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ORIGINAL RESEARCH

Comparison of two different generations of "NIRS" devices and transducers in healthy volunteers and ICU patients

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Abstract The purpose of this study is to compare Near Infrared Spectroscopy (NIRS) thenar eminence parameters obtained with 2 different devices from the same manufacturer (InSpectra Models 325 and 650, Hutchinson Tech, Min USA), and 2 different probes (15 vs. 25 mm spacing), in healthy volunteers (HV) and ICU patients. Prospective, observational study in ICU setting. Simultaneous, cross over NIRS inter-device comparison and comparison between different probes (25 vs. 15 mm spacing) were done at baseline and during vascular occlusion tests (VOTs). Forty patients (19 septic shock, 21 trauma), and 29 HV were included. NIRS inter-device comparison showed similar baseline StO_2 values in HV and patients. The VOT result were significantly different for minimal StO_2 value reached during VOT (StO_{2min}) (intraclass concordance coefficient (ICC) = 0.18), the occlusion slope (ICC = 0.16) and the reperfusion slope ($StO_{2reperf}$) (ICC = 0.26). The probe comparison was also significantly different for VOT parameters (StO_{2min} (ICC = 0.43), occlusion (ICC = 0.50) and $StO_{2reperf}$ (ICC = 0.48). The low concordance, poor agreement and large bias (ICC and Bland & Altman) observed, were related both to the device used and the probe spacing. StO_2 data obtained with NIRS model 650 and 15 mm probe differ from values obtained with the previous device (325 and probe spacing 25 or 15 mm). This difference is not related to the population tested, but to the device and probe spacing. As a consequence, despite similar trends for variations between HV and patients during VOT, threshold and predictive values for outcome should be revisited with the new device before the acceptance for routine clinical use.

Keywords Micro-oxygenation · Microcirculation · Near-infrared spectroscopy

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1 Introduction

Among the techniques proposed to assess microperfusion and tissue oxygenation, near infrared spectroscopy (NIRS) has acquired important credibility. It has been shown in different life threatening conditions that tissue hemoglobin oxygen saturation (StO_2) characterizes tissue hypoperfusion and effectiveness of therapies in trauma [1, 2], hemorrhagic shock [3], septic shock [4–7], and other acute systemic inflammatory conditions [8–11]. If baseline StO_2

seems contributive when systemic hemodynamic is compromised, this parameter looses interest when systemic hemodynamic is stabilized as in septic shock. In the context of resuscitated septic shock, patient's baseline StO_2 values did not differ from normal values, despite abnormal microcirculation [1, 2, 7, 12, 13]. Because of this, a dynamic test called vascular occlusion test (VOT) has been developed for NIRS measurements at the thenar eminence to detect microcirculation abnormalities [7, 14–17]. A derived parameter from VOT, the reperfusion slope ($StO_{2reperf}$) has been shown lower in the most severe septic patients and was associated with outcome, with predictive threshold for poor outcome [13, 18].

Developments made by the manufacturer put on the market a new device (InSpectra model 650; Hutchinson Technology, Minn, USA), linked to a new probe (15 mm spacing instead of 25 mm), updating data with higher frequency, and associated with an automated software to compute VOT derived parameters, such as occlusion and reperfusion slopes. We hypothesized that the new software, signal processing and probe spacing of the new device may influence StO_2 measurements compared to those obtained with the Model 325 (InSpectra; Hutchinson Technology, Minn, USA), particularly during and after VOT. If there were significant differences between each other, prognostic outcome attributable to NIRS parameters should be re-assessed. This study was design: 1- to perform an inter-device comparison of StO_2 values (baseline and VOT) and, 2- to compare the 2 different probe spacings (25 vs. 15 mm). These measurements were performed both on right and left sides on healthy volunteers and septic patients, since the potential impact of impaired microcirculation could not be predicted.

2 Materials and methods

This single center study was prospectively conducted in a surgical Intensive Care Unit (ICU) of Lariboisière University Hospital. The study was approved by the Ethics Committee of the French Society of Intensive Care (CE-SRLF 07-185) and the local Committee for the Protection of People waived the need for informed consent as observations were considered non invasive and no interventions were made.

2.1 Patients and healthy volunteers

2.1.1 Patients

Forty patients were enrolled for the study: 25 for the inter-device comparison and 15 for the comparison of the different probe spacings. Patients had sepsis [19] (n = 21) (52.5 %) or trauma (n = 19) (47.5 %) and all were mechanically ventilated, with a FiO_2 level settled to obtain a SaO_2 over 95 %. All patients were studied soon after hemodynamic stabilization despite their systemic inflammation. To be selected, patients had to be free of upper limb lesions, allowing use of the right and left thenar eminences locations for NIRS measurements. The arterial catheter for blood pressure monitoring and blood sampling was inserted into a femoral artery. Measurements were performed in semi-recumbent position, with both upper limbs resting extended at heart level, with no modification in sedation protocol or in cardiovascular support (for at least 1 h) during data acquisition. No interventions were based on StO_2 measured parameters.

2.1.2 Healthy volunteers

Data from patients were compared to 29 healthy volunteers (HV), without medical history and who were fasting, non smokers and free of medications: 21 participated in the inter-device comparison and 8 were tested for comparing the different probe spacings. As for patients, NIRS measurements were performed in sitting or semi-recumbent position, with both upper limbs resting extended at heart level.

2.2 StO_2 measurements

NIRS measurements were performed with devices coming from the same manufacturer. The new device (InSpectra model 650; Hutchinson Technology, Minn, USA) was linked only to a 15 mm probe and was compared to the previous device (InSpectra model 325; Hutchinson Technology, Minn, USA), which can be linked both to a 25 or 15 mm probe. The physical use of reflectance principle is well known. Briefly, the system measures the scattering light reflected at some distance from where the light is transmitted into the tissue. Near-infrared light (680–800 nm) easily crosses biological tissues, which have a low absorption power, and is absorbed only by hemoglobin, myoglobin, and oxidized cytochrome [20, 21]. In this way, it measures the saturation ratio of oxygenated and deoxygenated hemoglobin in all vessels (arterioles, capillaries and venules) comprised in the sampled volume of tissue illuminated by the NIRS sensor. The maximum depth of tissue sampled is estimated to equal half the distance between the probe's sending and receiving fibers (probe spacing) [15, 20, 22].

All measurements were performed at the thenar eminences instead of other locations like forearm, deltoid or masseter muscles [23–27], for the following reasons: most of the data during sepsis have been obtained in this location [6, 13, 18]; the VOT requires vascular occlusion easy to be performed on the forearm.

The inter-device comparison was made on both right and left thenar eminences. Baseline and VOT StO_2 variables

were simultaneously collected with the 2 different devices (InSpectra model 325-25 mm probe and model 650-15 mm probe; Hutchinson Technology, Minn, USA). InSpectra model 325-25 mm probe was tested first because most of the initial studies used this set up. After 5 min recording stable baseline StO_2, upper arms (brachial arteries) VOTs were performed as previously described [18]. Briefly, sphygmomanometer cuffs placed around each upper limb brachial artery were simultaneously, rapidly inflated up-to 250 mmHg and maintained for 3 min. Both cuffs were abruptly deflated and data continued to be acquired until the 5th minute. Preliminary tests showed that a delay of 10 min was sufficient to recover pre-VOT conditions. The same procedure was applied after shifting the side of probe and device, giving data for comparison from both right and left sides. The paired data from the same side with the 2 devices were compared. In addition, the values coming from right and left sides obtained with the same device were also analyzed, since distribution of flow might differ largely in severe sepsis and septic shock [28–31].

For the comparison between probes which implies different depths of measurement, StO_2 parameters were consecutively collected on the same thenar eminence with: model 325-15 mm probe, model 325-25 mm probe and model 650-15 mm probe, because of technological limitation (model 650 being linked only with a 15 mm probe). To evaluate the role of the probe itself, measurements obtained with the device 325-15 mm were compared with the device 350-25 mm. Again, a delay of at least 10 min was taken between serial VOTs.

For all the study, baseline StO_2 corresponded to the average value over all 5 min monitoring before VOT. StO_{2min} was the lowest StO_2 value reached during 3 min VOT. StO_2 occlusion and reperfusion slopes were calculated for all conditions and from the different devices-probe settings with the same software (InSpectra Analysis V3-03), using linear adjustment ($R^2 \geq 0.90$ to be valid).

2.3 Statistical analysis

Data were summarized as incidence and percentage for categorical variables. Quantitative variables were summarized as median, 25th and 75th percentiles or as mean and standard deviation (SD). Differences within population (G1a: septic shock, G1b: trauma, G1c: HV) were assessed using Kruskal–Wallis rank sum test, Wilcoxon rank sum test or Fisher's exact test. Differences between probes within the assigned population (patients, HV) were assessed using Wilcoxon rank sum test by pairs (model 325-15 mm vs. model 650-15 mm, and model 325-15 mm vs. model 325-25 mm) with post hoc correction by Holm method. Agreements between NIRS models 325 and 650, and comparison of probes, were evaluated using intraclass correlation (Intraclass Concordance Coefficient, ICC) [32] and Bland & Altman graph [33, 34]. Estimations of ICCs with their 95 % confidence intervals (CI) are presented. All tests were two-sided at the 0.05 significance level. Analyses were performed using R statistical package 2.10 [35].

3 Results

Inter-device comparison: 25 patients (15 septic shock (G1a), 10 trauma (G1b), and 21 HV (G1c) were included with no difference in sex distribution ($p = 0.07$). HV were younger than patients, and septic patients were older than trauma patients ($p < 0.001$). The only systemic hemodynamic significant difference between trauma and septic patients (G1a and G1b) was MAP, which was lower in septic patients ($p = 0.05$).

Comparison of the probes: another group of 15 patients (6 septic shock, 9 trauma) and 8 HV were included, with no difference among groups in sex distribution ($p = 0.67$). Since septic and trauma patients did not differ for systemic hemodynamic values, they were pooled for StO_2 data analysis. Figure 1 shows the flow chart of the protocol and the studied population (Tables 1, 2).

3.1 StO_2 data

Inter-device comparison: baseline StO_2 values were similar with both devices in all groups (Tables 3, 4). Regarding VOT results, the StO_{2min} values from model 325 differed from the values given by model 650 in all groups, reaching a significantly lower value in HV compared to septic or trauma patients ($p = 0.0006$); such a difference was not present when model 650 was used (Table 4). Similarly, the occlusion slope was significantly different between HV and patients when model 325 was used ($p = 0.0002$), a difference that disappeared when model 650 was used ($p = 0.2$) (tables 3 and 4). The reperfusion slope, $StO_{2reperf}$, was lower in patients compared to HV regardless the device used, $p < 0.0001$ (Tables 3, 4), though with numerical differences between the 2 models. Settled together, these results showed that baseline StO_2 values did not depend on the device and the linked probe. Only VOT items were largely influenced by the device used, especially for occlusion slope and minimum StO_2 values. The $StO_{2reperf}$, previously shown lower in patients than in HV, was confirmed with both devices, even with different numbers. Figure 2a, b, c shows the results of the concordance analysis for: baseline StO_2 (Fig. 2a); occlusion slope (Fig. 2b); and reperfusion slope (Fig. 2c). The concordance between the 2 devices was acceptable both with ICC (0.63) and Bland & Altman methods for baseline StO_2; it was poor for StO_{2min} (ICC = 0.18), occlusion slope (ICC = 0.16) (Fig. 2b) and reperfusion slope (ICC = 0.26)

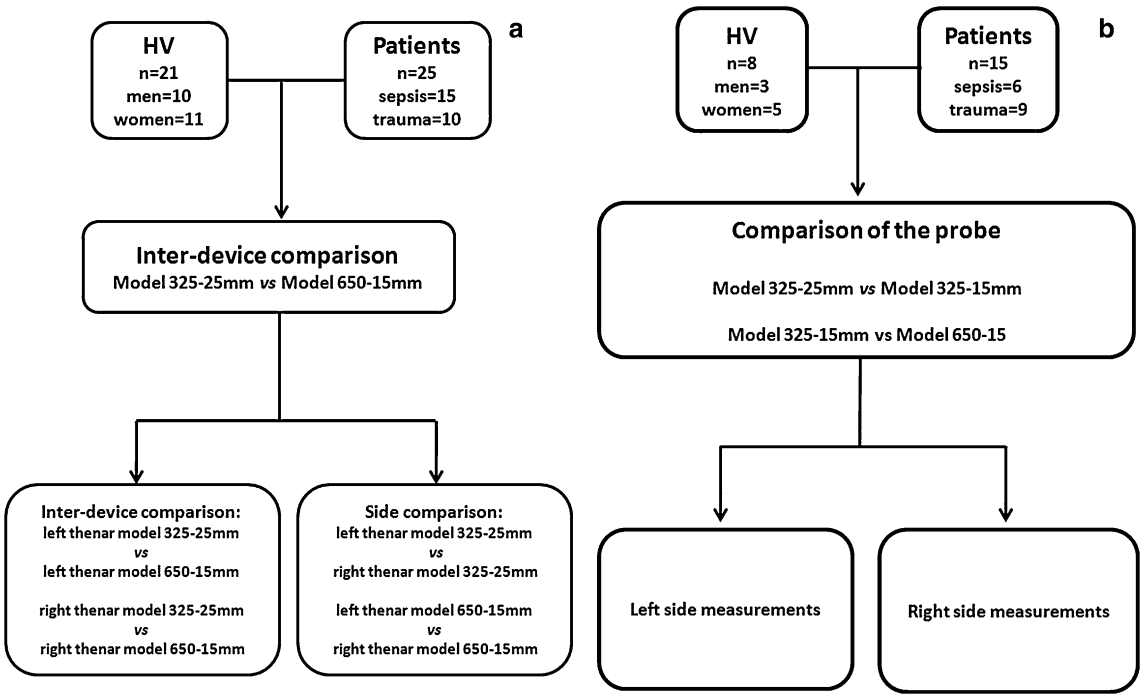

Fig. 1 Flow chart of the study design showing the distribution of patients and healthy volunteers (HV) tested for: **a** the inter-device comparison, **b** the comparison of probes

Table 1 Clinical characteristics of the inter-device comparison group: septic patients (G1a), trauma patients (G1b) and healthy volunteers (G1c)

Parameter	G1a (N = 15)	G1b (N = 10)	G1c (N = 21)	*p* value
Age	76 (62–79)	47 (23–65)	32 (29–37)	<0.0001
Sex (men: N, %)	5 (33.3)	8 (80)	10 (47.6)	0.07
SAPS II	51 (46–59)	47 (39–56)	NA	0.29
SOFA D VOT	8 (6–12)	8 (6–9)	NA	0.59
MAP (mmHg)	74 (67–86)	92 (78–102)	NA	0.05

SAPS II simplified acute physiology score II, *SOFA* sequential organ failure assessment, *VOT* vascular occlusion test, *MAP* mean arterial pressure. Kruskal–Wallis test, *NA* not applied

Table 2 Clinical characteristics of the groups used for the comparison of the probe: septic patients (G2a), trauma patients (G2b) and healthy volunteers (G2c)

Parameter	G2a (N = 6)	G2b (N = 9)	G2c (N = 8)	*p* value
Age	56 (43–67)	59 (54–68)	29 (26–32)	0.77*/0.04[&]
MAP (mmHg)	74 (70–86)	101 (81–112)	NA	0.16

MAP mean arterial pressure. * Mann–Whitney test, [&] Kruskal–Wallis test, *NA* not applied

(Fig 2c). The Bland & Altman showed poor agreement and a large bias for both parameters (Fig. 2b, c). The bias appeared to increase when absolute slope numbers increased.

Figure 3 shows a typical example of simultaneous data recording with models 325 and 650 during VOTs performed on both upper limbs. Both devices gave similar values for right and left measurements in all groups with good agreement and concordance: (StO_2: ICC = 0.65 for models 325 and 650; StO_{2min}: ICC = 0.65 for model 325, ICC = 0.56 for model 650; occlusion slope: ICC = 0.8 for model 325, ICC = 0.37 for model 650; $StO_{2reperf}$: ICC = 0.57 for model 325, 0.78 for model 650).

Comparison of the probes: If baseline StO_2 were similar for model 325-15 mm versus model 325-25 mm and between model 325-15 mm versus model 650-15 mm in the studied groups with good ICC values (whole group = 0.79, patients = 0.64, HV = 0.81), VOT values differed significantly as shown on Tables 5 and 6. The clear probe effect can be seen when model 325-25 was compared with the model 325-15 for VOT derived parameters: StO_{2min}, occlusion and reperfusion slopes significantly differed. Globally, the 25 mm probe linked to the device 325 gave lower StO_{2min} values, steeper occlusion slopes and faster reperfusion slopes than 325 linked with the 15 mm probe in all studied groups (Table 6). Only HV showed agreement for VOT derived parameters, but with wide CI for all parameters (Table 7). The effect of the

Table 3 Comparison of StO_2 parameters obtained with model 325-25 mm probe on left (L) and right (R) sides

	G1a (N = 15)		G1b (N = 10)		G1c (N = 21)		*p* value
Parameter/side	Model 325 (L)	Model 325 (R)	Model 325 (L)	Model 325 (R)	Model 325 (L)	Model 325 (R)	
StO_2 (%)	87 (71–92)	80 (75–88)	85 (71–93)	85 (72–90)	86 (82–90)	82 (79–86)	0.79*/0.86#
StO_2 min (%)	24 (14–34)	12 (5–23)	10 (4–54)	13 (4–31)	2 (1–9)	1 (1–2)	**0.00063*/<0.0001#**
Occ slope (%/s)	−0.27 (−0.36 to −0.21)	−0.36 (−0.51 to −0.27)	−0.28 (−0.56 to −0.14)	−0.38 (−0.54 to −0.13)	−0.54 (−0.69 to −0.46)	−0.63 (−0.75 to −0.53)	**0.0002*/0.0021#**
Rep slope (%/s)	3.79 (1.71–4.73)	6.60 (3.28, 8.47)	2.80 (1.55–7.08)	3.28 (2.62–4.61)	9.55 (8.02–15.25)	11.51 (9.00–13.39)	**<0.0001*#**

G1a: septic patients; G1b: trauma patients; and G1c: healthy volunteers

StO_2 tissue hemoglobin O_2 saturation, *StO_2 min* minimum tissue Hb O_2 saturation during VOT, *Occ slope* occlusion slope, *Rep slope* reperfusion slope. * Kruskal–Wallis testing group effect on left side (L); # Kruskal–Wallis testing groups on right side (R)

Table 4 Comparison of StO_2 parameters obtained with model 650, left (L) and right (R) sides

	G1a (N = 15)		G1b (N = 10)		G1c (N = 21)		*p* value
Parameter/side	Model 650 (L)	Model 650 (R)	Model 650 (L)	Model 650 (R)	Model 650 (L)	Model 650 (R)	
StO_2 (%)	75 (68–87)	80 (69–85)	79 (74–82)	78 (70–83)	78 (77–82)	78 (76–83)	0.65*/0.65#
StO_2 min (%)	41 (26–53)	39 (33–46)	47 (40–54)	42 (33–53)	43 (38–48)	40 (34–47)	0.69*/0.69#
Occ slope (%/s)	−0.17 (−0.20 to −0.12)	−0.18 (−0.26 to −0.15)	−0.16 (−0.23 to −0.12)	−0.15 (−0.24 to −0.11)	−0.19 (−0.24 to −0.17)	−0.23 (−0.28 to −0.16)	0.2*/0.2#
Rep slope (%/s)	2.20 (1.05–2.75)	2.71 (1.65–3.92)	1.55 (1.32–2.09)	1.62 (1.37–1.88)	4.80 (3.29–5.70)	4.45 (3.24–5.56)	**<0.0001*/0.00075#**

G1a: septic patients; G1b: trauma patients; and G1c: healthy volunteers

StO_2 tissue hemoglobin O_2 saturation, *StO_2 min* minimum tissue Hb O_2 saturation during VOT, *Occ slope* occlusion slope, *Rep slope* reperfusion slope. * Kruskal–Wallis testing group effect on left side (L); # Kruskal–Wallis testing groups on right side (R)

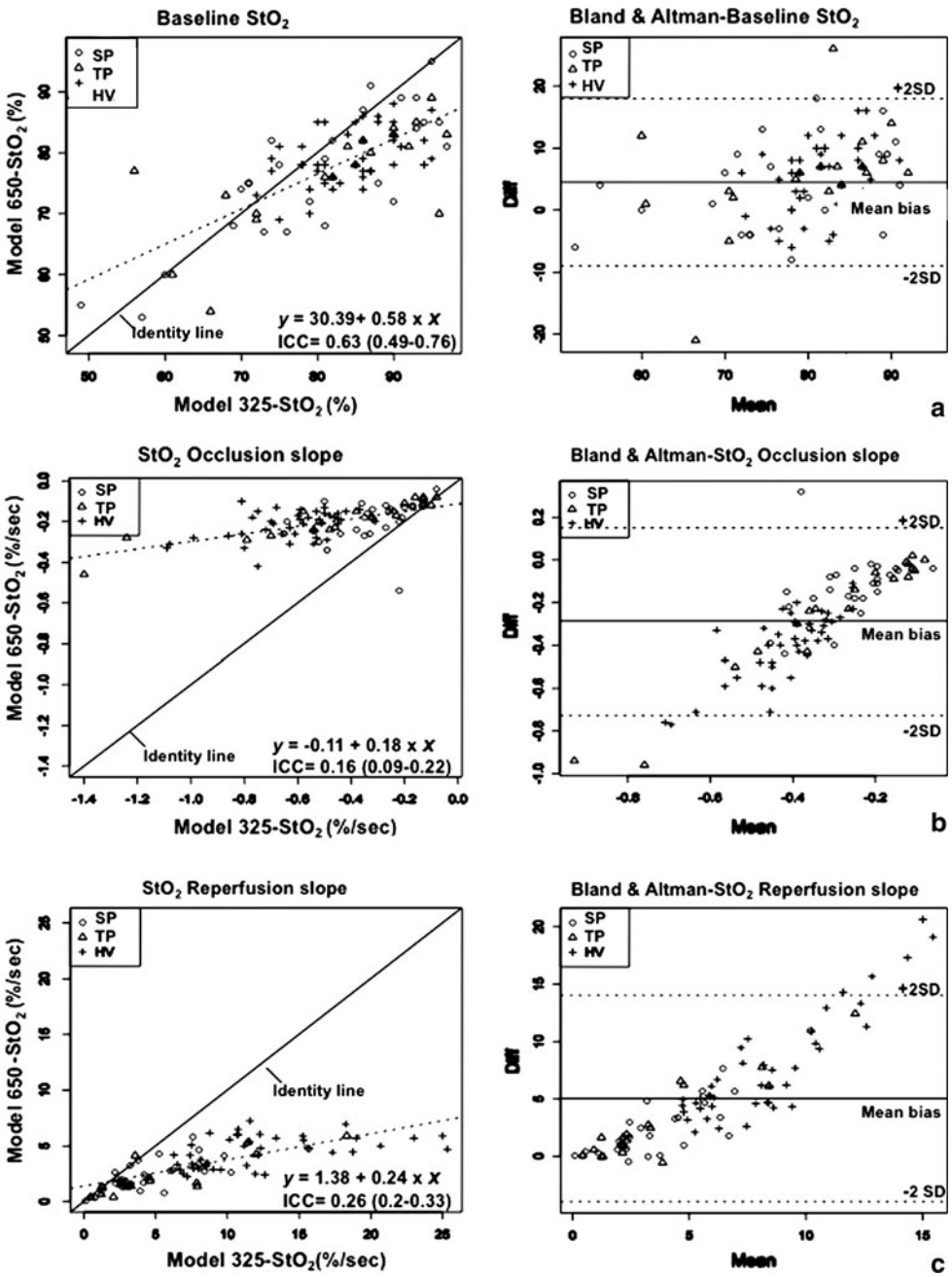

Fig. 2 Intraclass Correlation Coefficient (ICC) and Bland & Altman (B&A) for comparisons between NIRS models 325-25 mm probe and 650-15 mm probe. **a** shows acceptable ICC (0.63) and B&A (−8.94) (CI 4.51–17.95) agreement for baseline StO_2; **b** shows a very low ICC (0.16) and poor agreement and high bias in B&A for Occlusion Slope (−0.73) (CI −0.29 to 0.15); **c** shows a very low ICC (0.26) and poor agreement and high bias in B&A for Reperfusion Slope (−3.97) (CI 5.04–14.04). *SP* sepsis population, *TP* trauma population, *HV* healthy volunteers

probe spacing seems predominant than the device itself, since the comparison between 325-15 and 650-15 gave closer values, even still significantly different (Table 5). Table 7 summarizes the concordance of measurements among the 3 possible "device-probe" combinations, for the whole group, as well as for patients and HV separately.

4 Discussion

The major findings of this study are: (1) the new device 650 linked to a 15 mm probe gave different values for StO_2 measurements, not for baseline but for VOT compared to the device 325 linked either to a 25 mm or to a 25 mm spacing probe; (2) such differences exist both in HV and patients, with more important differences for patients, especially septic ones; (3) the probe spacing plays a predominant role on the observed differences; (4) the reperfusion slope is still significantly lower in patients compared to HV. Because of all this, all previously published remarkable values or thresholds that relate VOT parameters to outcome have to be reassessed to be used by clinicians.

As far as we know, there are no other studies performed in ICU patients in comparison with HV, testing the

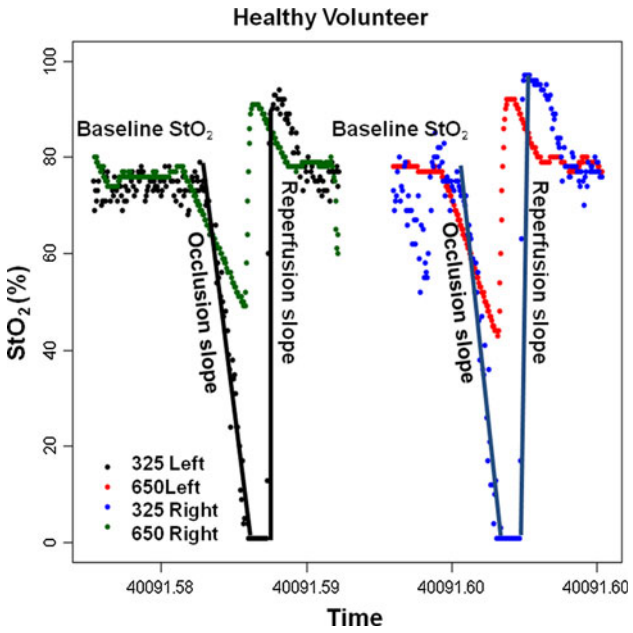

Fig. 3 Typical example of data recorded in a healthy volunteer with models 325-25 mm probe and 650-15 mm probe on right and left thenar eminence, during simultaneous vascular occlusion tests (VOTs). If baseline StO_2 values were similar, there were large differences in Occlusion slope, minimum StO_2 reached during VOT (StO_{2min}) and Reperfusion slope between the 2 models

influences on StO_2 parameters from different device models coming from the same manufacturer (new hardware and software) in combination with different probe spacing. Albeit the observed differences, such a non invasive method remains suitable for clinicians, since baseline StO_2 values between devices and probes set up were comparable and a slower reperfusion slope in patients with acute inflammation remained detected with all devices and probes. Although the major observed differences related mainly to VOT derived variables, our results do not invalid the previous studies proposing NIRS baseline StO_2 to detect hypovolemia. During unstable circulatory failure, baseline StO_2 was shown to correlate with $ScvO_2$ in hemorrhagic shock and in cardiac failure [9], but not in sepsis [9, 18]. That explains why we decided to compare HV and septic or trauma patients. We confirm that baseline StO_2 values obtained on thenar eminence did not differ between HV and patients after resuscitation and stabilization [13, 18]. It has been clearly shown that a large fraction of septic patients have abnormal microcirculation despite efficient systemic resuscitation [29]. To detect such abnormalities, many studies have used the VOT [4–7, 13, 18] showing consistently an abnormal reperfusion slope, which improved when the patient recovered. In addition, some studies proposed to use this parameter to predict outcome in severe sepsis or septic shock [13, 18]. The present study focused then on VOT parameters obtained on stabilized patients, to limit the effect of hemodynamic resuscitation.

Since most of the previously published data using the Hutchinson device have been obtained with a 325 model linked to a 25 mm probe spacing [13, 23, 24, 26], we compared the values obtained with model 650 linked to 15 mm probe to that set up. The large differences observed for VOT derived data as StO_{2min}, occlusion and reperfusion slopes with poor agreement and low ICC questioned the validity of the previous results. The hardware and software advances in model 650 may partly explain these differences. For example, a StO_{2min} around 8 % obtained with the 325-25 mm set up appeared non physiologic compared to 48 % obtained with 650-15 mm device. The output of StO_2 values was higher with the 650 device (1 value/2 s vs. 1 value/3.5 s) than with the 325 device. Consequently, the linear slope computation could be more accurate, and may explain the slower values of occlusion and reperfusion slopes with the 650 device. Such observation was made both in HV and in patients, with no clear differences between groups. In addition, these differences were similar whatever the side (right or left thenar eminence) of measurement.

Since the new device was proposed only with a probe spacing of 15 mm, we investigated the role of probe

Table 5 Comparison of StO_2 parameters using model 650 and 325 with 15 mm probe spacing in patients and HV

	Patients (N = 15)			HV (N = 8)		
Parameter	325-15 mm	650-15 mm	*p* value	325-15 mm	650-15 mm	*p* value
StO_2 (%)	85 (83; 86)	85 (82; 87)	0.08	84 (74; 91)	75 (73; 89)	0.59
StO_2 min (%)	28 (26; 40)	45 (41; 56)	**0.03**	39 (31; 49)	47 (39; 55)	**0.03**
Occ slope (%/s)	−0.25 (−0.31; −0.24)	−0.18 (−0.23; −0.16)	**0.04**	−0.21 (−0.28; −0.13)	−0.16 (−0.24; −0.1)	**0.03**
Rep slope (%/s)	3.55 (3.04; 4.38)	2.95 (2.72; 3.17)	0.06	3.24 (1.56; 4.07)	2.16 (1.31; 3.64)	**0.05**

StO_2 tissue hemoglobin O_2 saturation, StO_2 *min* minimum tissue Hb O_2 saturation during VOT, *Occ slope* occlusion slope, *Rep slope* Reperfusion slope

Wilcoxon test for transducer, with Hochberg post hoc correction

Table 6 Comparison of StO_2 parameters using 15 and 25 mm probe spacing in patients and HV

	Patients (N = 15)			HV (N = 8)		
Parameter	325-15 mm	325-25 mm	*p* value	325-15 mm	325-25 mm	*p* value
StO_2(%)	85 (83; 86)	88 (84; 94)	0.18	84 (74; 91)	87 (79; 93)	0.18
StO_2 min (%)	28 (26; 40)	6 (1; 11)	**0.002**	39 (31; 49)	17 (4; 36)	**0.03**
Occ slope (%/s)	−0.25 (−0.31; −0.24)	−0.44 (−0.49; −0.41)	**0.002**	−0.21 (−0.28; −0.13)	−0.3 (−0.48; −0.26)	**0.03**
Rep slope (%/s)	3.55 (3.04; 4.38)	7.63 (6.80; 8.25)	**0.0004**	3.24 (1.56; 4.07)	4.72 (3.06; 6.43)	**0.03**

StO_2 tissue hemoglobin O_2 saturation, *StO_2 min* minimum tissue Hb O_2 saturation during VOT, *Occ slope* occlusion slope, *Rep slope* reperfusion slope

Wilcoxon test for transducer, with Hochberg post hoc correction

Table 7 Concordance of measurements among StO_2 parameters obtained with the different combinations of NIRS models (325 and 650) and transducers (25 vs. 15 mm) (see the text)

Parameter	Global (n = 23)	Patients (n = 15)	HV (n = 8)
StO_2 (%)	**0.79 (0.58–0.89)**	**0.64 (0.14–0.84)**	**0.81 (0.55–0.92)**
StO_2 min (%)	0.43 (0.15–0.63)	0.07 (0.007–0.11)	**0.58 (0.26–0.76)**
Occ slope (%/s)	0.50 (0.21–0.71)	0.10 (−0.03 to 0.14)	**0.67 (0.32–0.84)**
Rep slope (%/s)	0.48 (0.22–0.66)	−0.003 (−0.12 to 0.22)	**0.64 (0.46–0.82)**

Concordance of measurements is presented as: global results (HV + Patients; N = 23); patients (N = 15) and healthy volunteers (HV; N = 8), separately. The values correspond to Intraclass Concordance Coefficient (ICC) with 95 % confidence interval (CI). Adequate concordance of measurements was defined as ICC >0.6

StO_2 tissue Hb O_2 saturation, *StO_2 min* minimum tissue Hb O_2 saturation during VOT, *Occ slope* occlusion slope, *Rep slope* reperfusion slope

spacing itself. To better achieve it, we compared the VOT derived values obtained with 325-25 mm and 325-15 mm. Our values obtained in HV matched those previously reported by Bezemer et al. [24] testing the same "device-probe" combination on thenar eminence. This concordance shows that NIRS data coming from different studies and groups can be compared when performed with the same "device-probe" combination, information that has to be provided in each study. In addition to the previous studies comparing probe spacing in HV using the 325 device, we provide new information on the impact of the device itself in HV and patients, when the same probe (15 mm) was used with the 2 devices. VOT derived values differed both in HV and patients, with no clear amplification of the errors between patients and HV. In all groups, StO_{2min} was higher with model 650, with a slower occlusion slope and a slower reperfusion slope. However, septic patients had a slower reperfusion slope than HV and trauma patients as previously reported [4, 5, 7, 12, 13, 18], a result that gives credit to published differences in septic patients compared to others.

5 Conclusion

This study shows for the first time that both the new device 650 and the use of 15 mm probe spacing provide very different VOT derived values both in HV and in patients compared to previous model 325 and a 25 mm probe. Among them, septic shock patients had a significant lower reperfusion slope than those of HV and trauma patients. The investigation of the relative contribution of the device versus probe spacing favors a major impact of probe spacing, the 15 mm probe seeming more suitable for thenar eminence. The previously published results with remarkable values or thresholds from VOT derived variables to predict outcome in sepsis or therapeutic efficiency need to be revisited using the new device set-up before clinical use.

References

1. Crookes BA, Cohn SM, Burton EA, Nelson J, Proctor KG. Noninvasive muscle oxygenation to guide fluid resuscitation after traumatic shock. Surgery. 2004;135:662–70.
2. Cohn SM, Nathens AB, Moore FA, Rhee P, Puyana JC, Moore EE, Beilman GJ. Tissue oxygen saturation predicts the development of organ dysfunction during traumatic shock resuscitation. J Trauma. 2007;62:44–54. (discussion 54-45).
3. Heyer L, Mebazaa A, Gayat E, Resche-Rigon M, Rabuel C, Rezlan E, Lukascewicz AC, Madadaki C, Pirracchio R, Schurando P, Morel O, Fargeaudou Y, Payen D. Cardiac troponin and skeletal muscle oxygenation in severe post-partum haemorrhage. Crit Care. 2009;13(Suppl 5):S8.
4. Skarda DE, Mulier KE, Myers DE, Taylor JH, Beilman GJ. Dynamic near-infrared spectroscopy measurements in patients with severe sepsis. Shock. 2007;27:348–53.

5. Doerschug KC, Delsing AS, Schmidt GA, Haynes WG. Impairments in microvascular reactivity are related to organ failure in human sepsis. Am J Physiol Heart Circ Physiol. 2007;293:H1065–71.
6. Pareznik R, Knezevic R, Voga G, Podbregar M. Changes in muscle tissue oxygenation during stagnant ischemia in septic patients. Intensive Care Med. 2006;32:87–92.
7. De Blasi RA, Palmisani S, Alampi D, Mercieri M, Romano R, Collini S, Pinto G. Microvascular dysfunction and skeletal muscle oxygenation assessed by phase-modulation near-infrared spectroscopy in patients with septic shock. Intensive Care Med. 2005;31:1661–8.
8. Uilkema RJ, Groeneveld AB. Correlates of thenar near-infrared spectroscopy-derived tissue O_2 saturation after cardiac surgery. Interact Cardiovasc Thorac Surg. 2007;6:265–9.
9. Podbregar M, Mozina H. Skeletal muscle oxygen saturation does not estimate mixed venous oxygen saturation in patients with severe left heart failure and additional severe sepsis or septic shock. Crit Care. 2007;11:R6.
10. Taylor JH, Mulier KE, Myers DE, Beilman GJ. Use of near-infrared spectroscopy in early determination of irreversible hemorrhagic shock. J Trauma. 2005;58:1119–25.
11. Moore FA, Nelson T, McKinley BA, Moore EE, Nathens AB, Rhee P, Puyana JC, Beilman GJ, Cohn SM. Massive transfusion in trauma patients: tissue hemoglobin oxygen saturation predicts poor outcome. J Trauma. 2008;64:1010–23.
12. Gomez H, Torres A, Polanco P, Kim HK, Zenker S, Puyana JC, Pinsky MR. Use of non-invasive NIRS during a vascular occlusion test to assess dynamic tissue O(2) saturation response. Intensive Care Med. 2008;34:1600–7.
13. Creteur J, Carollo T, Soldati G, Buchele G, De Backer D, Vincent JL. The prognostic value of muscle StO_2 in septic patients. Intensive Care Med. 2007;33:1549–56.
14. Hampson NB, Piantadosi CA. Near infrared monitoring of human skeletal muscle oxygenation during forearm ischemia. J Appl Physiol. 1988;64:2449–57.
15. Mancini DM, Bolinger L, Li H, Kendrick K, Chance B, Wilson JR. Validation of near-infrared spectroscopy in humans. J Appl Physiol. 1994;77:2740–7.
16. Creteur J. Muscle StO_2 in critically ill patients. Curr Opin Crit Care. 2008;14:361–6.
17. Neviere R, Mathieu D, Chagnon JL, Lebleu N, Millien JP, Wattel F. Skeletal muscle microvascular blood flow and oxygen transport in patients with severe sepsis. Am J Respir Crit Care Med. 1996;153:191–5.
18. Payen D, Luengo C, Heyer L, Resche-Rigon M, Kerever S, Damoisel C, Losser MR. Is thenar tissue hemoglobin oxygen saturation in septic shock related to macrohemodynamic variables and outcome? Crit Care. 2009;13(Suppl 5):S6.
19. Levy MM, Fink MP, Marshall JC, Abraham E, Angus D, Cook D, Cohen J, Opal SM, Vincent JL, Ramsay G. 2001 SCCM/ESICM/ACCP/ATS/SIS international sepsis definitions conference. Crit Care Med. 2003;31:1250–6.
20. Myers DE, Anderson LD, Seifert RP, Ortner JP, Cooper CE, Beilman GJ, Mowlem JD. Noninvasive method for measuring local hemoglobin oxygen saturation in tissue using wide gap second derivative near-infrared spectroscopy. J Biomed Opt. 2005;10:034017.
21. Scheeren TW, Schober P, Schwarte LA. Monitoring tissue oxygenation by near infrared spectroscopy (NIRS): background and current applications. J Clin Monit Comput. 2012;26:279–87.
22. Ward KR, Ivatury RR, Barbee RW, Terner J, Pittman R, Filho IP, Spiess B. Near infrared spectroscopy for evaluation of the trauma patient: a technology review. Resuscitation. 2006;68:27–44.
23. Bezemer R, Karemaker JM, Klijn E, Martin D, Mitchell K, Grocott M, Heger M, Ince C. Simultaneous multi-depth assessment of tissue oxygen saturation in thenar and forearm using near-infrared spectroscopy during a simple cardiovascular challenge. Crit Care. 2009;13(Suppl 5):S5.
24. Bezemer R, Lima A, Myers D, Klijn E, Heger M, Goedhart PT, Bakker J, Ince C. Assessment of tissue oxygen saturation during a vascular occlusion test using near-infrared spectroscopy: the role of probe spacing and measurement site studied in healthy volunteers. Crit Care. 2009;13(Suppl 5):S4.
25. Soller BR, Ryan KL, Rickards CA, Cooke WH, Yang Y, Soyemi OO, Crookes BA, Heard SO, Convertino VA. Oxygen saturation determined from deep muscle, not thenar tissue, is an early indicator of central hypovolemia in humans. Crit Care Med. 2008;36:176–82.
26. Gomez H, Mesquida J, Simon P, Kim HK, Puyana JC, Ince C, Pinsky MR. Characterization of tissue oxygen saturation and the vascular occlusion test: influence of measurement sites, probe sizes and deflation thresholds. Crit Care. 2009;13(Suppl 5):S3.
27. Colin G, Nardi O, Polito A, Aboab J, Maxime V, Clair B, Friedman D, Orlikowski D, Sharshar T, Annane D. Masseter tissue oxygen saturation predicts normal central venous oxygen saturation during early goal-directed therapy and predicts mortality in patients with severe sepsis. Crit Care Med. 2012;40:435–40.
28. Weil MH, Shubin H. Proposed reclassification of shock states with special reference to distributive defects. Adv Exp Med Biol. 1971;23:13–23.
29. De Backer D, Creteur J, Preiser JC, Dubois MJ, Vincent JL. Microvascular blood flow is altered in patients with sepsis. Am J Respir Crit Care Med. 2002;166:98–104.
30. Spronk PE, Zandstra DF, Ince C. Bench-to-bedside review: sepsis is a disease of the microcirculation. Crit Care. 2004;8:462–8.
31. Elbers PW, Ince C. Mechanisms of critical illness–classifying microcirculatory flow abnormalities in distributive shock. Crit Care. 2006;10:221.
32. Lee J, Koh D, Ong CN. Statistical evaluation of agreement between two methods for measuring a quantitative variable. Comput Biol Med. 1989;19:61–70.
33. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1:307–10.
34. Bland JM, Altman DG. Measurement error and correlation coefficients. BMJ. 1996;313:41–2.
35. R Development Core Team. R: a language and environment for statistical computing; from R Foundation for Statistical Computing, Vienna, Austria. 2012. http://www.R-project.org/.