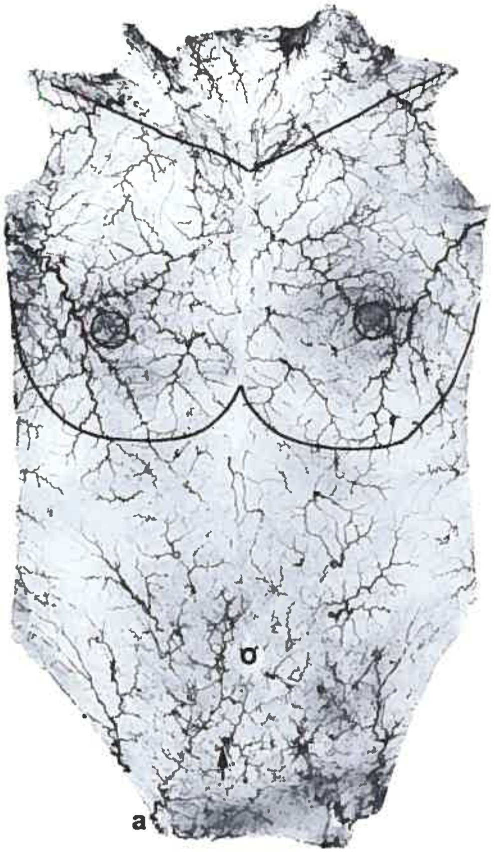


Fig. 1. Skin angiogram of the anterior trunk. Note the inferior epigastric artery (*a*) and a perforator from the deep inferior epigastric artery (*arrow*).

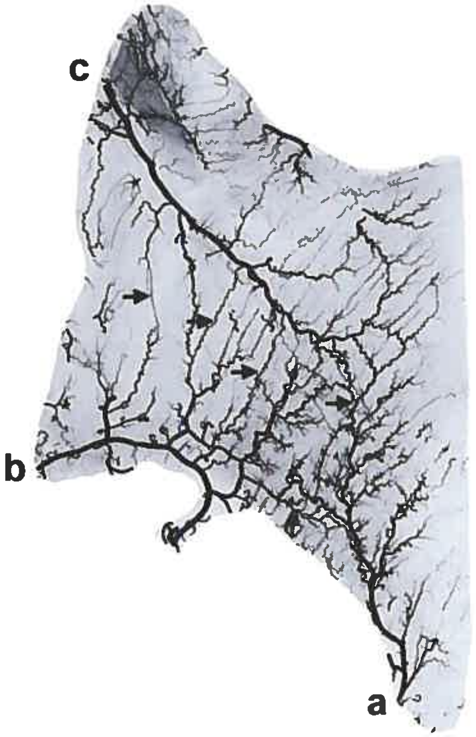


Fig. 2. Muscle angiogram of the external oblique muscle. Note the intramuscular anastomotic connections (*arrows*) between the deep circumflex iliac (*a*), fourth lumbar artery (*b*), and twelfth intercostal (*c*) arteries.

disease, extensive muscle atrophy, extensive surgical scars, scars over the area of interest, pressure sores, postmortem body degradation, evidence of skin metastasis or neoplasia, missing limb, major joint fusion, disarticulation or prosthesis suggesting extensive surgical exploration, and anatomical landmark distortion.

Body preparation and injection are performed within 48 hours of death. The femoral artery and vein are approached unilaterally by means of a minimal longitudinal incision inferior to the inguinal ligament. Foley catheters of appropriate sizes are inserted proximally and distally by means of a longitudinal or transverse arteriotomy. The femoral vein is cannulated with a standard metallic embalming cannula that is large enough to accommodate the passage of large blood cloths. Five to 10 liters of tap water containing 30 g/liter of potassium acetate is warmed to 40 to 50°C. It is then injected in the arterial system under continuous perfusion at 140 to 170 kPa until venous return is clear. Manual compression of the extremities from distal to proximal can increase the rate of intravascular cleaning. When capillary thrombosis occurs in dependant areas, gentle massage of the discolored skin improves capillary cleaning as evidenced by skin whitening.

The body is then floated into a warm bath of water at approximately 40°C. This step relieves pressure points over bony prominences and helps liquefy residual blood. We believe it is the most crucial step in the injection technique. The warm bath significantly increases the temperature of the integument and keeps the lead oxide–gelatin mixture above its melting point. This allows the injectate to circulate in the microvasculature without solidifying. Water temperature over 50°C can denature certain types of gelatins,[1] and temperatures above 60°C can induce skin burn and sloughing.

The lead injectate is prepared as follows: 5 g of 300 Bloom pharmaceutical grade gelatin derived from porcine skin (Merck KGaA, Darmstadt, Germany) is diluted in 100 ml of tap water heated to 40°C; 100 g of red lead oxide is then added to the solution. The solution is stirred at regular intervals

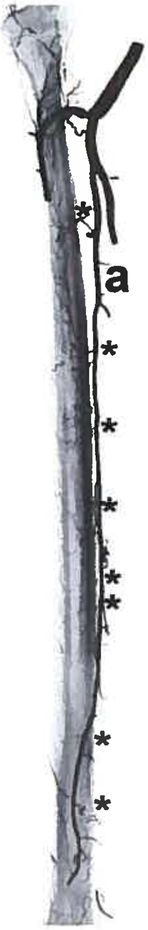


Fig. 3. Bone angiogram of a fibula. Note the contribution of the peroneal artery (*a*) to the periosteum of the fibula (*asterisks*).

Fig. 5. Angiogram of the peritoneum of the right hemiabdomen, from the iliac crest to the costal margin (*U*, umbilicus). Note the contribution of the deep circumflex iliac artery (*a*) to the peritoneum in an "axial" pattern.

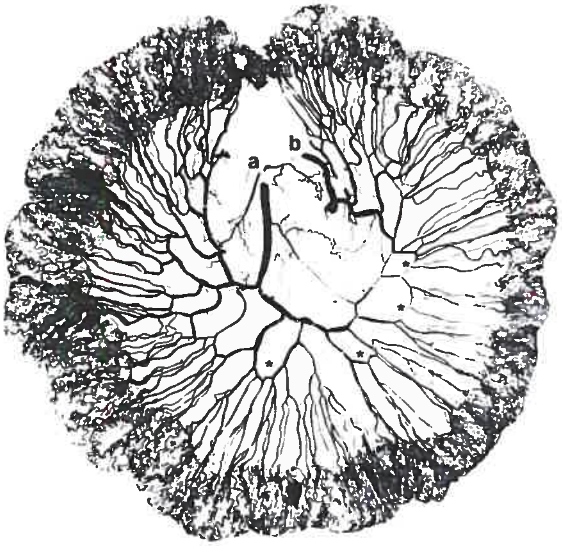


Fig. 4. Small bowel angiogram. Note the vascular arcades (*asterisks*) between two branches of the superior mesenteric artery (*a* and *b*).

to prevent sedimentation of the lead oxide. Rapid injection of the arterial system is undertaken until the characteristic patchy orange pattern is seen on the integuments, extremities, and conjunctiva. Once finished, Foley catheters are clamped. The average time required for injection is approximately 5 to 10 minutes. The average amount of lead oxide mixture injected is between 20 and 30 cc/kg, depending on the cadaver's degree of obesity. Thinner bodies require less mixture per kilogram and obese bodies require more mixture per kilogram.

The skin is rinsed to remove any deposits of lead oxide and the cadaver is placed in a freezer. After 48 hours, whole-body radiographs are taken to plan dissection. The body is then split in the appropriate planes and eviscerated while still frozen to prevent the spillage of contents of hollow organs. Angiograms are taken at every step to further define the vascular anatomy and variations encountered.

Angiograms are digitalized with a 5-megapixel Nikon Coolpix 5000 camera (Nikon Corporation, Tokyo, Japan). Images are manipulated and assembled to scale as required with Adobe Photoshop CS (Adobe Systems, Inc., San Jose, Calif.). Measurements and surface area calculations are performed with Scion Image Beta 4.02 (Scion Corporation, Frederick, Md.). Typical angiograms can be seen in Figures 1 through 7.

DISCUSSION

Our modification of the lead oxide injection technique is a simple method for produce high-quality angiograms. Three main problems with traditional injection methods have been addressed. First, a lead oxide suspension in gelatin with optimal radiopacity and elasticity and a lower sedimentation rate has been devised (Table 3). Second, pressure points from prolonged body storage are relieved by floating the body in warm water. Third, keeping the integument temperature above the melting point of gelatin during injection allows better penetrance of the fine angiosomal networks of the integuments. Our technique allows us to obtain high-quality angiograms of integuments, muscles, bones, periosteum, tendons, nerves, viscera, and peritoneum (Figs. 1 through 7).

Fig. 6. Angiogram of the quadriceps tendon and patellar ligament. Note the vascular arcades at the junction of the quadriceps ligament with the patella (*a*) and at the junction of the patella with the patellar ligament (*b*).

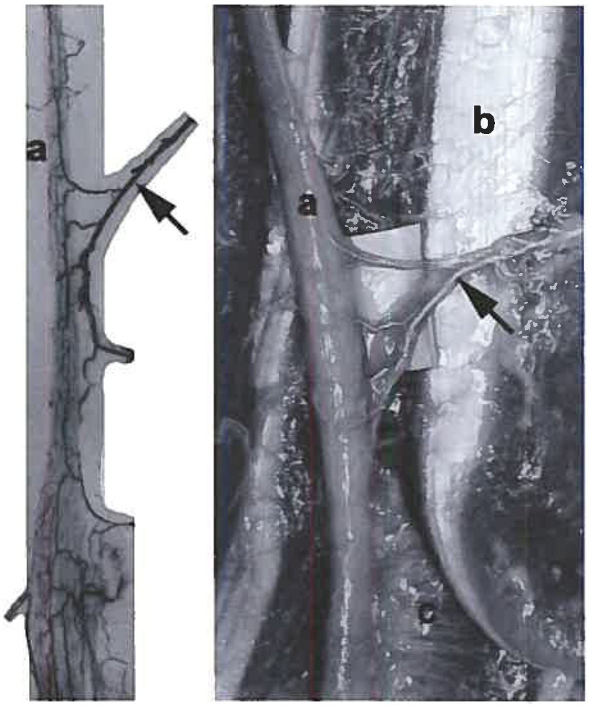


Fig. 7. Nerve angiogram of the median nerve. Note the intraneural course of a branch of the radial artery (*arrow*) in the median nerve (*a*). Flexor pollicis longus (*b*); pronator quadratus (*c*).

Limitations of the method include the inability to prevent bursting of small capillaries when excessive pressure is applied during injection, inability to reverse postmortem degradation of the vascular system, and inability to completely inject areas of unrecognized premortem pressure sores. Also, overfilling of the arterial system can lead to venous filling, sometimes seen in the superficial venous system of the extremities. Lead oxide is also a toxic substance that requires the operator to wear a mask and gloves during manipulation. A special facility for disposal of lead is also necessary.

CONCLUSIONS

This article provides a historical review of injection techniques. Multiple injection techniques

Table 3. Lead Oxide Preparation

Ingredients	Quantity
300 Bloom gelatin	5 g
Tap water (40–50°C)	100 ml
Lead oxide (Pb_3O_4)	100 g

of interest to the plastic surgeon have been reviewed. The details provided in the article should allow the investigator to produce high-quality angiograms of the microcirculation that are necessary for the study of perforator flaps.

Steven F. Morris, M.D., M.Sc.
Division of Plastic Surgery, Room 4443
1796 Summer Street
Halifax, Nova Scotia B3H 3A7, Canada
[redacted]

REFERENCES

1. Tang, M., Geddes, C. R., Yang, D., et al. Modified lead oxide-gelatin injection technique for vascular studies. *Chin. J. Clin. Anat.* 1: 73, 2002.
2. Paweletz, N. Birth of the life sciences in The Netherlands and Belgium. *Nat. Rev. Mol. Cell. Biol.* 2: 857, 2001.
3. Whitten, M. B. A review of the technical methods of demonstrating the circulation of the heart. *Arch. Intern. Med.* 42: 846, 1928.
4. Palmer, J. H., and Taylor, G. I. The vascular territories of the anterior chest wall. *Br. J. Plast. Surg.* 39: 287, 1986.
5. Taylor, G. I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. *Plast. Reconstr. Surg.* 64: 595, 1979.
6. Stokes, R. B., Whetzel, T. P., Sommerhaug, E., et al. Arterial vascular anatomy of the umbilicus. *Plast. Reconstr. Surg.* 102: 761, 1998.
7. Taylor, G. I., and Palmer, J. H. The vascular territories (angiosomes) of the body: Experimental study and clinical applications. *Br. J. Plast. Surg.* 40: 113, 1987.
8. Whetzel, T. P., and Lechtman, A. N. The gracilis myofasciocutaneous flap: Vascular anatomy and clinical application. *Plast. Reconstr. Surg.* 99: 1642, 1997.
9. Gajisin, S., Bednarkiewicz, M., and Zbrodowski, A. Blood supply of the digital sheath. *Chir. Main* 17: 147, 1998.
10. Gajisin, S., and Zbrodowski, A. Local vascular contribution of the superficial palmar arch. *Acta Anat. (Basel)* 147: 248, 1993.
11. Zbrodowski, A., Gumener, R., Gajisin, S., et al. Blood supply of subcutaneous tissue in the leg and its clinical application. *Clin. Anat.* 8: 202, 1995.
12. Zbrodowski, A., Mariethoz, E., Bednarkiewicz, M., et al. The blood supply of the lumbrical muscles. *J. Hand Surg. (Br.)* 23: 384, 1998.
13. Zenn, M. R., and Heitmann, C. Extended TRAM flap: Feasibility study on fresh human cadavers. *Ann. Plast. Surg.* 50: 256, 2003.
14. Yousif, N. J., Ye, Z., Grunert, B., et al. Analysis of the distribution of cutaneous perforators in cutaneous flaps. *Plast. Reconstr. Surg.* 101: 72, 1998.
15. Godat, D. M., Sanger, J. R., Lifchez, S. D., et al. Detailed neurovascular anatomy of the serratus anterior muscle: Implications for a functional muscle flap with multiple independent force vectors. *Plast. Reconstr. Surg.* 114: 21, 2004.
16. Spalteholz, W., and Hirsch, C. Coronararterien und Herzmuskel: Anatomische und experimentelle Untersuchungen. *Dtsch. Med. Wochenschr.* 1: 790, 1907.
17. Gelberman, R. H., and Mortensen, W. W. The arterial anatomy of the talus. *Foot Ankle* 4: 64, 1983.
18. Handley, R. C., and Pooley, J. The venous anatomy of the scaphoid. *J. Anat.* 178: 115, 1991.
19. Fasol, P., Munk, P., and Strickner, M. Blood supply of the scaphoid bone of the hand. *Acta Anat. (Basel)* 100: 27, 1978.
20. Geppert, M. J., Sobel, M., and Hannafin, J. A. Microvasculature of the tibialis anterior tendon. *Foot Ankle* 14: 261, 1993.
21. Sobel, M., Geppert, M. J., Hannafin, J., et al. Microvascular anatomy of the peroneal tendons. *Foot Ankle* 13: 469, 1992.
22. Weinstabl, R., Wagner, M., Schabus, R., et al. Anatomical bases of patellar tendon grafts used in anterior cruciate ligament reconstruction. *Surg. Radiol. Anat.* 8: 163, 1986.
23. Mikic, Z. The blood supply of the human distal radioulnar joint and the microvasculature of its articular disk. *Clin. Orthop.* 275: 19, 1992.
24. Koebke, J., Schafer, W., and Aust, T. Carpal tunnel topography during endoscopic decompression. *J. Hand Surg. (Br.)* 24: 3, 1999.
25. Mu, L., Yan, Y., Li, S., et al. Transparent morphology of the thoracoabdominal wall. *J. Reconstr. Microsurg.* 17: 611, 2001.
26. Bernardes, A., Esperanca-Pina, J. A., Goyri O'Neill, J., et al. Diaphanization: Modifications of organ weight and volume (in French). *Bull. Assoc. Anat. (Nancy)* 76: 53, 1992.
27. Steinke, H., and Wolff, W. A modified Spalteholz technique with preservation of the histology. *Ann. Anat.* 183: 91, 2001.
28. Zhong, S. Z., Wang, G. Y., Yuan, L., et al. Anatomic basis of venous drainage in donor flaps. *Surg. Radiol. Anat.* 16: 349, 1994.
29. Crouzet, C., Fournier, H., Papon, X., et al. Anatomy of the arterial vascularization of the lips. *Surg. Radiol. Anat.* 20: 273, 1998.
30. Cheung, L. K. The blood supply of the human temporalis muscle: A vascular corrosion cast study. *J. Anat.* 189: 431, 1996.
31. Winters, H. A., Bouman, M. B., Boom, F., et al. The peritoneal free flap: An anatomic study. *Plast. Reconstr. Surg.* 100: 1168, 1997.
32. Travers, V., Kanaujia, R. R., and Ikuta, Y. Resin corrosion cast in experimental evaluation of femoral microanastomosis. *Ann. Chir. Main* 6: 324, 1987.
33. Skinner, S. A., Tutton, P. J., and O'Brien, P. E. Microvascular architecture of experimental colon tumors in the rat. *Cancer Res.* 50: 2411, 1990.
34. Walocha, J. A., Szczepanski, W., Miodonski, A. J., et al. Application of acrylic emulsion Liquitex R (Binney and Smith) for the preparation of injection specimens and immunohistochemical studies: An observation. *Folia Morphol. (Warsz.)* 62: 157, 2003.
35. Haschek, E., and Linderthal, O. T. Ein Beitrag zur praktischen Verwerthung der Photographie nach Rontgen. *Wien Klin. Wochenschr.* 9: 63, 1896.
36. Ferguson, F. R. Roentgenological injection masses: Old and new. *J. Anat.* 59: 297, 1924–25.
37. Dutto, U. Photographies du système artériel obtenues avec les rayons de Röntgen. *Arch. Ital. Biol.* 25: 320, 1896.
38. Dutto, U. Fotografi del sistema arterioso ottenute con raggi Rõntgen. *Rendic Reale Acad. Lincei.* 5: 129, 1896.
39. Braus, H. Uber Photogramme von Metallinjektionen mittels Rontgenstrahlen. *Anat. Anz.* 11: 625, 1896.
40. Gough, J. A. A method of injecting the blood-vessels for roentgenological studies and simultaneously embalming. *Anat. Rec.* 18: 193, 1920.
41. Baumgarten, W. Infarction in the heart. *Am. J. Physiol.* 2: 243, 1899.
42. Frank, O., and Alwens, W. Kreislaufstudien am rontgenschirm. *Munch. Med. Wochenschr.* 57: 950, 1910.
43. Jamin, F., and Merkel, H. *Die Koronararterien des menschlichen Herzens unter normalen und pathologischen Verhaltnissen.* Jena: G. Fisher, 1907.
44. Parker, G. H. Notes on Roentgen-ray injection masses. *Anat. Rec.* 7: 247, 1913.

45. Hinman, F., Morison, D. M., and Lee-Brown, R. K. Methods of demonstrating the circulation in general. *J.A.M.A.* 81: 177, 1923.
46. Cadenat, F. M. Endartérite oblitérante du tronc axillo-huméral droit; repérage du siège de l'oblitération par injection intra-artérielle de lipiodol. *Bull. Mém. Nat. Soc. Chir. Paris* 50: 1149, 1924.
47. Berberich, J., and Hirsch, S. Die roentgenographische Darstellung der Arterien und Venen am Lebenden. *Munch. Klin. Wochenschr.* 49: 2226, 1923.
48. Salmon, M. Artères de la peau: étude anatomique et chirurgicale. Paris: Masson, 1936.
49. Salmon, M. Artères des muscles de la tête et du cou. Paris: Masson, 1936.
50. Schlesinger, M. J. An injection plus dissection study of coronary artery occlusions and anastomoses. *Am. Heart J.* 15: 528, 1938.
51. Schlesinger, M. J. New radiopaque mass for vascular injection. *Lab. Invest.* 6: 1, 1957.
52. Olovson. Beitrag zur Kenntnis des Verbindungen zwischen a. iliaca interna und a. femoralis beim Menschen. *Acta Chir. Scand.* Suppl. 67, 1941.
53. Lindbom, A. Arteriosclerosis and arterial thrombosis in the lower limb: A roentgenological study. *Acta Radiol. Suppl.* 80: 1, 1950.
54. Trueta, J., and Harrison, M. H. M. The normal vascular anatomy of the femoral head in adult man. *J. Bone Joint Surg. (Br.)* 35: 442, 1953.
55. Shehata, R. Radio-opaque modification of Kellner's injection mass. *Acta Anat.* 87: 461, 1974.
56. Rees, M. J., and Taylor, G. I. A simplified lead oxide cadaver injection technique. *Plast. Reconstr. Surg.* 77: 141, 1986.
57. Tan, B. K., Ng, R. T. H., Tay, N. S., et al. Tissue microangiography using a simplified barium sulphate cadaver injection technique. *Ann. Acad. Med. Singapore* 28: 152, 1999.
58. Quinodoz, P., Quinodoz, M., Nussbaum, J., et al. Barium sulphate and soft-tissue radiology: Allying the old and the new for the investigation of animal cutaneous microcirculation. *Br. J. Plast. Surg.* 55: 664, 2002.
59. Jamin, F., and Merkel, H. Stereoscopic skiagrams of the coronary arteries of the human heart under normal and pathological conditions (Abstract). *Arch. Roentg. Ray* 11: 328, 1906–07.
60. Houseman, N. D., Taylor, G. I., and Pan, W. R. The angiosomes of the head and neck: Anatomic study and clinical applications. *Plast. Reconstr. Surg.* 105: 2287, 2000.
61. Taylor, G. I. New approach to vascular injection in fresh cadaver dissection (Discussion). *J. Reconstr. Microsurg.* 20: 457, 2004.
62. Burgio, L., Clark, R. J., and Firth, S. Raman spectroscopy as a means for the identification of plattnerite (PbO2), of lead pigments and of their degradation products. *Analyst* 126: 222, 2001.

2.6.3 Comparison of different investigation methods

Older anatomical investigation techniques relied on the selective injection of blood vessels with either ink[6] or radiopaque material[99]. It is though that selective injection of blood vessels could overestimate the actual anatomical territory of a given vessel since the injectate overflows in adjacent territories via choke vessels[100,101]. However, there is no objective information on this topic in the literature, which could be useful in comparing our results with earlier studies.

2.7 Literature review summary

The DCIA osteocutaneous flap with iliac crest has been one of the major flaps used for mandibular reconstruction since its description in 1979[5,6]. It is known for the large amount of vascularized bone available, the similarity in shape between the iliac crest and the mandible, and its vascular pedicle length and size. Anatomical research has allowed precise characterisation of various flap components and improvements over the original flap design have been achieved. The inner cortex of the iliac crest is mainly supplied by the DCIA through periosteal circulation[6]. This allows the longitudinal splitting of the crest[8,9] to reduce flap bulk and diminish donor site morbidity. The iliac crest can also be osteotomized to better fit the jaw contour as long as its the periosteum is left intact[10]. Others have characterized the contribution of the DCIA to the internal oblique muscle[11], which has been used to facilitate closure of through and through osteomucocutaneous defects of the mandible[12].

The soft-tissue component of the DCIA flap however, has received little attention. Two major problems have halted the development and usage of the DCIA osteomusculocutaneous flap for mandibular reconstruction: the unnecessary bulk brought by the "obligatory muscle cuff" [13-15] and the tethering of the skin to the bone which renders soft tissue placement problematic in complex oromandibular reconstructions[13-15]. Rapid developments in the field of perforator flap surgery could help solve this problem.

Current anatomical descriptions of the DCIA perforators[5,6,13] are conflicting. Pioneering efforts by Safak[13] and Kimata[14,15] at designing a DCIA perforator flaps have had limited success and reliability of the DCIA perforators has been questioned. The exact number and location of perforators, and skin territory of the DCIAP remains unclear.

3 Research questions and hypothesis

Our main research question is: "Is it possible to reliably design and use a DCIA osteocutaneous perforator flap?" To answer this question, three specific questions need to be answered:

- Are there consistent DCIA perforators?
- Do DCIA perforators have common characteristics?
- Do these characteristics allow the dissection of a DCIA osteocutaneous perforator flap?

The research objectives of this thesis are thus:

- To clarify the presence or absence of DCIA perforators.
- To determine a common set of characteristics for the DCIA perforators
- To demonstrate the vascularization of a DCIA osteocutaneous perforator flap.

We hypothesize that it is possible to establish the anatomical basis of a DCIA osteocutaneous perforator flap. This section expands on measurements necessary to answer the research questions and states the research hypotheses.

3.1 Are there DCIA perforators?

The existence of DCIA perforators is assessed through two variables: the presence or absence of perforators, and the number of perforators. Measures: identification and counting of each cutaneous perforators from the DCIA in the lumbar region with the help of angiography and photography. Presence of DCIA perforator(s) in at least 80% of specimen is adequate. This number is generally accepted in clinical practice to say that the vascular anatomy of a flap is reliable.

Hypothesis 1

There are consistent DCIA perforators.

3.2 *Do DCIA perforators have common characteristics?*

The DCIA perforators characteristics pertinent to this research relate to the number of perforators, the perforator diameter, the distance to iliac crest, the distance from ASIS, the pedicle length to deep fascia, the angiosome surface, and the “perforator zone” surface. Measures: Average number of perforators, mean perforator diameter, shortest distance to iliac crest, distance from ASIS, pedicle length to deep fascia, angiosome surface, “perforator zone” surface.

Hypothesis 2

DCIA perforators have a set of common characteristics that allows their clinical location.

3.3 *Do these DCIA perforators characteristics allow the dissection of a DCIA perforator flap?*

The possibility to dissect a DCIA perforator flap is assessed through five criteria: the perforator diameter, the location of perforators, the cutaneous territory supplied by the perforator, the identification of the perforator, and the integrity of the vascularization. These criteria are presented with the corresponding measures.

1) Perforator diameter

Measure : internal diameter >0,5mm.

The cutoff size is set at >0,5mm since the microanastomosis of vessel smaller than 0,5mm is nearly impossible in current clinical practice. Also, Dopplers commonly used to map pre-operatively perforators cannot easily detect vessels smaller than 0,5mm. Internal diameter has been chosen as it is the most accurate method to measure vessel diameters with the lead oxide technique.

2) Location of perforators

The location of the perforator must be precisely described.

Measure : Distance from anatomical landmarks (iliac crest and ASIS).

3) Cutaneous territory

Each perforator should supply an adequate skin region.

Measure : Average perforator zone. Set at 22cm^2, this is the average perforator zone of musculocutaneous perforators, as reported by Cormack and Lamberty[102].

4) Discriminant and confluent identification of the perforator during dissection

a) Discriminating measure. During dissection, the DCIAP should be distinguishable from other perforators in the area.

Measure: presence or absence of a cutaneous nerve accompanying the perforator vessel. Absence of a nerve: DCIA or iliolumbar artery. Presence of a nerve: intercostal or lumbar perforator.

b) Confluent measure. During dissection, confirmation of the DCIAP identification should be possible.

Measures:

Origin of perforator superior to the iliac crest.

Orientation of the pedicle origin in the abdominal wall. Splitting of external oblique fibers reveals an anterior origin of the perforator: DCIA perforator. A posterior origin is from the iliolumbar artery.

5) Demonstrate the integrity of the vascularization of a DCIA osteocutaneous flap with split iliac crest

Measure: Demonstrate by angiography the integrity of the DCIA osteocutaneous perforator flap with split iliac crest vascularization on the cadaveric model.

Hypothesis 3

It is possible to design a

DCIA osteocutaneous perforator flap.

4 Methods

4.1 Body donation and ethics approval

Fresh cadavers are obtained through the Dalhousie University Donor Programme of the Department of Anatomy and Neurobiology. Full ethics approval has been obtained by the Health Sciences Human Research Ethics Board of Dalhousie University.

4.2 Inclusion and exclusion criteria

Fresh cadavers were obtained within 48 hours of death through the Dalhousie Donor Programme. Exclusion criteria included: evidence of severe peripheral vascular disease, extensive muscle atrophy, extensive surgical scars, scars over the area of interest, pressure sores, post-mortem body degradation, evidence of skin metastasis or neoplasia, missing limb, major joint fusion, disarticulation or prosthesis suggesting extensive surgical exploration and anatomical landmark distortion.

Embalmed cadavers were made available through the Gross Anatomy Laboratories of the department of Anatomy and Neurobiology. Complete bodies were considered for dissection.

4.3 Preliminary studies

This section relates our experience with the study of perforators on embalmed and fresh cadavers. We have experienced with various methods described in the literature and found that the lead oxide-gelatine technique in fresh cadavers was the only suitable technique to study fine vessels such as perforators. Also, older studies were made by selective injection of ink in vessels. Although technically challenging, we demonstrated the difference in cutaneous territories measured by photography and by angiography.

4.3.1 Embalmed cadavers

4.3.1.1 Gross dissection

Because of limited supply of fresh cadavers and the availability of a large number of embalmed bodies, preliminary DCIA dissection studies were attempted on embalmed cadavers. Most embalmed cadavers available through the Anatomy and Neurobiology Department could not be used because their abdomen had been previously dissected near the iliac crest. It was also found that when perforator vessels were difficult to identify when they were not injected with gelatine or latex, especially in discoloured and rigid embalmed tissues. Vessel measurements such as vessel diameter and cutaneous distribution could not be made either, so the usage of embalmed cadavers was abandoned.

4.3.1.2 Ink injection

One embalmed body was used to test ink injections. The DCIA was selectively cannulated at its origin on the external iliac artery. Skin staining did not occur as expected. The DCIA was then dissected out. The main trunk was stained but not its smaller branches. Microscopic examination revealed intravascular clots in fine vessels, while others were empty without any apparent reason. Macroscopic findings showed that adjacent large vessels were stained, suggesting that ink preferred flowing through the larger anastomotic system of the DCIA rather than perfusing smaller vessels. While large calibre vessels have a readily apparent lumen, small vessels are inelastic and have a constricted lumen. We concluded that the rigidity of tissues secondary to formalin rendered injection studies in embalmed cadavers unreliable.

4.3.2 Fresh cadavers

Fresh cadavers have been used by the Plastic Surgery Laboratory in the past. Lead oxide-gelatine injection technique has been proven to be the best technique to study vascular anatomy[30,31,103-105]. However, earlier studies on the DCIA angiosome were made with selective injection of ink in the DCIA. It is thought that this method overestimates the true anatomical territory[100,101], but this has never been demonstrated.

4.3.2.1 Ink territories versus lead oxide territories

Because selective ink injection in a vessel usually requires extensive dissection of a vessel and that the whole body lead oxide injection technique requires maximal tissue integrity to prevent tissue spillage of lead oxide, it was thought that it was impossible to compare the two methods in a same specimen.

The lumen of DCIA and the SCIA were easily accessible with very minimal dissection at the usual lead oxide injection site. The lumens were cannulated with Arrow arterial catheters (Arrow International, Reading, Pennsylvania, USA). Four percent ink was injected in each artery by increments of 10cc. Skin territories were documented by photography. The injections were stopped at 30 cc as the skin territories did not expand more and ink backflowed through the other cannulas. The cannulas were capped for technical reasons. The body was flushed with saline and injected with the lead oxide-gelatine technique as described later.

The skin territory supplied by the SCIA and the DCIA was removed en bloc, in continuity with the DCIA and the iliac crest. Pictures of the skin staining were taken, the flap was x-rayed and territories obtained by photography and angiography were superimposed in Photoshop CS (Adobe Systems Incorporated, San Jose, California, USA). Surface area measurements were calculated with Scion Image Beta 4.02 (Scion Corporation, Frederick, Maryland, USA) (Table 2). This demonstration suggests that selective vessel injection can overestimate the anatomical territory.

Table 2. Comparison of cutaneous territories as measured by photography and angiography.

	Surface area by selective vessel injection (ink)	Surface area by whole body injection (lead oxide)	Overestimation of anatomical territory by selective vessel injection
DCIA	153,3 cm^2	73,2 cm^2	209 %
SCIA	174,4 cm^2	66,6 cm^2	262 %

4.4 Technique

4.4.1 Presentation of article 2

This article presents the results obtained during our investigations on the anatomical basis of the DCIA perforator flaps. It constitutes the core of this thesis by article. Its format and content is in accordance with requirements of Plastic and Reconstructive Surgery.

Dr Bergeron designed the experiment, collected results and wrote the article.

4.4.2 Article 2: The anatomical basis of the deep circumflex iliac artery perforator flap (DCIAP) with iliac crest

Bergeron, L, Tang, M, Morris, SF. The anatomical basis of the deep circumflex iliac artery perforator flap (DCIAP) with iliac crest. *Plast Reconstr Surg. (Accepted for publication). Reproduced with permission by the Editor.*

The anatomical basis of the deep circumflex iliac artery perforator flap (DCIAP) with iliac crest

Authors: Leonard Bergeron, MD, CM
Maolin Tang, MD
Steven F Morris, MD, MSc, FRCS(C)

Affiliation :

Department of Anatomy and Neurobiology and Surgery, Dalhousie University, Halifax, Nova Scotia, Canada.

Corresponding author contact information page

Dr Steven F Morris
Division of Plastic Surgery,
Rm 4443, 1796 Summer Street
Halifax, NS, B3H 3A7 Canada.
Tel No: (902) 473 7054
Fax No: (902) 473 8773
Email: [redacted]

Awarded the Best Paper Award of the GAM Canada (Group for the Advancement of Microsurgery, Canada) 26th Annual Meeting, Nanaimo, British Columbia, Canada on June 8th 2005.
Presented in part at: 50th Anniversary meeting of the Plastic Surgery Research Council, Toronto, Ontario, Canada. May 20th 2005.
Presented in part at: Plastic Surgery 2005, Chicago, Illinois, USA. September 28th 2005.

Structured abstract

Background: Perforator flaps are increasingly utilized due to advantages including reduced flap bulk, less donor site morbidity and more donor site options. The deep circumflex iliac artery (DCIA) osteomusculocutaneous flap with iliac crest has been one of the most useful flaps used for mandibular reconstruction. However, its use has been limited by its bulkiness and added donor-site morbidity due to the inclusion of an "obligatory muscle cuff" of abdominal muscle. Early results at designing a DCIA perforator (DCIAP) flap to circumvent this problem have been varied. Details regarding the location, number, and reliability of DCIA musculocutaneous perforators have been conflicting. The purpose of this article is to comprehensively document the anatomical basis of the DCIAP flap.

Methods: Six fresh bodies underwent whole body lead oxide injection (n=12 specimens). Landmarks were identified with radiopaque markers. Dissection, angiography and photography were used to document the precise course of individual perforators in the flank region. Angiograms were assembled with Adobe Photoshop and analyzed with Scion Image Beta.

Results: An average of 1.6 DCIA perforators with a diameter of 0.7mm were present in 92% of specimens. Perforators were located 5-11 cm posterior to the anterior superior iliac spine, 1-35mm superior to the iliac crest, with a perforator zone of 31 cm^2. The DCIA perfused the medial aspect of the iliac crest.

Conclusion: This article establishes the anatomical basis of the DCIAP flap with iliac crest. This perforator flap, along with a split iliac crest will likely diminish donor site morbidity and facilitate oromandibular reconstruction.

Keywords:

Perforator flap, deep circumflex iliac artery perforator flap, DCIA, DCIAP, surgical flap, mandible, bone transplantation, osteocutaneous flap, osseocutaneous flap, bone and bones/blood supply, ilium, human, cadaver, arteries/anatomy, abdominal wall/blood supply, skin/blood supply, lead/diagnostic use, injections, arterial, angiography.

Introduction

The classic deep circumflex iliac artery (DCIA) osteomusculocutaneous flap with iliac crest has been one of the most commonly used flaps for mandibular reconstruction[1-7] since its description by Taylor in 1979[8,9]. The iliac crest osteomusculocutaneous flap provides a large segment of vascularized bone that is similar to the shape of the mandible[10], and its vascular pedicle is long and of large diameter[8,9]. The medial (inner) cortex of the iliac crest is mainly supplied by the DCIA through periosteal circulation[9]. This allows the longitudinal splitting of the crest[3,6] to diminish donor site morbidity and osteotomization to better fit the jaw contour if the periosteum is preserved [11].

Despite the numerous advantages of using the iliac crest, the widespread use of the DCIA flap has been limited by the unnecessary bulk of the "obligatory muscle cuff" and the tethering of the skin to the bone which renders soft tissue placement problematic in complex oromandibular reconstructions [12-14]. Pioneering efforts by Safak[12] and Kimata[13,14] at designing a DCIA perforator (DCIAP) flap to reduce the soft-tissue bulk of the flap and diminish donor site morbidity have had limited success [13,14]

The macroscopic vascular anatomy of the DCIA and its contribution to the skin overlying the iliac crest has been established[8,9,15]. However, current anatomical descriptions of its cutaneous perforators[8,9,12] are conflicting. Taylor found an average of 6 cutaneous perforators above the iliac crest[8,9]. Safak found a series of musculocutaneous perforators in 70% of dissections and a single dominant perforator in 30%. The exact number, location, and skin territory of the deep circumflex iliac artery perforators therefore remains unclear and might explain the failure to locate them surgically[13,14]. The main purpose of this article is to describe the anatomy of DCIA perforators to provide the anatomical basis of the DCIA perforator flap. Secondary goals include reviewing the surgical anatomy of the DCIA and its contribution to the iliac crest with the whole body lead oxide-gelatine technique.

Methods

Twelve specimens from 6 cadavers were obtained through the Dalhousie University Donor Programme. The project was approved by the Health Sciences Human Research Ethics Board of the institution.

Anatomical landmarks were identified: anterior superior iliac spine (ASIS), iliac crest, costal margin, anterior and posterior midline. The 6 fresh cadavers underwent whole body radiopaque contrast injection according to a modified lead oxide-gelatine technique[16]. A femoral artery and vein were accessed through a short incision and minimal dissection in the inguinal region. The vessels were cannulated, the blood flushed, and the lead oxide-gelatine mixture was injected. The mixture was allowed to set by freezing the cadaver. Appropriate sections of the cadavers were completed, and the specimen was thawed prior to dissection. In one specimen, the DCIA and its classic salvage pedicle, the superficial circumflex iliac artery (SCIA)[13,14], were selectively injected with 30mL of 4% ink prior to lead-oxide injection.

The cutaneous perforators in the flank and upper thigh regions were dissected carefully at the level of the deep fascia. Radiopaque markers were placed on perforating vessels and the integument was removed. Dissection notes, angiograms, and photographs of the dissected tissues were taken. These steps were repeated for each layer of the abdominal wall (external oblique, internal oblique, transversus abdominis muscles) and for the iliac crest until all source arteries in the flank area were identified.

Angiograms were then digitalized and assembled in Adobe Photoshop CS (Adobe Systems Incorporated, San Jose, California, USA). The location and course of individual perforators was carefully reconstituted according to dissection notes, photographs and angiograms. The DCIA angiosome and adjacent territories were outlined for each dissection according to criteria established by Cormack and Lamberty[17]. Vessel measurements and distance to landmarks were made directly on the original angiograms. Cutaneous angiosomes and perforator zones (the skin territory perfused by a single perforator) were calculated with Scion Image Beta 4.02 (Scion Corporation, Frederick, Maryland, USA) and Microsoft Excel 2003 (Microsoft Corporation, Redmond, Washington, USA) based on measurements from the digitalized angiograms. Results were compiled and analyzed with Microsoft Excel 2003.

Results

DCIA perforators were found in all but one dissection (n=11; 92%). Perforators were located on the superior aspect of the iliac crest, 5 to 10.5 cm posterior to the anterior superior iliac spine (ASIS). Table 1 presents the details of the anatomy of DCIA perforators. A specimen where the DCIA perforator was absent was excluded from analysis. Also, one specimen had one of five perforators anterior to the ASIS. This perforator was excluded from analysis, as it would likely not be included in a standard DCIA flap. Figure 1 presents the distribution of DCIAPs along the iliac crest.

The flank region was found to be richly vascularized from a number of source arteries (Figure 2). Perforators from the DCIA, SCIA, intercostal, lumbar and iliolumbar arteries were found in close proximity in this region. During dissection, many perforators were encountered in the area superior to the iliac crest. It was observed that the DCIA perforator(s) could be distinguished from intercostal and lumbar perforators as they did not have an accompanying cutaneous nerve. Distinction between DCIA and iliolumbar perforators could be made by spreading the external oblique muscle fibres at the base of the perforator. DCIA perforators had an anterior origin and iliolumbar perforators had a posterior orientation. These findings were supported by the angiographic studies which confirmed the source artery of individual perforators.

The main trunk of the DCIA originates from the external iliac artery, just deep and superior to the inguinal ligament. It then ascends on the medial aspect of the iliac bone towards the ASIS (Figure 3). En route, it sends one or two ascending branches to the abdominal wall. The ascending branch travels sandwiched between the transversus abdominis and the internal oblique muscles. The DCIA (the transverse branch of the DCIA) continues travelling along the iliac crest, between the insertion of the transversus abdominis and the internal oblique. It gives small branches to the iliacus muscle and sends 1-2 musculocutaneous perforators to the overlying skin before its main trunk anastomoses with the lumbar and/or iliolumbar arteries (Figure 4). *Venae comitantes* accompany the DCIA and its perforators. The venous system converges at the level of the inguinal ligament to form a single vein that drains in the external iliac vein.

The DCIA provides arterial supply to the iliac crest segment included in a DCIA flap by two routes. In the first pathway, the DCIA's main trunk or its transverse branch sends a few branches to the periosteum of the medial cortex of the iliac crest near the ASIS (figure 2). In the second pathway, the DCIA transverse branch, as it travels along the iliac crest, sends off small branches to the iliacus muscles. These branches eventually reach the underlying periosteum and anastomose with other periosteal vessels.

Discussion

The classic DCIA osteomusculocutaneous flap has been well described[8,9] and has remained for many years the gold standard for oromandibular reconstruction because of the large bone stock available, the similar shape of the iliac crest and the mandible, and the large calibre of the DCIA. It has fallen out of favour somewhat because of flap bulk and donor site morbidity.

The concept of perforator flaps enables surgeons to precisely include the required tissues in flaps elevated and transferred[18]. The harvest of tissues simply to protect flap pedicle vessels is therefore unnecessary. This decreases flap bulk and increases its versatility. Also, pedicle length is usually increased and donor site morbidity is reduced. By excluding unnecessary muscular components from the DCIA flap, and consequently leaving the different muscular layers of the abdominal intact, donor site morbidity and flap bulk can be reduced. This necessitates a better characterisation of perforators in order to locate, identify, and dissect such fine vessels. This study looks specifically at the anatomy of the DCIAPs with the whole body lead oxide-gelatine injection technique[16]. The underlying assumption is that a better understanding of the distribution and characteristics of these perforators will provide a roadmap to the DCIAPs and increase DCIAP flap success rate.

Taylor *et al.*[9] established the anatomical basis of the classic DCIA osteomusculocutaneous flap. The DCIA was selectively injected with ink in 40 specimens from 40 cadavers. Information was collected on the anatomy of the DCIA main trunk, its ascending branch, its transverse branch, location of the skin paddle, and perfusion of the iliac crest by the DCIA. Thirty angiograms of the DCIA on living subjects were also used to confirm the gross anatomy of the DCIA. The DCIA was found to give an average of 6 cutaneous perforators in a 2.5 cm wide area extending anteriorly from the ASIS, to 6 cm posteriorly, and bordered inferiorly by the iliac crest. The authors described the presence of a "dominant perforator" in all cases.

In Taylor's original description of this flap[8,9], details on the DCIAPs were obtained from counting cutaneous perforators as they emerged from the external oblique during abdominal lipectomy in 10 patients. As there is no doubt that DCIA perforators can be found in this region, as demonstrated by this study, prior ink injection studies[9] and clinical cases[8], it is likely that their number may have been somewhat overestimated. In our study, a similar number of perforators were encountered in the area during dissection superficial to the external oblique and within a few centimetres superior to the iliac crest. Dissection of individual perforators to their source artery combined with precise angiographic tracing of these vessels with radiopaque markers has revealed that some of these perforators are in fact from other source arteries (intercostal, lumbar and iliolumbar perforators). We found that the actual number of perforator is probably lower than that originally described.

Safak *et al.*[12] performed 20 dissections on 10 fresh cadavers to study the distribution of DCIA perforators, along with two case reports of DCIA perforator flaps. The DCIA was not injected with ink or radiocontrast. DCIAPs were found in all dissections. As opposed to Taylor, they did not always identify a "dominant perforator". Instead, the authors report a series of small musculocutaneous perforators in 70% of cases (0,3-0,5mm external diameter), and the presence of a dominant musculocutaneous perforator in 30% of cases (1,5 mm external diameter). We have not observed these patterns of small and large perforators in this study during dissection or during angiographic analysis. This variation in vessel size might be a limitation of the technique used by the authors. Precise diameter measurements are difficult to perform on perforators of fresh cadavers that have not been injected with gelatine or latex. Empty perforator lumens tend to collapse and give false measurements depending on kinking or stretching exerted on vessels to expose pedicles. The gelatine used in the lead oxide technique keeps the lumens opened and vessels appear to be less subject to mechanical distortion during measurements.

Skin territory results are difficult to compare with those reported in the literature as published results are often obtained through ink injection studies. These selective vessel injection studies are thought to provide inaccurate information on the exact size of an anatomical territory[19,20]. This might be due to the fact that the intra-angiosomal content can spill into adjacent vascular territories via choke vessels during the injection. Whole body radio-contrast injections are more reliable to determine vascular anatomical territories. Based on angiographic criteria established by Cormack and Lamberty[17], angiosomes and perforator zones can be objectively delineated. Cormack and Lamberty also reported, based on whole-body barium injection studies, an average perforator zone of $22cm^2$ for individual musculocutaneous perforators of the body[17]. The average perforator vascular zone found in this study of the DCIA is $31cm^2$.

The cutaneous territories measured here are (static) anatomical vascular territories. A cutaneous perforator zone is the cutaneous territory perfused by a single perforator. A cutaneous angiosome is the cutaneous territory perfused by a named artery. An angiosome is made of one or more perforator zones depending on the number of perforators. The perforator zone is thought to be the smallest size of a given flap since designing a smaller skin paddle would entail the risk of not including a perforator in the flap[17]. Clinical research will need to be conducted to define the exact dynamic (physiological) territory of the DCIA, which can not be studied on a static, anatomical model. Our findings demonstrate the presence of a rich network of anastomotic choke vessels communicating with adjacent perforator zones. McGregor and Morgan[21] have reported that vascular territories can extend beyond their anatomical territory if an adjacent artery is occluded. It would therefore be safe to predict that the actual viable skin paddle will be larger than the perforator zone.

In all cases, the portion of the iliac crest usually included in a flap (2.5 cm thick section of the medial crest cortex) was perfused by the DCIA through a rich periosteal network along its medial cortex. Figure 4 demonstrates that the vascular integrity of the flap can be preserved by raising a DCIAP flap with a split iliac crest[3,6]. Splitting the iliac crest further reduces morbidity of the donor site[3,6].

In a clinical setting, the DCIA osteocutaneous perforator flap could be indicated for combined bone and soft tissue defects such as for mandibular reconstruction. Based on the information presented in Table 1, the DCIAP should be located with a Doppler in a 4 x 6 cm rectangular area on the superior aspect of the iliac crest, 5 cm posterior to the ASIS (figure 5). The skin paddle should be centered on this rectangular area. A superior to inferior dissection, through a superior skin paddle incision only would allow identification of the DCIA perforator(s). Dissection and angiographic findings show that vascular pedicles encountered which are accompanied by a nerve are likely to be intercostal or lumbar perforators. If there is a doubt concerning the source vessel of a perforator when approaching the iliac crest, gentle splitting of the external oblique fibres will reveal to source artery of that perforator. A posterior origin suggests that the source vessel is the iliolumbar artery while an anterior origin suggests that it arises from the DCIA. In the advent that the DCIA is aberrant or injured during dissection, the superior skin incision could be sutured back, or the skin paddle could be raised on the SCIA[13,14,22]. Once the DCIA perforator is isolated, the lower skin incision of the skin island can be performed and the rest of the operation proceeds as usual.

Although this flap appears to be a promising osteocutaneous flap, several limitations persist. Surgeons should be familiar with the vascular anatomy of the region, especially in the event of an absent or aberrant DCIAP. The SCIA (Figure 4) has been suggested as an alternate pedicle to rescue the skin island[13,14]. The advent of Multidetector-row helical CT usage for perforator location[23] will likely help screening out pre-operatively the 8% of patients lacking a DCIA perforator. It might also help gather anatomical information more quickly than the laborious and time-consuming whole body injection studies[16,24], which is still the method of choice to observe fine vascular structures. The split iliac crest DCIAP flap may yield the lowest donor site morbidity results but could be technically very challenging.

Conclusion

This article establishes the anatomical basis of the DCIAP flap with iliac crest. It reports with greater accuracy the size and location of DCIAPs. One or two perforators of significant size are usually located along the iliac crest, 5-11 cm posterior to the ASIS. It offers a large quantity of bone on a pedicle of large diameter. The mobility of the skin component allows better tissue positioning during complex reconstructions. The exclusion of abdominal wall musculature, along with a split iliac crest design will likely facilitate donor site closure and diminish the incidence of hernias. Perforator flaps that include bone and skin are few. The DCIAP flap with iliac crest will likely allow refinement of current surgical techniques for mandibular reconstruction.

Acknowledgements:

Funding provided by the Capital District Health Authority Research Foundation, Halifax, Nova Scotia, Canada, and the Department of Surgery, Dalhousie University, Halifax, Nova Scotia, Canada.

References

1. Disa, J.J., and Cordeiro, P.G. Mandible reconstruction with microvascular surgery. *Semin. Surg. Oncol.* 19: 226, 2000.

2. Daniel, R.K. Mandibular reconstruction with free tissue transfers. *Ann. Plast. Surg.* 1: 346, 1978.

3. Taylor, G.I., and Daniel, R.K. Aesthetic aspects of microsurgery: composite tissue transfer to the face. *Clin. Plast. Surg.* 8: 333, 1981.

4. David, D.J., Tan, E., Katsaros, J. et al. Mandibular reconstruction with vascularized iliac crest: a 10-year experience. *Plast. Reconstr. Surg.* 82: 792, 1988.

5. Jewer, D.D., Boyd, J.B., Manktelow, R.T. et al. Orofacial and mandibular reconstruction with the iliac crest free flap: a review of 60 cases and a new method of classification. *Plast. Reconstr. Surg.* 84: 391, 1989.

6. Shenaq, S.M. Refinements in mandibular reconstruction. *Clin. Plast. Surg.* 19: 809, 1992.

7. Shenaq, S.M., and Klebuc, M.J. Refinements in the iliac crest microsurgical free flap for oromandibular reconstruction. *Microsurgery.* 15: 825, 1994.

8. Taylor, G.I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Clinical work.

Plast. Reconstr. Surg. 64: 745, 1979.

9. Taylor, G.I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Experimental work. *Plast. Reconstr. Surg.* 64: 595, 1979.

10. Manchester, W.M. Some technical improvements in the reconstruction of the mandible and temporomandibular joint. *Plast. Reconstr. Surg.* 50: 249, 1972.

11. Urken, M.L. Composite free flaps in oromandibular reconstruction. Review of the literature. *Arch. Otolaryngol. Head Neck Surg.* 117: 724, 1991.

12. Safak, T., Klebuc, M.J., Mavili, E. et al. A new design of the iliac crest microsurgical free flap without including the "obligatory" muscle cuff. *Plast. Reconstr. Surg.* 100: 1703, 1997.

13. Kimata, Y. Deep circumflex iliac perforator flap. *Clin. Plast. Surg.* 30: 433, 2003.

14. Kimata, Y., Uchiyama, K., Sakuraba, M. et al. Deep circumflex iliac perforator flap with iliac crest for mandibular reconstruction. *Br. J. Plast. Surg.* 54: 487, 2001.

15. Taylor, G.I. The angiosomes of the body and their supply to perforator flaps. *Clin. Plast. Surg.* 30: 331, 2003.

16. Tang, M., Geddes, C.R., Yang, D. et al. Modified lead oxide-gelatin injection technique for vascular studies. *Chin J Clin Anat.* 1: 73, 2002.

17. Cormack, G.C., and Lamberty, B.G. Cadaver studies of correlation between vessel size and anatomical territory of cutaneous supply. *Br. J. Plast. Surg.* 39: 300, 1986.

18. Geddes, C.R., Morris, S.F., and Neligan, P.C. Perforator flaps: evolution, classification, and applications. *Ann. Plast. Surg.* 50: 90, 2003.

19. Taylor, G.I. Invited discussion: "New approach to vascular injection in fresh cadaver dissection" (J Reconstr Microsurg 2004;20:311-315). *J. Reconstr. Microsurg.* 20: 457, 2004.

20. Taylor, G.I. Invited discussion: "Blood supply of the abdomen revisited, with emphasis on the superficial inferior epigastric artery" (Plast Reconstr Surg 1984;54:657-70). *Plast. Reconstr. Surg.* 74: 667, 1984.

21. McGregor, I.A., and Morgan, G. Axial and random pattern flaps. *Br. J. Plast. Surg.* 261973.

22. Koshima, I., Nanba, Y., Tsutsui, T. et al. Sequential vascularized iliac bone graft and a superficial circumflex iliac artery perforator flap with a single source vessel for established mandibular defects. *Plast. Reconstr. Surg.* 113: 101, 2004.

23. Clavero, J.A., and Masia, J. Multidetector-row CT in the planning of

abdominal perforator flaps. In Blondeel, P.N., Morris, S.F., Hallock, G.G. et al. (Eds.), *Perforator flaps: Anatomy, technique, & clinical applications*, St. Louis: Quality Medical Publishing, Inc., 2006. Pp. 103.

24. Rees, M.J., and Taylor, G.I. A simplified lead oxide cadaver injection technique. *Plast. Reconstr. Surg.* 77: 141, 1986.

Figure Legends

Figure 1. Distribution of DCIA perforators along the iliac crest.

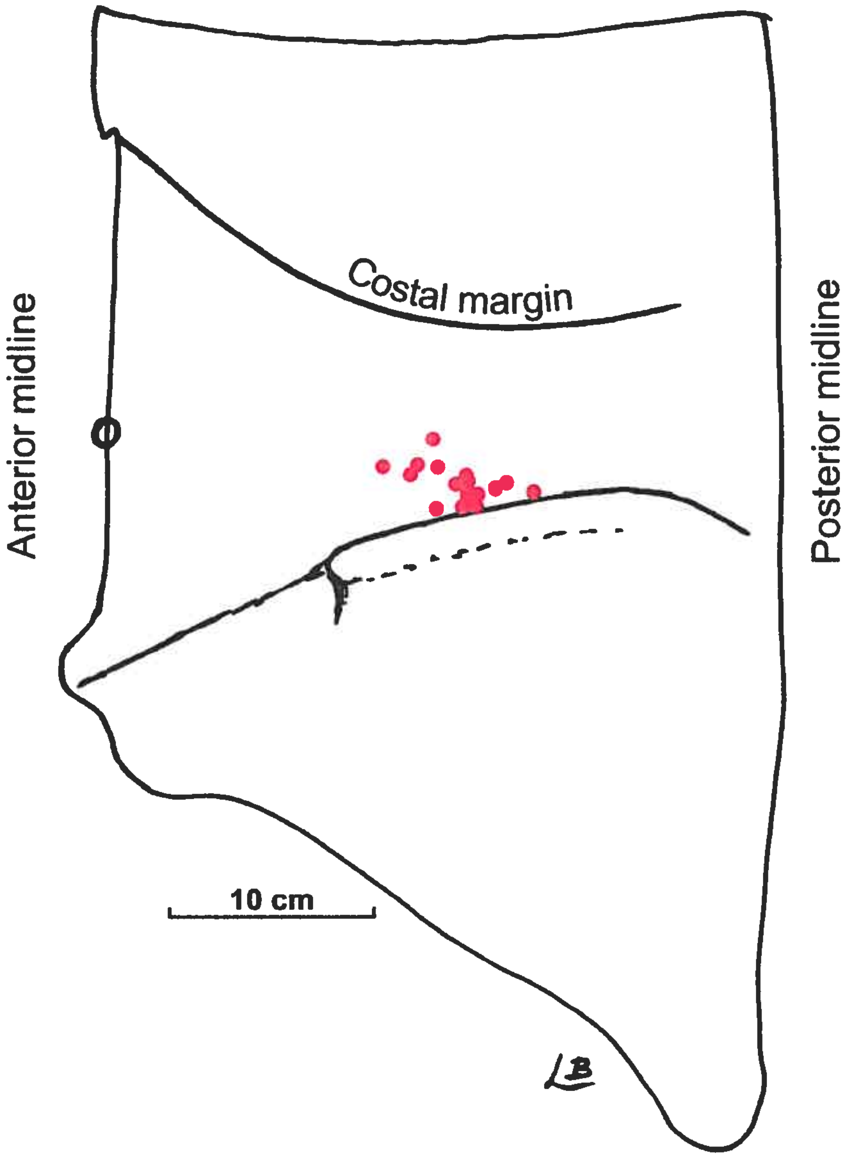


Figure 2. The DCIA cutaneous angiosome. Note angiosomes in close proximity to the DCIA in this cutaneous specimen of the left flank prepared with the whole body lead oxide and gelatine technique. 1: DCIA, 2: superficial circumflex iliac artery, 3: intercostal, 4: iliolumbar, 5: lumbar perforators. Radiopaque markers identify the position of M: mid-axillary line, N: Nipple, X: xiphoid, U: umbilicus, P: pubic symphysis.

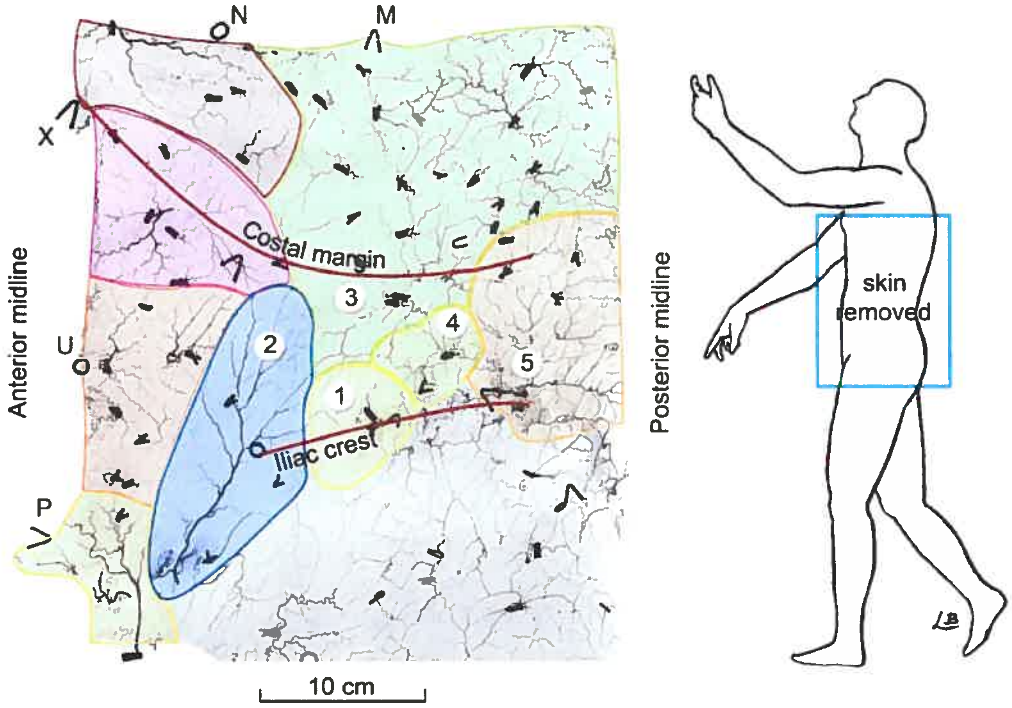


Figure 3. Contribution of the DCIA to the iliac crest. Angiogram of the flank area with skin, peritoneum, iliacus, and internal organs removed. 1: DCIA, 2: iliolumbar, 3: 4th lumbar, 4: External iliac artery. 1a: Ascending branch of the DCIA, 1b: transverse branch of the DCIA. The shaded yellow area represents a typical bone segment that could be used for mandibular reconstruction. The DCIA sends off branches to the medial (inner) periosteum of the iliac crest through small branches (yellow arrows). It then anastomoses with the iliolumbar and lumbar arteries. Note that the transverse branch of the DCIA sends a cutaneous perforator to the skin as identified with a radiopaque marker (red arrow).

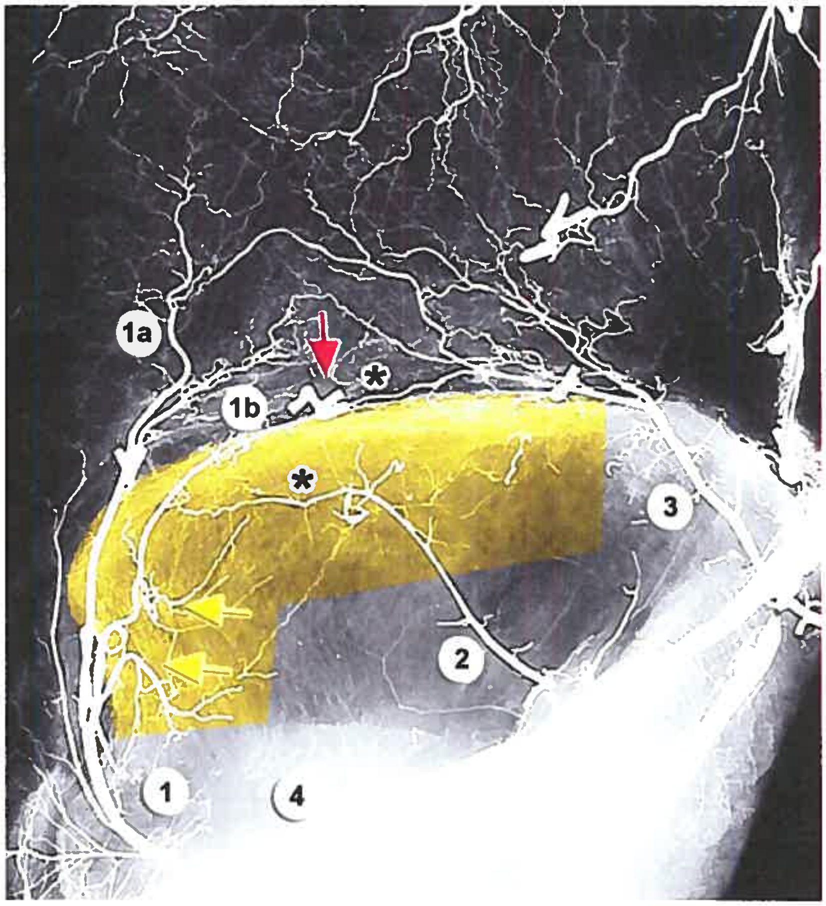


Figure 4. Angiogram of the DCIAP flap with split iliac crest. The superficial circumflex iliac artery (SCIA) is the classic pedicle used to rescue the skin paddle in case of damage to the DCIAP during dissection. Note that a perforator flap design can facilitate tissue components separation and potentially facilitate their positioning. The venous system (not shown) parallels the arterial system. Ink injection territories were outlined for readers more familiar with ink injection studies. The radiopaque ring identifies the anterior superior iliac spine. The radiopaque U marks the lateral midline (mid-axillary line).

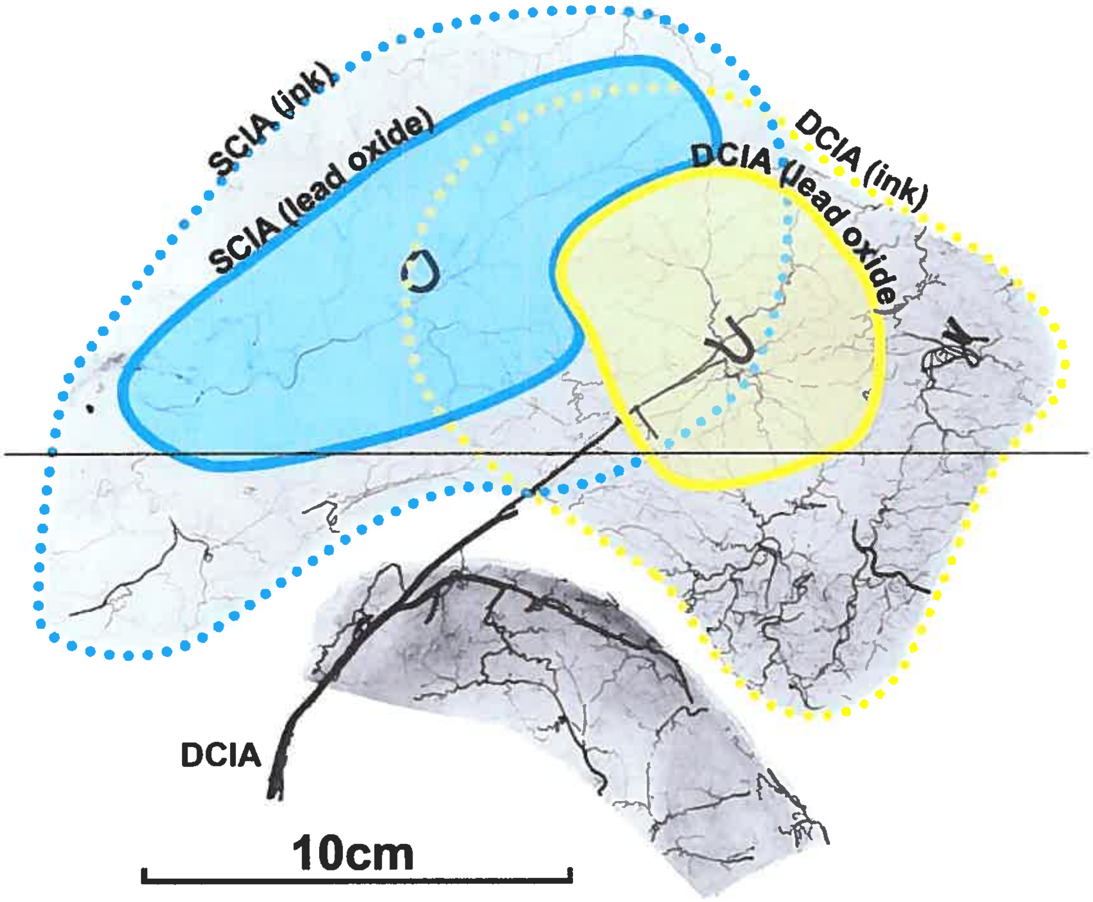


Figure 5. Location of the DCIAPs. DCIAPs were found in a 6x4 cm rectangular area superior to the iliac crest, 5 cm posterior to the anterior superior iliac spine ASIS. Because the DCIA does not always have a perforator, the dissection should proceed from superior to inferior through the superior skin incision of the elliptical skin island. Once the DCIAP is identified, the inferior skin incision can be completed and dissection proceeds as usual.

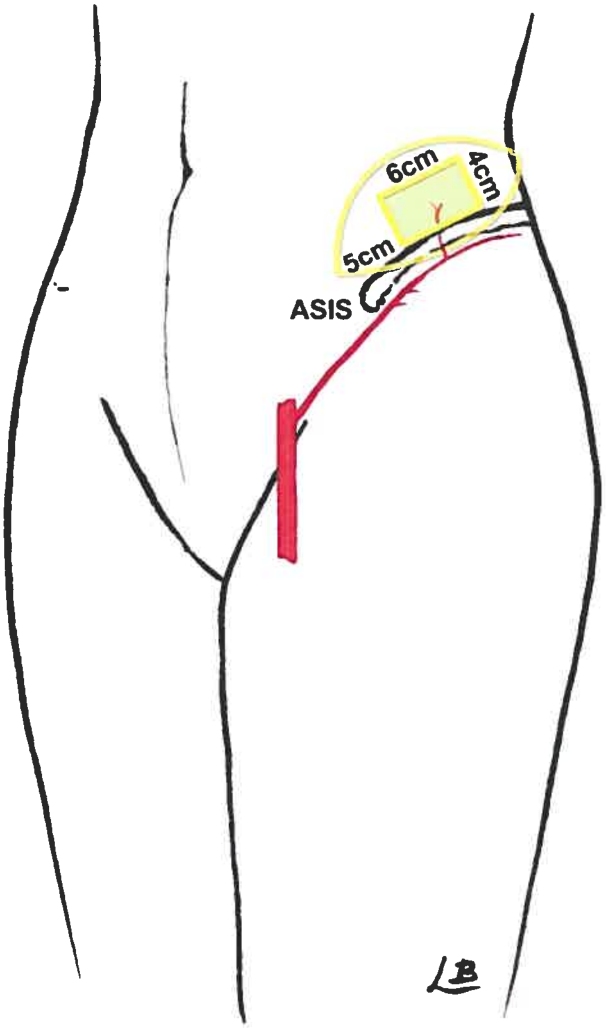


Table 1. Deep circumflex iliac perforators

	Value	Range
Presence of a perforator	92 %	
Average number of perforators	1.6	0-5
Mean perforator diameter	0.7 mm	0.5-1.8 mm
Average distance to iliac crest	8 mm	1-35 mm
Distance from ASIS	7.4 cm	5-10.5 cm
Pedicle length to deep fascia	1.3 cm	0.5-2.9 cm
Angiosome surface	54 cm^2	26-69 cm^2
Perforator zone surface	31 cm^2	13-68 cm^2

4.4.3 Whole body lead oxide-gelatine infusion

6 fresh cadavers underwent whole body lead oxide and gelatine injection[30] (c.f. Technique section of the manuscript entitled “A review of vascular injection techniques for the study of perforator flaps). Bodies were split sagitally in the midline. A total of 12 hemi-trunks were available for studying.

4.4.4 Dissection

With the help of angiography and photography, each layer of the abdomen was dissected and individual perforators traced back to their respective source artery. Vessel internal diameters were measured directly on the original angiograms. Angiograms were then digitalized with a Nikon Coolpix 5000 digital camera (Nikon Corporation, Tokyo, Japan), assembled in Adobe Photoshop CS (Adobe Systems Incorporated, San Jose, California, USA), and surface measurements were done with Scion Image beta 4.02 (Scion Corporation, Frederick, Maryland, USA).

5 Results

[See results section in the article/manuscript entitled “Deep circumflex iliac artery osteocutaneous perforator flap”]

6 Discussion

In this section, we will review the main findings of this study and discuss their application in clinical practice. It is complementary to the discussion found in the previous article. Limitations of the cadaveric model are also discussed.

6.1 Review of main findings

The DCIAP were present in 92% of specimen. A 31cm^2 perforator zone was found centered on perforators 5-10 cm posterior to the ASIS along the iliac spine. During dissection, DCIAP could be differentiated from the intercostals and lumbar perforators by the absence of a nerve travelling with the DCIAP pedicle. In the presence of an iliolumbar perforator along the iliac crest, it could be identified by exposing the base of the perforator: an anterior origin for the DCIAP and a posterior origin for the iliolumbar perforator.

6.2 Significance of main findings

The first hypothesis, "There are DCIA perforators" is confirmed. DCIAP were present in 92% of specimen, and absent in one. This constitutes an acceptable rate of anatomical variation.

The second hypothesis, "DCIA perforators have a set of common characteristics that allows their clinical location" was also confirmed. The perforators were located in a definable area along the iliac crest which is compatible with surgical isolation of these perforators.

The third hypothesis, “It is possible to design a DCIA osteocutaneous perforator flap” was confirmed. The continuity of the DCIA system along the iliac crest and through the abdominal to the overlying skin has been observed through photography and angiography. The integrity of the vascularization on the DCIAP flap design has also been demonstrated in the article entitled “Deep circumflex iliac artery osteocutaneous perforator flap”, where the continuity of the DCIA vascularization can be observed through the proposed design in an actual dissection. Therefore, the conclusion to our main research question is that it is possible to design a DCIAP osteocutaneous perforator flap.

6.3 *Limitations*

6.3.1 Limitations of the method

Throughout this paper, we make the assumption that these findings can be applied to human models. There are a few things that should be clarified when transposing these static anatomical variables to a living, dynamic human model.

6.3.1.1 Vessel measurements

In our experience, the lead oxide-gelatine injection technique has been the most reliable way to dissect, measure, and document the course the perforator vessels. Cadaveric vessels tend to collapse and this make identification and dissection of fine vessels difficult. This was recognized by Swammerdam (1637-1680) who injected colored wax in arteries and veins[106] to facilitate dissection and preservation of the structures. The lead oxide-gelatine included in the mixture keeps vessels patent and its bright orange color facilitates identification of fine vessels.

During the dissections, it would be difficult and tedious to measure and chart the external diameter of perforating vessels as their source vessel is not always known. We have found by trial and error that the easiest and fastest way to measure and document vessel diameters was after identification of the respective source artery, which can only be done after dissection and x-raying of all tissue layers. The diameters obtained are thus internal diameters. This complicates comparison with others reports in the literature because they are usually external diameter. However, the internal diameter appears to be a more clinically relevant parameter than the external diameter because ultimately, it is the lumen of the blood vessel that allows circulation of blood to the flap, and inclusion of the vessel wall thickness in the measurements acts as a confounding factor. Cormack and Lamberty have also used radiographic internal diameters[102].

Other factors that might affect measurements are the manual pressure applied by the operator on the injectacte seringe or the proximity of the injection port to the studied vessels. Both factors could possibly affect intra-arterial perfusion pressure. The mechanical properties of cadaveric vessel walls are not known and could be potentially affected by this. However, measurement of vessel sizes obtained in bodies injected by different operators and different injection sites are similar and this has allowed adequate and reliable comparison of vessel measurements between bodies.

6.3.1.2 Cutaneous territory measurements

Measurement errors for surface area are inherent to the technique. The integument has to be removed from its three-dimensional conformation and laid flat on a surface for x-raying. It is also necessary to directly visualise the arterial pedicle to identify cutaneous territories. Fortunately, the trunk is relatively cylindrical and measurement errors on the "unwrapped" skin appear minimal.

Our laboratory has previously completed a CT scan of a cadaver injected with lead oxide to digitalize and measure surface areas more accurately. This has proven to be difficult due to the refraction caused by the current lead oxide technique. The high radiopacity of the lead make it one of the only radiocontrast useable to visualise fine perforator vessels and their cutaneous distribution. However, lead oxide in larger, named arteries creates metallic artefacts which render any evaluation of perforator vessels impossible.

6.3.1.3 Prediction of the maximal cutaneous territory

Cutaneous territories measured here are anatomical territories. An anatomical model is a static model. It is therefore not advisable to comment on the dynamic and potential territories, which are regulated by physiological variables. These cadaveric observations potentially miscalculate the real cutaneous territories in living models. The real cutaneous territory or tissue mass that can be supported by a single perforator remains unknown, as well as factors regulating blood flow in perforator vessels, vasodilation, spasm, etc.

6.3.1.4 Transposition of findings to a clinical setting

It is not known if there is a direct correlation between vessel size measured in cadavers and in vivo. In vivo, vessel sizes are regulated by local and systemic factors, a factor that can not be accounted for in fresh cadaver studies. Despite this, anatomical studies remain the main foundation of surgical flap designs. When planning a perforator flap, it is common practice to determine preoperatively the presence and location of perforators with a portable Doppler[48].

7 Conclusion

We have successfully demonstrated the anatomical basis of the DCIA osteocutaneous perforator flap. This allows the reduction of donor site morbidity by sparing abdominal wall musculature while decreasing the bulk of the flap and increasing the mobility of the cutaneous component. At least one DCIA perforator is present 92% of the time. It is located 1 to 35 mm superior to the iliac crest, 5 to 10 cm posterior to the ASIS. A skin territory of at least 31cm^2 can be included on each perforator. The next step will consist in locating DCIA perforators with a Doppler in patients candidates for a mandibular reconstruction and attempt a DCIA perforator flap according to the algorithm proposed.

8 References

1. Mathes, S., and Nahai, F. *Clinical applications for muscle, musculocutaneous flaps*. St. Louis: CV Mosby, 1982.

2. McGraw, J.B., and Vasconez, L.O. Musculocutaneous flaps: principles. *Clin. Plast. Surg.* 7: 9, 1980.

3. Mathes, S.J., and Alpert, B.S. Advances in muscle and musculocutaneous flaps. *Clin. Plast. Surg.* 7: 15, 1980.

4. Maxwell, G.P. Musculocutaneous free flap. *Clin. Plast. Surg.* 7: 111, 1980.

5. Taylor, G.I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Clinical work. *Plast. Reconstr. Surg.* 64: 745, 1979.

6. Taylor, G.I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Experimental work. *Plast. Reconstr. Surg.* 64: 595, 1979.

7. Manchester, W.M. Some technical improvements in the reconstruction of the mandible and temporomandibular joint. *Plast. Reconstr. Surg.* 50: 249, 1972.

8. Taylor, G.I., and Daniel, R.K. Aesthetic aspects of microsurgery: composite tissue transfer to the face. *Clin. Plast. Surg.* 8: 333, 1981.

9. Shenaq, S.M. Refinements in mandibular reconstruction. *Clin. Plast. Surg.* 19: 809, 1992.

10. Urken, M.L. Composite free flaps in oromandibular reconstruction. Review of the literature. *Arch. Otolaryngol. Head Neck Surg.* 117: 724, 1991.

11. Ramasastry, S.S., Tucker, J.B., Swartz, W.M. et al. The internal oblique muscle flap: an anatomic and clinical study. *Plast. Reconstr. Surg.* 73: 721, 1984.

12. Urken, M.L., Vickery, C., Weinberg, H. et al. The internal oblique-iliac crest osseomyocutaneous microvascular free flap in head and neck reconstruction. *J. Reconstr. Microsurg.* 5: 203, 1989.

13. Safak, T., Klebuc, M.J., Mavili, E. et al. A new design of the iliac crest microsurgical free flap without including the "obligatory" muscle cuff. *Plast. Reconstr. Surg.* 100: 1703, 1997.

14. Kimata, Y. Deep circumflex iliac perforator flap. *Clin. Plast. Surg.* 30: 433, 2003.

15. Kimata, Y., Uchiyama, K., Sakuraba, M. et al. Deep circumflex iliac perforator flap with iliac crest for mandibular reconstruction. *Br. J. Plast. Surg.* 54: 487, 2001.

16. Geddes, C.R., Morris, S.F., and Neligan, P.C. Perforator flaps: evolution, classification, and applications. *Ann. Plast. Surg.* 50: 90, 2003.

17. Taylor, G.I., and Palmer, J.H. The vascular territories (angiosomes) of the body: experimental study and clinical applications. *Br. J. Plast. Surg.* 40: 113, 1987.

18. Cormack, G.C., and Lamberty, B.G.H. *The arterial anatomy of skin flaps*, 1. Edinburgh: Churchill Livingstone, 1986.

19. Gillies, H., and Millard, D.R. *The principles and art of plastic surgery.* Boston: Little and Brown, 1957.

20. Koshima, I., Nanba, Y., Tsutsui, T. et al. Medial plantar perforator flaps with supermicrosurgery. *Clin. Plast. Surg.* 30: 447, 2003.

21. Daniel, R.K., and Taylor, G.I. Distant transfer of an island flap by microvascular anastomoses. A clinical technique. *Plast. Reconstr. Surg.* 52: 111, 1973.

22. Taylor, G.I., and Daniel, R.K. The free flap: composite tissue transfer by vascular anastomosis. *Aust. N. Z. J. Surg.* 43: 1, 1973.

23. Taylor, G.I., and Daniel, R.K. The anatomy of several free flap donor sites. *Plast. Reconstr. Surg.* 56: 243, 1975.

24. Brookes, M. *The blood supply of bone*. London: Butterworths, 1971.

25. Wood, M.B., and Gilbert, A. *Microvascular bone reconstruction.* London: Martin Dunitz Ltd, 1997.

26. Bakamjian, V.Y., and Poole, M. Maxillo-facial and palatal reconstructions with the deltopectoral flap. *Br. J. Plast. Surg.* 30: 17, 1977.

27. Koshima, I., and Soeda, S. Inferior epigastric artery skin flaps without rectus abdominis muscle. *Br. J. Plast. Surg.* 42: 645, 1989.

28. Kroll, S.S., and Rosenfield, L. Perforator-based flaps for low posterior midline defects. *Plast. Reconstr. Surg.* 81: 561, 1988.

29. Kawai, K., Imanishi, N., Nakajima, H. et al. Vascular Anatomy of the Anterolateral Thigh Flap. *Plast. Reconstr. Surg.* 114: 1108, 2004.

30. Tang, M., Geddes, C.R., Yang, D. et al. Modified lead oxide-gelatin injection technique for vascular studies. *Chin J Clin Anat.* 1: 73, 2002.

31. Rees, M.J., and Taylor, G.I. A simplified lead oxide cadaver injection technique. *Plast. Reconstr. Surg.* 77: 141, 1986.

32. Wei, F.C., Jain, V., Celik, N. et al. Have we found an ideal soft-tissue flap? An experience with 672 anterolateral thigh flaps. *Plast. Reconstr. Surg.* 109: 2219, 2002.

33. Guerra, A.B., Metzinger, S.E., Bidros, R.S. et al. Breast reconstruction with gluteal artery perforator (GAP) flaps: a critical analysis of 142 cases. *Ann. Plast. Surg.* 52: 118, 2004.

34. Allen, R.J. The superior gluteal artery perforator flap. *Clin. Plast. Surg.* 25: 293, 1998.

35. Allen, R.J., and Tucker, C., Jr. Superior gluteal artery perforator free flap for breast reconstruction. *Plast. Reconstr. Surg.* 95: 1207, 1995.

36. Koshima, I., Inagawa, K., Urushibara, K. et al. Paraumbilical perforator flap without deep inferior epigastric vessels. *Plast. Reconstr. Surg.* 102: 1052, 1998.

37. Koshima, I., Moriguchi, T., Fukuda, H. et al. Free, thinned, paraumbilical perforator-based flaps. *J. Reconstr. Microsurg.* 7: 313, 1991.

38. Gedebou, T.M., Wei, F.C., and Lin, C.H. Clinical experience of 1284 free anterolateral thigh flaps. *Handchir. Mikrochir. Plast. Chir.* 34: 239, 2002.

39. Houseman, N.D., Taylor, G.I., and Pan, W.R. The angiosomes of the head and neck: anatomic study and clinical applications. *Plast. Reconstr. Surg.* 105: 2287, 2000.

40. Taylor, G.I., and Pan, W.R. Angiosomes of the leg: anatomic study and clinical implications. *Plast. Reconstr. Surg.* 102: 599, 1998.

41. Inoue, Y., and Taylor, G.I. The angiosomes of the forearm: anatomic study and clinical implications. *Plast. Reconstr. Surg.* 98: 195, 1996.

42. Taylor, G.I., and Minabe, T. The angiosomes of the mammals and other vertebrates. *Plast. Reconstr. Surg.* 89: 181, 1992.

43. Palmer, J.H., and Taylor, G.I. The vascular territories of the anterior chest wall. *Br. J. Plast. Surg.* 39: 287, 1986.

44. Taylor, G.I., and Corlett, R. The vascular territories of the body and their relation to tissue transfer. *Plastic Surgery Forum.* 41981.

45. Lamberty, B.G., and Cormack, G.C. Fasciocutaneous flaps. *Clin. Plast. Surg.* 17: 713, 1990.

46. McGregor, I.A., and Morgan, G. Axial and random pattern flaps. *Br. J. Plast. Surg.* 261973.

47. Taylor, G.I., Doyle, M., and McCarten, G. The Doppler probe for planning flaps: anatomical study and clinical applications. *Br. J. Plast. Surg.* 43: 1, 1990.

48. Hallock, G.G. Doppler sonography and color duplex imaging for planning a perforator flap. *Clin. Plast. Surg.* 30: 347, 2003.

49. Daniel, R.K. Mandibular reconstruction with free tissue transfers. *Ann. Plast. Surg.* 1: 346, 1978.

50. Disa, J.J., and Cordeiro, P.G. Mandible reconstruction with microvascular surgery. *Semin. Surg. Oncol.* 19: 226, 2000.

51. Shenaq, S.M., and Klebuc, M.J. The iliac crest microsurgical free flap in mandibular reconstruction. *Clin. Plast. Surg.* 21: 37, 1994.

52. Snyder, C.C., Bateman, J.M., Davis, C.W. et al. Mandibulo-facial restoration with live osteocutaneous flaps. *Plast. Reconstr. Surg.* 45: 14, 1970.

53. Conley, J. Use of composite flaps containing bone for major repairs in the head and neck. *Plast. Reconstr. Surg.* 49: 522, 1972.

54. Cuono, C.B., and Ariyan, S. Immediate reconstruction of a composite mandibular defect with a regional osteomusculocutaneous flap. *Plast. Reconstr. Surg.* 65: 477, 1980.

55. Siemssen, S.O., Kirkby, B., and O'Connor, T.P. Immediate reconstruction of a resected segment of the lower jaw, using a compound flap of clavicle and sternomastoid muscle. *Plast. Reconstr. Surg.* 61: 724, 1978.

56. Buncke, H.J., Furnas, D.W., Gordon, L. et al. Free osteocutaneous flap from a rib to the tibia. *Plast. Reconstr. Surg.* 59: 799, 1977.

57. Taylor, G.I., Miller, G.D., and Ham, F.J. The free vascularized bone graft. A clinical extension of microvascular techniques. *Plast. Reconstr. Surg.* 55: 533, 1975.

58. Salibian, A.H., Rappaport, I., Furnas, D.W. et al. Microvascular reconstruction of the mandible. *Am. J. Surg.* 140: 499, 1980.

59. Hidalgo, D.A., and Pusic, A.L. Free-flap mandibular reconstruction: a 10-year follow-up study. *Plast. Reconstr. Surg.* 110: 438, 2002.

60. Rogers, S.N., Lakshmiah, S.R., Narayan, B. et al. A comparison of the long-term morbidity following deep circumflex iliac and fibula free flaps for

reconstruction following head and neck cancer. *Plast. Reconstr. Surg.* 112: 1517, 2003.

61. David, D.J., Tan, E., Katsaros, J. et al. Mandibular reconstruction with vascularized iliac crest: a 10-year experience. *Plast. Reconstr. Surg.* 82: 792, 1988.

62. Ramasastry, S.S., Granick, M.S., and Futrell, J.W. Clinical anatomy of the internal oblique muscle. *J. Reconstr. Microsurg.* 2: 117, 1986.

63. Urken, M.L., Vickery, C., Weinberg, H. et al. The internal oblique-iliac crest osseomyocutaneous free flap in oromandibular reconstruction. Report of 20 cases. *Arch. Otolaryngol. Head Neck Surg.* 115: 339, 1989.

64. Urken, M.L., Weinberg, H., Vickery, C. et al. The internal oblique-iliac crest free flap in composite defects of the oral cavity involving bone, skin, and mucosa. *Laryngoscope.* 101: 257, 1991.

65. Serafin, D. *Atlas of microsurgical composite tissue transplantation.* Philadelphia: W.B. Saunders Company, 1996.

66. Chen, Z.W., and Yan, W. The study and clinical application of the osteocutaneous flap of fibula. *Microsurgery.* 4: 11, 1983.

67. Swartz, W.M., Banis, J.C., Newton, E.D. et al. The osteocutaneous scapular flap for mandibular and maxillary reconstruction. *Plast. Reconstr. Surg.* 77: 530, 1986.

68. Foucher, G., van Genechten, F., Merle, N. et al. A compound radial artery forearm flap in hand surgery: an original modification of the Chinese forearm flap. *Br. J. Plast. Surg.* 37: 139, 1984.

69. Taylor, G.I., and Watson, N. One-stage repair of compound leg defects with free, revascularized flaps of groin skin and iliac bone. *Plast. Reconstr. Surg.* 61: 494, 1978.

70. Penteado, C.V. Venous drainage of the groin flap. *Plast. Reconstr. Surg.* 71: 678, 1983.

71. Bitter, K. Bone transplants from the Iliac crest to the maxillo-facial region by the microsurgical technique. *J. Maxillofac. Surg.* 8: 210, 1980.

72. Bitter, K., and Danai, T. The iliac bone or osteocutaneous transplant pedicled to the deep circumflex iliac artery. I. Anatomical and technical considerations. *J. Maxillofac. Surg.* 11: 195, 1983.

73. Karcher, H., Hellbom, B., and Radner, H. The osteomusculocutaneous musculoperitoneal groin flap in head and neck reconstruction. *J. Reconstr. Microsurg.* 5: 31, 1989.

74. Yiming, A., Baque, P., Rahili, A. et al. Anatomical study of the blood supply of the coxal bone: radiological and clinical application. *Surg. Radiol. Anat.* 24: 81, 2002.

75. Huang, G.K., Liu, Z.Z., Shen, Y.L. et al. Microvascular free transfer of iliac bone based on the deep circumflex iliac vessels. *J. Microsurg.* 2: 113, 1980.

76. Ozaki, W., and Buchman, S.R. Volume maintenance of onlay bone grafts in the craniofacial skeleton: micro-architecture versus embryologic origin. *Plast. Reconstr. Surg.* 102: 291, 1998.

77. Hardesty, R.A., and Marsh, J.L. Craniofacial onlay bone grafting: a prospective evaluation of graft morphology, orientation, and embryonic origin. *Plast. Reconstr. Surg.* 85: 5, 1990.

78. Gosain, A.K., McCarthy, J.G., Staffenberg, D. et al. The histomorphologic changes in vascularized bone transfer and their interrelationship with the recipient sites: a 1-year study. *Plast. Reconstr. Surg.* 97: 1001, 1996.

79. Goldberg, V.M., Shaffer, J.W., Field, G. et al. Biology of vascularized bone grafts. *Orthop. Clin. North Am.* 18: 197, 1987.

80. Klein, L., Stevenson, S., Shaffer, J.W. et al. Bone mass and comparative rates of bone resorption and formation of fibular autografts: comparison of vascular and nonvascular grafts in dogs. *Bone.* 12: 323, 1991.

81. Shaffer, J.W., Field, G.A., Goldberg, V.M. et al. Fate of vascularized and nonvascularized autografts. *Clin. Orthop.*: 32, 1985.

82. Cutting, C.B., and McCarthy, J.G. Comparison of residual osseous mass between vascularized and nonvascularized onlay bone transfers. *Plast. Reconstr. Surg.* 72: 672, 1983.

83. LaTrenta, G.S., McCarthy, J.G., and Cutting, C.B. The growth of vascularized onlay bone transfers. *Ann. Plast. Surg.* 18: 511, 1987.

84. Chen, R.S., Liu, Y.X., Liu, C.B. et al. Anatomic basis of iliac crest flap pedicled on the iliolumbar artery. *Surg. Radiol. Anat.* 21: 103, 1999.

85. Winters, H.A., van Harten, S.M., and van Royen, B.J. The iliolumbar artery as the nutrient pedicle for an iliac crest graft: a new technique in reconstruction of the lumbar spine. *Plast. Reconstr. Surg.* 109: 249, 2002.

86. Hayashi, A., Maruyama, Y., Okajima, Y. et al. Vascularized iliac bone graft based on a pedicle of upper lumbar vessels for anterior fusion of the thoraco-lumbar spine. *Br. J. Plast. Surg.* 47: 425, 1994.

87. Huang, G.K., Hu, R.Q., Miao, H. et al. Microvascular free transfer of iliac bone based on the deep superior branches of the superior gluteal vessels. *Plast. Reconstr. Surg.* 75: 68, 1985.

88. Reddy, D.M., and Koul, A.R. Free split iliac-bone flap transfer based on the superior gluteal vessels: anatomy and case reports. *J. Reconstr. Microsurg.* 13: 229, 1997.

89. Mialhe, C., and Brice, M. A new compound osteo-myocutaneous free flap: the posterior iliac artery flap. *Br. J. Plast. Surg.* 38: 30, 1985.

90. Medot, M., and Fissette, J. The cutaneous territory of the transverse tensor fascia lata flap: further anatomical considerations. *Surg. Radiol. Anat.* 15: 255, 1993.

91. Scheflan, M. The tensor fascia lata: variations on a theme. *Plast. Reconstr. Surg.* 68: 59, 1981.

92. Koshima, I., Hosoda, M., Ohta, S. et al. Free vascularized iliac osteomusculocutaneous flaps based on the lateral circumflex femoral system for repair of large mandibular defects. *Ann. Plast. Surg.* 33: 581, 1994.

93. Shenaq, S.M., and Klebuc, M.J. Refinements in the iliac crest microsurgical free flap for oromandibular reconstruction. *Microsurgery.* 15: 825, 1994.

94. Quillen, C.G., Wiener, B., Mendoza, L. et al. Experiences in the use of eight cutaneous and osteocutaneous superficial and deep circumflex iliac free flaps. *J. Reconstr. Microsurg.* 1: 269, 1985.

95. Koshima, I., Nanba, Y., Tsutsui, T. et al. Sequential vascularized iliac bone graft and a superficial circumflex iliac artery perforator flap with a single source vessel for established mandibular defects. *Plast. Reconstr. Surg.* 113: 101, 2004.

96. Wei, F.C., Demirkan, F., Chen, H.C. et al. Double free flaps in reconstruction of extensive composite mandibular defects in head and neck cancer. *Plast Reconstr Surg.* 103: 39, 1999.

97. Shpitzer, T., Neligan, P.C., Gullane, P.J. et al. The free iliac crest and fibula flaps in vascularized oromandibular reconstruction: comparison and long-term evaluation. *Head Neck.* 21: 639, 1999.

98. Forrest, C., Boyd, B., Manktelow, R. et al. The free vascularised iliac crest tissue transfer: donor site complications associated with eighty-two cases. *Br. J. Plast. Surg.* 45: 89, 1992.

99. Taylor, G.I., Corlett, R.J., and Boyd, J.B. The versatile deep inferior epigastric (inferior rectus abdominis) flap. *Br. J. Plast. Surg.* 37: 330, 1984.

100. Taylor, G.I. Invited discussion: "New approach to vascular injection in fresh cadaver dissection" (J Reconstr Microsurg 2004;20:311-315). *J. Reconstr. Microsurg.* 20: 457, 2004.

101. Taylor, G.I. Invited discussion: "Blood supply of the abdomen revisited, with emphasis on the superficial inferior epigastric artery" (Plast Reconstr Surg 1984;54:657-70). *Plast. Reconstr. Surg.* 74: 667, 1984.

102. Cormack, G.C., and Lamberty, B.G. Cadaver studies of correlation between vessel size and anatomical territory of cutaneous supply. *Br. J. Plast. Surg.* 39: 300, 1986.

103. Crosthwaite, G.L., Taylor, G.I., and Palmer, J.H. A new radio-opaque injection technique for tissue preservation. *Br. J. Plast. Surg.* 40: 497, 1987.

104. Salmon, M. *Artères de la peau: étude anatomique et chirurgicale*. Paris: Masson, 1936.

105. Salmon, M. *Artères des muscles de la tête et du cou*. Paris: Masson, 1936.

106. Whitten, M.B. A review of the technical methods of demonstrating the circulation of the heart. *Arch Int Med.* 42: 846, 1928.

ANNEXE II

ACCORD DES AUTEURS ET PERMISSION DE L'ÉDITEUR

A. Déclaration des coauteurs d'un article

1. Identification de l'étudiant et du programme

Nom de l'étudiant : Léonard Bergeron

Sigle et titre du programme, en indiquant l'option s'il y a lieu :
M.Sc. sciences biomédicales

2. Description de l'article

Bergeron L, Tang M and Morris S F. A review of vascular injection techniques for the study of perforator flaps. *Plast Reconstr Surg* 2006;117:2050-2057

3. Déclaration de tous les coauteurs autres que l'étudiant

À titre de co-auteur des articles identifiés ci-dessus, je suis d'accord pour que Léonard Bergeron incluse cet article dans son mémoire de maîtrise qui a pour titre « Les bases anatomiques du lambeau perforant ostéocutané de l'artère iliaque circonflexe profonde ».

Coauteur : Steven F Morris [redacted] (2 oct 2006)

Coauteur : Maolin Tang (2 oct 2006)

B. Permission de l'éditeur d'une revue

1. Identification de la revue

Plastic and Reconstructive Surgery

2. Identification de l'éditeur

Dr Rod J Rohrich

3. Identification des articles

The student Leonard Bergeron is authorised to include the article "*Bergeron L, Tang M, Morris SF. A review of vascular injection techniques for the study of perforator flaps. Plast Reconstr Surg 2006: 117: 2050-7*" in his masters thesis entitled "The anatomical basis of the deep circumflex iliac artery perforator flap".

[redacted]

Editor's name and signature: Date: 8/24/06

ANNEXE II

ACCORD DES AUTEURS ET PERMISSION DE L'ÉDITEUR

A. Déclaration des coauteurs d'un article

1. Identification de l'étudiant et du programme

Nom de l'étudiant : Léonard Bergeron

Sigle et titre du programme, en indiquant l'option s'il y a lieu :
M.Sc. sciences biomédicales

2. Description des articles

Bergeron L, Tang M and Morris S F. The anatomical basis of the deep circumflex iliac artery perforator flap (DCIAP) with iliac crest. *Plast Reconstr Surg* . Accepté pour publication, date de parution à venir.

3. Déclaration de tous les coauteurs autres que l'étudiant

À titre de co-auteur des articles identifiés ci-dessus, je suis d'accord pour que Léonard Bergeron incluse cet article dans son mémoire de maîtrise qui a pour titre « Les bases anatomiques du lambeau perforant ostéocutané de l'artère iliaque circonflexe profonde ».

Coauteur : Steven F Morris [redacted] (2 oct 2006)
Coauteur : Maolin Tang (2 oct 2006)

B. Permission de l'éditeur d'une revue

1. Identification de la revue

Plastic and Reconstructive Surgery

2. Identification de l'éditeur

Dr Rod J Rohrich

3. Identification des articles

The student Leonard Bergeron is authorised to include the article PRS-D-05-01154R2, entitled "*The anatomical basis of the deep circumflex iliac artery perforator flap (DCIAP) with iliac crest" (accepted for publication, unknown publication date)* in his masters thesis entitled "The anatomical basis of the deep circumflex iliac artery perforator flap".

Editor's name and signature: [redacted] Date: 8/24/06