Microvascular Free Flaps in Mandibular Reconstruction—The Role of Computational Fluid Dynamics Modelling

John Loh, Intekhab Islam, and Raymond Wong

Abstract

Mandibular composite defects due to traumatic amputation or oncological resection, often involves reconstruction using vascularised free flaps. Micro-vascular anastomoses are needed in the tissue revascularization (Wain in J plast Reconstr Aesthetic surg JPRAS 67:951–959, [1]). Success rates in the order of 95% and above are enjoyed in the micro-vascular tissue autotransplantation (Rickard in J Surg Res 153:1-11, [2]). There are few computational studies done to further understand the fluid dynamics in the free tissue transfer graft. The areas of interests include the blood flow in vessels of different calibre, the flow dynamics in different sections of the free flap and the flow differences during the insetting of the flap at different rotations and angles. At present, there is no standard computational model to study the fluid dynamics in these flaps. Profound knowledge of the fluid dynamics of the flaps will have vast clinical applications and potential to ensure better clinical outcomes. There are thus many areas of possible collaboration and development in computational modelling research between the bio-engineers and the clinicians.

Keywords

Mandibular reconstruction • Computational fluid dynamics modelling • Microvascular • Free flaps

1 Introduction

Ablative surgery or traumatic injuries to the mandible can lead to dento-facial deformities. Unlike other parts of the body, such disfigurements might not be so easily hidden and these defects could become a social or cultural stigma for life. The health of the affected person might eventually be compromised too, a consequence of any decrease of function of the oral cavity due to the mandibular defects. The aim of mandibular reconstruction is thus to restore the mandibular function as well as creating an aesthetic result.

Before the use of vascularised tissue flaps, efforts to reconstruct the mandible using autogenous, non-vascularised bone grafts were frequently less successful due to loss of graft tissue and infections, from salivary contamination and post operative adjuvant radiation [3]. The lack of blood supply to the graft compromised its ability to withstand the physiological challenges imposed on it during its healing process in the recipient site. With the use of pedicled flaps, such as the pectoralis major muscle with rib, or the trapezius muscle with scapula flaps, the success of such reconstructive procedures improved [4–6]. Microvascular surgery since the 1980 s allowed the transfer of vascularized tissue flaps from distant parts of the body for use in the oro-mandibular

Possible Research Areas
Design of a standardized computational model for fluid dynamics studies of each of the common flap used in the reconstruction of the maxillofacial defects after ablative surgery. With these models available, further studies could be done on different variables encountered in the clinical settings, for example, different sizes of the flaps, and the length of the blood vessels, i.e. pedicles used.

J. Loh (✉) · I. Islam · R. Wong
Discipline of Oral and Maxillofacial Surgery, Faculty of Dentistry, National University of Singapore, 11 Lower Kent Ridge Road, Singapore, Singapore
e-mail: denlspj@nus.edu.sg

J. Loh · I. Islam · R. Wong
Discipline of Oral and Maxillofacial Surgery, National University Hospital, Singapore, Singapore

T. Vo Van et al. (eds.), *6th International Conference on the Development of Biomedical Engineering in Vietnam (BME6)*, IFMBE Proceedings 63, https://doi.org/10.1007/978-981-10-4361-1_91

region. The radial forearm [7] and the fibula [8] flaps are examples of vascularised free tissue flaps used in the reconstruction of the mandibular defects. It has enabled the transfer of soft tissue as well as bone with its own blood supply. This greatly enhanced the success rates of these reconstructive procedures. The use of micro-vascular free flaps has now become the gold standard adopted in many head and neck reconstructive surgery, including the mandible.

With the availability of technology, the planning of such surgery has become more precise and the surgical outcome made more predictable. Simulation modelling involving computational fluid dynamics, or CFD, is one such example.

2 Computational Fluid Dynamics Modelling

Mandibular composite defects due to traumatic amputation or oncological resection, often involve reconstruction using vascularised free soft tissue flaps. Micro-vascular anastomoses of the blood vessels are needed in the tissue revascularization [1]. Success rates in the order of 95% and above are enjoyed in the micro-vascular tissue autotransplantation [2, 9]. This, however, requires much expertise and clinical experience. There are few computational studies done to further understand the fluid dynamics and perfusion in the free tissue transfer graft [10, 11]. The areas of interests included the blood flow in vessels of different calibre, the flow dynamics in different sections of the free flap and the flow differences during the insetting of the flaps at different rotations and angles. At present, there is no standard computational model to study the fluid dynamics in these flaps. Profound knowledge of the fluid dynamics of the flaps will have vast clinical applications and the potential for better clinical outcomes.

There have been efforts to establish a 3-dimensional working model to study the haemodynamics of blood flow and perfusion in a radial forearm flap [10]. Included in the research design was the comparison of a porous and a non-porous model. It was found that the porous model was more representative of the free flap in the clinical setting. The pressure difference of 7050 Pa/52.8 mmHg between the radial artery and vein was similar to the actual clinical figures, as it became possible to maintain the arterial pressure consistently.

Computational fluid dynamics has also been used to compare and contrast the blood flow and perfusion in the 4 different methods of vessel anastomosis [11]. These included the simulation of anastomosis of vessels of matching size, stump anastomosis, anastomosis of the pedicle vessel at an angle to the end of the recipient vessel and the pedicle vessel to the side of the recipient vessel. It has been found, using the computational modelling that the pressure in the flap was highest in anastomosis of matching size. The blood flow has also been found to be smooth in anastomosis of the pedicle vessels at an angle as well as to the side of the recipient vessels.

The effect of micro-vascular sutures and its position in the vessel anastomosis, on the blood flow characteristics was also studied using a computational fluid dynamics model [12]. The vessel walls were assumed as non-compliant and obeyed a continuous Newtonian flow. These were compared clinically with similar vessels using Doppler ultrasound scans. The shear strain rate [12] was one of the outcomes measured. The parameters that affected the shear strain rate were suture bite angle and width as well as the spacing between these sutures.

Computational fluid dynamics has also been used to study the outcomes of anastomosis done using sutures compared with those done by coupling devices [1]. The thrombotic elements in the blood flow characteristics were investigated. These included the velocity changes of the blood flow, wall shear stress and the shear strain rate.

3 Discussions/Future Research Potentials

CFD modelling has been used extensively in cardiovascular medicine research [13]. It has, however, not been widely utilised to understand the micro-vascular characteristics of free tissue flaps in head and neck reconstruction, following ablative surgery or loss of tissue to trauma. Thus, there is a large potential for CFD modelling to be used in research in this field, including the mandible rehabilitation. The use of CFD modelling could possibly improve the predictability and success of the free tissue flap transfer operation for the reconstructive surgeon. There is currently a lack of geometrical data available for input into the CFD modelling process. This could be improved through more in vitro basic research. Data translation from the computational model to the clinical setting would indeed help the surgeon to select the most appropriate flap and its design for the operation. It could complement the existing virtual planning technology for free flap transfers. Ultimately, the patient would be the main beneficiary of the possible improved outcomes.

References

1. Wain RA, Whitty JP, Dalal MD, Holmes MC, Ahmed W (2014) Blood flow through sutured and coupled microvascular anastomoses: a comparative computational study. J plast Reconstr Aesthetic surg JPRAS 67:951–959
2. Rickard RF, Meyer C, Hudson DA (2009) Computational modeling of microarterial anastomoses with size discrepancy (small-to-large). J Surg Res 153:1–11
3. Bak M, Jacobson AS, Buchbinder D, Urken ML (2010) Contemporary reconstruction of the mandible. Oral Oncol 46:71–76

4. Conley J (1972) Use of composite flaps containing bone for major repairs in the head and neck. Plast Reconstr Surg 49:522–526
5. Panje W, Cutting C (1980) Trapezius osteomyocutaneous island flap for reconstruction of the anterior floor of the mouth and the mandible. Head Neck Surg 3:66–71
6. Cuono CB, Ariyan S (1980) Immediate reconstruction of a composite mandibular defect with a regional osteomusculocutaneous flap. Plast Reconstr Surg 65:477–484
7. Yang GF, Chen PJ, Gao YZ, Liu XY, Li J et al (1997) Forearm free skin flap transplantation: a report of 56 cases. 1981. Br J Plast Surg 50:162–165
8. Hidalgo DA (1989) Fibula free flap: a new method of mandible reconstruction. Plast Reconstr Surg 84:71–79
9. Zhang C, Sun J, Zhu H, Xu L, Ji T et al (2015) Microsurgical free flap reconstructions of the head and neck region: shanghai experience of 34 years and 4640 flaps. Int J Oral Maxillofac Surg 44:675–684
10. Xu LQ, Fan QY, Zhang BL, Zhang H, Zhang CP, Hu GH (2011) Establishment of hemodynamic model of human radial forearm free flap. Shanghai Kou Qiang Yi Xue 20:136–140
11. Xu LQ, Fan QY, Zhang BL, Zhang LL, Zhang CP, Hu GH (2011) Computational-fluid-dynamical analysis of the flow field of forearm flap with four types of venous anastomotic techniques. Shanghai Kou Qiang Yi Xue 20:246–250
12. Wain RA, Hammond D, McPhillips M, Whitty JP, Ahmed W (2016) Microarterial anastomoses: a parameterised computational study examining the effect of suture position on intravascular blood flow. Microvasc Res 105:141–148
13. Morris PD, Narracott A, von Tengg-Kobligk H, Silva Soto DA, Hsiao S et al (2016) Computational fluid dynamics modelling in cardiovascular medicine. Heart 102:18–28
14. Van Tricht I, De Wachter D, Tordoir J, Verdonck P (2006) Comparison of the hemodynamics in 6 mm and 4–7 mm hemodialysis grafts by means of CFD. J Biomech 39:226–236