

# Non-invasive Determination of Bone Perfusion in Jaw Augmentation – A Pilot Study

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## Abstract

**Introduction:** Autologous bone transplantation is a standard procedure in dentoalveolar surgery for filling bone defects prior to implant placement. Information about bone perfusion is essential in the assessment of bone donor and recipient sites. A valid assessment of tissue microcirculation is possible without applying an invasive technique. Until now, it has been impossible to measure bone perfusion as part of a non-invasive procedure. **Materials and Methods:** Bone perfusion was determined for two augmentation procedures, both during the procedure and three months later. In one case, the graft and the recipient site were measured (mental bone graft), in the other, measurements were taken only at the time of augmentation (pelvic bone graft). It was measured in 2mm depth the relative blood flow, the venous oxygen saturation of haemoglobin and the regional haemoglobin concentration. **Results:** Flow, SO<sub>2</sub> and rHb could be determined about the whole course of the intervention. Above all the comparison between the augmentation and the control after 3 months could occur. The values were consistent with the clinical situation and allowed an assessment of perfusion. **Conclusion:** The measurements taken on the two patients have shown that the probe is well suited to measure local circulation in bones. It was possible to measure bone perfusion at all times. The method can be declared safe and practicable. It was demonstrated that this non-invasive method of measuring bone perfusion provides reproducible data that offer information on the perfusion of the graft and the recipient site at any time during the procedure and thus provide a valid assessment of vitality.

*Key Words: Noninvasive bone perfusion, Bone vascularization*

## Introduction

Autologous bone transplantation is a standard procedure in dentoalveolar surgery for filling bone defects prior to implant placement [1]. Most grafts are harvested from loco-regional sites with the harvested bone transplanted to the defect site for osseointegration [2]. It is currently not possible to evaluate a graft's osseointegration capability. Previously, assessments of grafts and recipient sites have exclusively been based on visual inspections. Assessments frequently relied solely on the amount of blood in the drilled holes, since there is so far no non-invasive method of determining bone perfusion in dentoalveolar surgery. Adequate perfusion is indispensable for tissue vitality [3,4]. The blood flow not only transports oxygen to the cells but also removes toxic metabolites. Moreover, perfusion is responsible for cutaneous thermoregulation [5]. Microcirculation can be assessed by monitoring blood flow and oxygen saturation in the tissue [6,7]. Because of the O<sub>2</sub> gradient along the capillaries, the arterial, capillary and venous oxygen saturations of the haemoglobin must be measured to be able to assess the O<sub>2</sub> saturation of the organ tissues. While techniques such as angiography or Doppler sonography are routine methods for measuring macrocirculation in clinical practice, microcirculation was until now only measured indirectly by analysing metabolic products. Common methods include measurement of arterial pO<sub>2</sub> and pCO<sub>2</sub> or pulse oximetry as parameters of arterial oxygen-haemoglobin saturation. Complex imaging techniques such as PET and SPECT can be used to determine blood flow in tissue, but continuous (real-time) measurement is not possible [8]. A new technique combines two methods, namely tissue spectrometry and laser Doppler flowmetry. Application of these two techniques at the same time and on the same site using a probe makes a

determination of the following parameters possible in nearly any tissue:

- Flow: relative blood flow
- SvO<sub>2</sub>: venous oxygen saturation of haemoglobin
- rHb: regional haemoglobin concentration

All measuring parameters are derived from the microvascular system. Tissue spectrometry is used to determine venous oxygen saturation and regional haemoglobin concentration, whereas the laser Doppler technique is applied to determine the relative blood flow [9]. The tissue is illuminated with laser light. The movement of the red blood cells causes changes in frequency. To determine these frequency shifts, a technique called "heterodyne light scattering technique" is applied. It involves a mixing of remitted, non-frequency-shifted light with the remitted, frequency-shifted light [10]. The resulting beat frequencies are subsequently analysed. The resulting frequency distribution depends on the distribution of velocities among the moving particles. The amplitudes of the frequencies can, in a first approximation, be interpreted as the amount of moving particles [11]. The statistical detection depth can be influenced by the geometry of probes, in particular their separation and the distance between the light source and the detector [12,13]. The measuring device was optimised for determining the moving red blood cells in capillaries, arterioles, venules and smaller vessels.

Tissue spectrophotometry was implemented as the second optical method. The tissue spectrophotometry used is based on a broadband, non-coherent light source in the wavelength range between 450 nm and 850 nm, which disperses the light remitted from the tissue and serves as a basis for determining the tissue parameters SvO<sub>2</sub> and rHb [14,15]. The broadband

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light is radiated into the tissue locally. The light is scattered in the tissue and absorbed. Because of the light scattering in the tissue, the light can be measured at the tissue surface. The oxygen saturation of the haemoglobin in the local microvascular vessels are derived from the absorption [16]. The diffusion equation [17], an approximation of the transport equation [18], is used to provide a mathematical description of light propagation in biological tissue. It treats light as a particle rather than a wave. Oxygen saturation is expressed as a percentage and corresponds to the average oxygen capacity of haemoglobin (0% completely deoxygenated haemoglobin, 100% completely oxygenated haemoglobin).

By combining the two methods, a valid assessment of tissue microcirculation is possible without applying an invasive technique. Until now, it has been impossible to measure bone perfusion as part of a non-invasive procedure.

This pilot study was designed to establish the quality of a probe for measuring bone perfusion.

### Materials and Methods

This study has been approved by the responsible ethics committee. The approval was followed by the recruitment of two eligible patients (1 and 2), who were informed in great detail about the planned procedure. Patient 1 underwent a mandibular sandwich osteotomy including transplant of an autologous mental bone graft. Patient 2 underwent a transplantation of an autologous pelvic bone graft to the left mandible for vertical and horizontal augmentation. By the first patient we need bone for two dental implants, so that the area of measurement was limited of a bone area of two teeth. By the second patient the area of measurement was in a size for three teeth. Perfusion was determined at various times during the augmentation in 2 mm depth at different points around the augmentation area and around the donor side. All procedures were performed under general anaesthesia. Basically the measurements can be also carried out without anaesthesia or in local anaesthesia.

The probe used is specifically designed for non-invasive measurement of bone perfusion through the skin or mucosa. Measurements are taken between the two plug gauges, which do not penetrate the skin or mucosa. In order to prevent perfusion by the surrounding tissue, the probe was pressed on the tissue with a defined pressure (3N) (Figure 1).



Figure 1: Picture of the probe. Between two spones the measurement occurs.

Thus, the local perfusion in the tissue was prevented and only the perfusion in the underlying bone was measured. With

the measuring values it concerns relative figures which must be always looked in the comparison and can be assigned to no unity.

### Results

The results of patient 1 can be seen in figures 2 and 3. Blue indicates the venous oxygen saturation of haemoglobin (SvO<sub>2</sub>), red the regional haemoglobin concentration (rHb) and green the relative blood flow (Flow). If one looks at the data measuring points 1 and 2 A so no essential difference appears between both measuring points, also with the measuring points 1 and 2 B. The preparation of the gingiva and the osteotomy of the bone also still show no difference. After withdrawal of the graft no Flow is more measurable, SO<sub>2</sub> and rHb are still measurable. 1 F shows the values directly after the augmentation. Flow is measurable very slightly, SO<sub>2</sub> becomes fewer. rHb seems a little changed. After 3 months the measuring values have risen again.

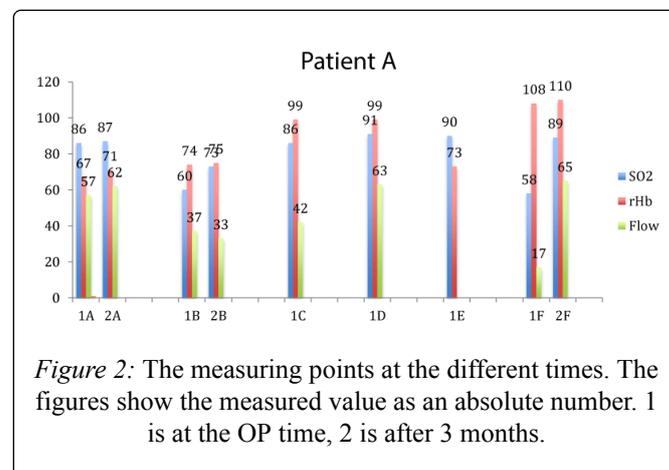


Figure 2: The measuring points at the different times. The figures show the measured value as an absolute number. 1 is at the OP time, 2 is after 3 months.

The results of patient 2 are displayed in figures according to the same pattern. In patient 2 a look at the data measuring points A and B no essential difference appears between both measuring points. With the measuring points C, D and E no Flow is more measurable and SO<sub>2</sub> continuously drops. Only to the measuring point F a Flow is measurable again, SO<sub>2</sub> rises here also again. Unfortunately, patient 2 has not appeared after 3 months, so that here the second investigation could not occur.

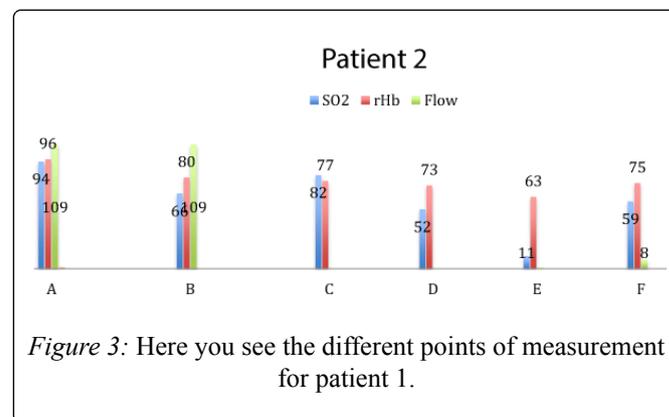


Figure 3: Here you see the different points of measurement for patient 1.

### Discussion

The measurements taken on the two patients have shown that the probe is well suited to measure local circulation in bones.

The clinical result after 3 months confirmed the impression of the measuring results. They suggest with it the suspicion that the measuring results are plausible. Further measurements with other methods would be necessary to conclude that it is a well suited method and should be performed to allow a certain conclusion. Data comparison for patient 1 reveals no significant difference between measuring during the gingiva now and after three months, which suggests that the probe is a high quality measuring device. Measuring the bone before and after the bone preparation are identical; D is following osteotomy but with the graft still in situ. Again, there is no significant difference between the measured values; this is an indication that the perfusion of the graft is mainly coming from the deeper regions rather than the perimeter. After the harvest, at measuring point E, no flow or velocity was measured. The fact that levels of venous oxygen saturation of haemoglobin (SvO<sub>2</sub>) and of regional haemoglobin concentration (rHb) were measured can best be explained by residual blood in the graft. After the augmentation, measuring point 1F, the venous oxygen saturation of haemoglobin (SvO<sub>2</sub>) dropped a little further, which can be attributed to the time factor and the resulting consumption. After three months, 2F, flow and velocity are measurable again, indicating successful osseointegration and perfusion.

Similar values were obtained for the second patient. The recipient site and the native pelvis were well supplied with blood. Following osteotomy of the pelvis, but with the graft still in situ, no velocity values were measured in the graft. This means that perfusion of the pelvis, unlike the chin, comes from the periphery rather than from the depth. After the harvest, at measuring point D, venous oxygen saturation of haemoglobin (SvO<sub>2</sub>) drops while the regional haemoglobin concentration (rHb) remains almost constant. It is only after some time outside the body that at measuring point E the regional haemoglobin concentration (rHb) drops, similar to the venous oxygen saturation of haemoglobin (SvO<sub>2</sub>). Following transplantation to the recipient site, the venous oxygen saturation of haemoglobin (SvO<sub>2</sub>) and the regional haemoglobin concentration (rHb) increased again; flow value also became measurable again, although they were very low and probably resulting from blood flow at the recipient site.

It was demonstrated that this non-invasive method of measuring bone perfusion provides reproducible data that offer information on the perfusion of the graft and the recipient site at any time during the procedure and thus provide a valid assessment of vitality. Well perfused grafts and recipient sites improve the probability of osseointegration [19,20], and measuring the parameters described above is a quality assurance tool as well. Up to now there was still no method that was able to examine so small donors and receiver's side for her blood circulation [21]. Though by means of the SPECT and the PET a statement could be met to the blood circulation of the jaw, but a specific statement to a certain area of the jaw could not occur. Not to neglect remains the fact that with the known procedures of PET and SPECT a radiotherapy and the application of radionuclide are necessary. The pure CT. evaluation allows no valid statement to the blood circulation. The measurement by means of ultrasound detects merely the main artery, however, permits no basic statement to the blood circulation of the bone only surely not

for the relatively small part it is required for the augmentation for a dental implant [22]. More studies on determining bone perfusion in medically compromised patients will follow.

## Conclusion

Bone perfusion can be measured non-invasively. This method offers valid results and is designed to improve the predictability of augmentation. Bone perfusion, and thus the probability of osseointegration, can be assessed in advance, during planning and diagnosis.

## Competing Interests section

The authors declare that they have no competing interests.

## Authors' contributions

Marcus Stoetzer, Björn Rahlf, Juliane Lemound and Nils-Claudius Gellrich conceived of the study and participated in its design and coordination. Marcus Stoetzer and Björn Rahlf made substantial contributions to data acquisition and conception of manuscript. Marcus Stoetzer, Constantin von See; Thomas Derfuss and Björn Rahlf drafted and designed the manuscript and contributed equally to this work. Nils-Claudius Gellrich and Constantin von See were involved in revising the manuscript. All authors read and approved the final manuscript.

## Consent statement

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal.

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