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A COMPARISON OF RESPONSE TIME TO DESATURATION BETWEEN TRACHEAL OXIMETRY AND PERIPHERAL OXIMETRY

Li Wang, MM[1], Wei Wei, MD[2], Ming Gong, PhD[3] and Ling Mu, MB[2]

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ABSTRACT. Objective. Trachea is an alternative site for pulse oxygen saturation monitoring. The response time of the oximetry probe has been reported more rapid when placed in central than in peripheral. The purpose of this study is to compare the performance of the oximetry probes placed in trachea and peripheral site during rapid desaturation. **Methods.** Endotracheal tubes with an oximetry sensor were intubated in ten anesthesia dogs. Both the oxygen saturation signals from trachea (S_tO_2) and tail (S_pO_2) were shown on the same monitoring screen. The mechanical ventilation was disconnected to produce a rapid desaturation when both S_tO_2 and S_pO_2 were 100%, and the mechanical ventilation was reconnected when S_pO_2 decreased to 80%. The time of S_tO_2 and S_pO_2 dropped to 95, 90, 85, and 80% was recorded, respectively during the mechanical ventilation disconnection, and the arterial blood was sampled for arterial oxygen saturation (S_aO_2) measurement simultaneously. The levels of measurement agreement between two oximetry readings (S_pO_2, S_tO_2) and S_aO_2 were analyzed, respectively with the Bland and Altman method. **Results.** The mean response time of S_tO_2 was significantly shorter than S_pO_2 when both of them decreased from 100 to 80% (172.6 ± 68.9 vs 220.7 ± 72.3 s) during rapid desaturation. The 95% confidence interval for absolute difference between S_pO_2 and S_aO_2 was 4.12 ± 6.47%, and between S_tO_2 and S_aO_2 was 3.33–3.46%. **Conclusions.** Oxymetry placed in trachea provides a better monitoring for detecting rapid desaturation than in peripheral.

KEY WORDS. oximetry, response time, desaturation.

INTRODUCTION

Pulse oximetry has been a standard practice in current clinic settings for avoiding severe hypoxemia in operating room and intensive care unite since its introduction over 20 years ago [1]. Usually, peripheral tissues with rich vessels, such as finger, ear, and forehead are used as pulse oximetry monitoring sites. Unfortunately, the performance of peripheral oximetry is often affected by many factors, including poor tissue perfusion caused by hypovolemia, hypothermia, ambient light, and venous blood contamination. Recently, the possibility and accuracy of blood oxygenation monitoring in alternative sites such as cheeks, pharynx, esophagus, and trachea were investigated. The high quality pulse signals in these alternative sites had been detected by ordinary pulse oximetry sensor, and the signals were better than typical finger signals in poor peripheral perfusion [2–8].

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From the [1]Department of Anesthesiology, NO. 1 People's Hospital of Yibin, Yibin, Sichuan, China; [2]Department of Anesthesiology, West China Hospital, Sichuan University, No 37 Guo-xue-xiang Street, 610041 Chengdu, Sichuan, China; [3]School of Physical Science and Technology, Sichuan University, Chengdu, Sichuan, China.

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Address correspondence to W. Wei, Department of Anesthesiology, West China Hospital, Sichuan University, No 37 Guo-xue-xiang Street, 610041 Chengdu, Sichuan, China.
E-mail: 111weiwei@sohu.com

There are some problems may occur during mechanical ventilation (MV), such as ventilator disconnecting, failure of oxygen supply or tracheal tube kinking. These problems can be the reason of severe hypoxemia if they are not recognized immediately. The key points to prevent adverse events associated to hypoxemia are to detect hypoxemia earlier and to keep sufficient oxygen delivery. Currently, the response time of commercial pulse oxygen is about $4 \sim 20$ s. Shortening the response time will increase the unexpected alarms. Whereas, the incidence of adverse events will be increased if the response time is too long [9]. The response time mainly focuses on the signal processing by analog filtering or moving average techniques [10]. The response time of oximetry in central has been reported to be more rapid than peripheral [11]. In this study, the sensitivity and accuracy of oximetry sensors placed in trachea and tail were compared during rapid desaturation in dogs.

METHODS

After the approval was obtained from local ethical committee for animal experiments, 10 Mongrel dogs (weight, $11 \sim 15$ kg) were enrolled in this study. The tracheal oximetry probe was modified from a single-use pediatric pulse oximetry sensor (Nellcor Puritan Bennett Inc, Pleasanton, CA, USA). The distance between light source and detector of oximetry sensor was shortened to 10 mm to fit the need of reflectance measurement [12]. Then, the modified oximetry sensor was attached to the cuffed portion of an endotracheal tube (inside diameter, 8.0 mm) with an adhesive dressing (3 M, Shanghai, China).

Anesthesia was induced with midazolam 2 mg kg^{-1}, pentobarbital 25 mg kg^{-1} and maintained with bolus injection of pentobarbital, fentanyl and vecuronium. After the induction of anesthesia, the tracheal oximetry probe was inserted into trachea. During MV, the inhaled oxygen was 60%, the tidal volume and respiratory frequence was set as 25 ml per kg and 30 times per minute, respectively. The depth of the trachea tube was adjusted till the high quality trans-tracheal pulse oxygen saturation (S_tO_2) signals were shown in the monitoring screen (Figure 1, part A), then fixed the tracheal oximetry probe, and recorded the depth inserted and orientation of the oximetry probe. Both the oximetry sensors in peripheral (on scraped tail) and trachea were connected with the same monitor (SpaceLabs 1700, Spacelabs Medical Inc, Redmond, USA). An 18G femoral arterial catheter was placed for blood sampling and arterial blood pressure monitoring. The default average time of pulse signal was set as 8 s.

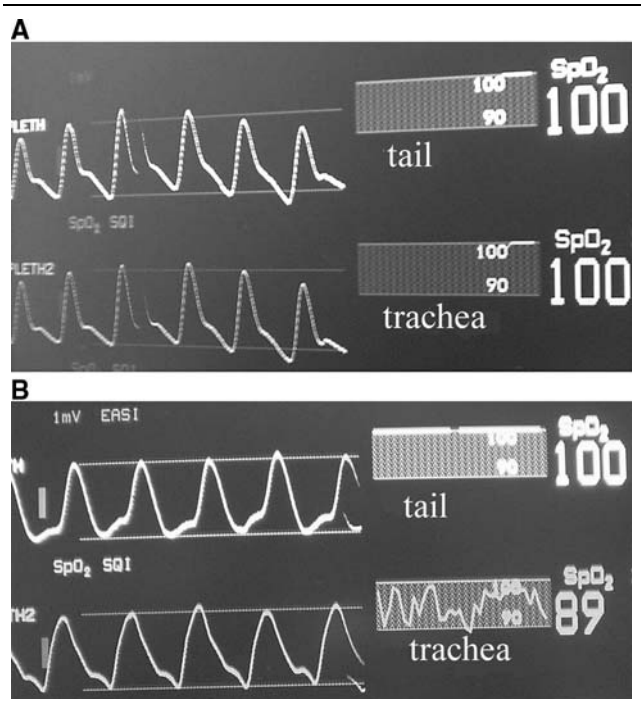

Fig. 1. The S_pO_2 signals from tail site and trachea site were shown in the same screen. Part A, before disconnecting ventilation; Part B, during disconnecting ventilation, the pulse oximetry in trachea was sensitive to rapid desaturation.

All data in monitoring screen were continuously recorded by a Sony video recorder.

At least 5 min after MV, when both readings of S_tO_2 and tail pulse oxygen saturation (S_pO_2) were 100%, MV was disconnected to produce a rapid desaturation. Then MV was reconnected when the readings of S_pO_2 decreased to 80%. S_tO_2, S_pO_2, MAP, HR, and ECG were monitored continuously during desaturation. Arterial blood was sampled for arterial blood oxygen saturation (S_aO_2) measurement as a golden standard at following 6 time points: before MV disconnected; when the readings of S_tO_2 and S_pO_2 start to decrease (from 100 to 99%); when S_pO_2 readings were decreased to 95, 90, and 80% after MV disconnected. The time from MV disconnected to both readings of S_tO_2 and S_pO_2 dropped to 95, 90, 85, and 80% and the lowest value were recorded as the response time to desaturation, respectively.

During MV disconnection, there were two types of changes in the S_pO_2 and S_tO_2 readings: (1) Oximetry readings decreased orderly such as 100, 99, 98, 97, 96, which were defined as continuous readings; (2) Oximetry readings changes were disorderly such as 99, 95, 98, 97, 99, which were defined as discontinuous readings.

Difference of response time between tracheal and tail oximetry were analyzed using one-way analysis of

variance. $P < 0.05$ was taken as significant. The levels of measurement agreement between two oximetry readings (S_pO_2, S_tO_2) and golden standard (S_aO_2) were analyzed, respectively with the Bland and Altman method [13]. The 95% confidence intervals for the absolute difference between two oximetry readings (S_tO_2, S_pO_2) and S_aO_2 were calculated. All data were expressed as means ± SD.

RESULTS

S_tO_2 signals were successfully obtained in nine dogs. The mean ± SD for weight and the proper inserted depth of the tracheal oximetry probe for detecting satisfied S_tO_2 signals were 12.8 ± 1.0 kg and 24.3 ± 0.5 cm, respectively. The desaturation tests by MV disconnection were performed 15 times in 9 S_tO_2 detected dogs. During desaturation, the performance of tracheal oximetry was obviously better than the tail oximetry. The percent of continuous S_tO_2 readings was 53.3% (8/15), and the percent of continuous S_pO_2 readings was only 13.3% (2/15) when S_pO_2 decreased from 100 to 90%. However, both recorded readings of S_tO_2 and S_pO_2 were discontinuous readings when S_pO_2 further decreased to lower than 90%. During MV disconnection, tracheal oximetry was more sensitive to detect the rapid change of oxygen saturation than tail oximetry (Figure 1, part B). The response times of tracheal oximetry for detecting rapid desaturation were significantly shorter than tail oximetry from MV disconnecting to the readings of oximetries decreasing to 95, 90, 85, and 80%, respectively (Table 1).

In addition, the values of S_tO_2 were more accurate than S_pO_2 during desaturation. The curve of S_tO_2 was almost overlapped the curve of S_aO_2 when $S_tO_2 \geq 90\%$, and the curve of S_pO_2 was obviously shifted to right (Figure 2). The 95% confidence interval for absolute difference was 4.12–6.47% between S_pO_2 and S_aO_2, and was 3.33–3.46% between S_tO_2 and S_aO_2. The Bland and Altman agreement analysis between S_pO_2 and S_aO_2 was presented in Figure 3, the mean difference ±2SD between the S_pO_2 and S_aO_2 was 4.3 ± 11.0%. The Bland and Altman

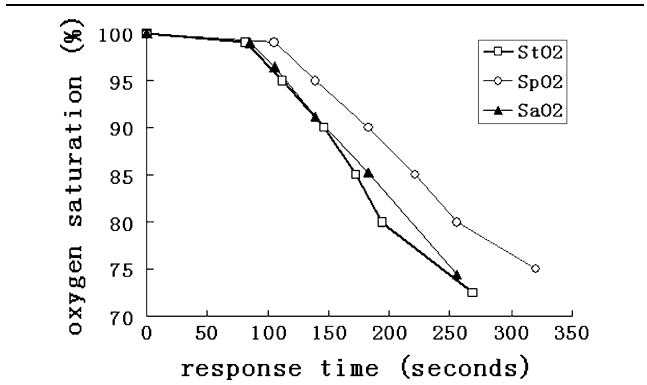

Fig. 2. The time-change of S_tO_2, S_pO_2 and S_aO_2 in the rapid desaturation period. S_tO_2-oxygen saturation readings from tracheal oximetry, S_pO_2-oxygen saturation readings from tail's oximetry, S_aO_2-oxygen saturation values from gas analysis.

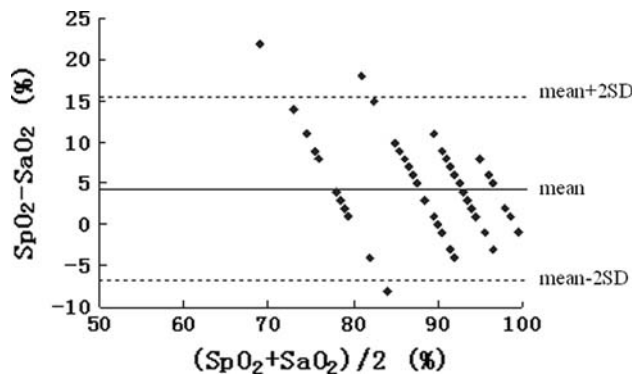

Fig. 3. Bland and Altman graph comparing the differences in 10 dogs between S_pO_2 and S_aO_2 versus the mean oxygen saturation by the two methods. The mean difference ±2SD between the S_pO_2 and S_aO_2 was 4.3 ± 11.0%.

Table 1. The response time [mean ± SD (range)] is the time intervals from mechanical ventilation disconnecting to the readings of oximetries decreasing to 95% (↓95), 90% (↓90), 85% (↓85), 80% (↓80), the lowest value (↓ lowest)

Readings of oximetries	Response time (seconds)	
	Tracheal oximetry	Tail's Oximetry
↓99	81.2 ± 18.2 (60–107)★	105.6 ± 23.7(73–144)
↓95	111.7 ± 29.7 (79–174)★	139.3 ± 29.8 (92–184)
↓90	145.9 ± 42.1 (101–234)★	183.4 ± 49.9 (118–252)
↓80	172.6 ± 68.9 (118–293)★	220.6 ± 72.3 (144–315)
Lowest	269.2 ± 55.8 (178–368)★	320.2 ± 62.3 (238–407)

★$P < 0.001$, compared to tail's oximetry.

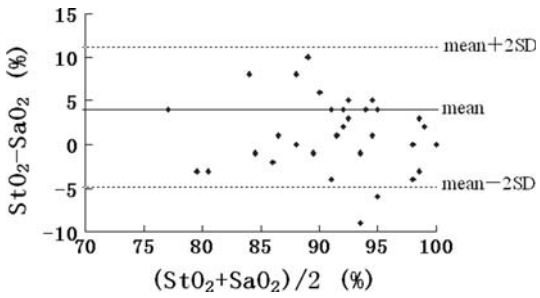

Fig. 4. Bland and Altman graph comparing the differences in 10 dogs between S_tO_2 and S_aO_2 versus the mean oxygen saturation by the two methods. The mean difference ±2SD between the S_pO_2 and S_tO_2 was 1.15 ± 8.38%.

agreement analysis between S_tO_2 and S_aO_2 was presented in Figure 4, the mean difference ±2SD between the S_tO_2 and S_aO_2 was 1.15 ± 8.38%.

DISCUSSION

The oximetry in trachea is not affected by the impact of low blood pressure, hypothermia, and hypoperfusion because trachea is located in the deep of thorax and adjacents to large blood vessels. Our study shows that the pulse oximeter in trachea can detect a stable and adequate signal through trachea wall during desaturation. In this study, continuous S_tO_2 readings were detected in 53.3% of 15 times desaturation, whereas continuous S_pO_2 is only 13.3% after disconnecting ventilation. Therefore, the performance of pulse oximetry in trachea is better than in peripheral during rapid desaturation.

The response of oximetry probe in trachea is found to be quicker than in peripheral during rapid desaturation. In this study, the response time to detect the hypoxemia ($S_pO_2 < 90\%$) was about 37 s delay in tail oximetry compared with the tracheal oximetry (145.9 ± 42.1 vs 183.4 ± 49.9). Mcleod D.B [14] reported that the delay of oximetry from ear to finger was 19 s during rapid desaturation, and David M [15] found that the delay from ear to finger was 24.0 ± 2.3 s during acute resaturation.

There are three explanations for the pulse oximetry in trachea performing well during rapid desaturation. (1) The oximetry probe located in trachea directly detects the S_tO_2 signals from aortic branches such as carotid and subclavian artery, and it takes time for arterial blood to travel from heart to peripheral monitoring site. (2) The quantity and quality of S_tO_2 signals from large vessels are higher than peripheral vessels, and during the onset of hypoxemia, the peripheral S_pO_2 signals will decreased due to peripheral vasoconstriction. (3) Peripheral oximetry sensors are easily affected by room temperature and ambient light. During general anesthesia, the skin temperature is usually decreased, and mild hypothermia will delay the response time of peripheral oximetry [14].

Although the accuracy of pulse oximetry measuring arterial oxygen saturation is within ±2% in normal condition, it does not reflect the actual condition when S_aO_2 is less than 80%. Webb RK [16] reported that nearly 30% of 244 values reviewed were in error by more than 5% when actual S_aO_2 was less than 80%. A test of seven models of oximetry showed that all oximetry performed well when hemoglobin oxygen saturation was high, but all were inaccurate when S_aO_2 was approximately 75% [17]. In this study, when S_aO_2 is less than 90%, the curves of S_tO_2 and S_pO_2 are obviously separated from S_aO_2 (Figure 2). During rapid desaturation, the 95% confidence interval for absolute difference between S_tO_2 and S_aO_2 is about 3%, and difference between S_pO_2 and S_aO_2 is about 4%, which indicates that both of S_pO_2 and S_tO_2 can not reliably reflect the real changes of blood oxygenation during the onset of hypoxemia, or the performance of oximetry is not reliable during rapid desaturation.

It takes about 146 s in trachea oximetry and 183 s in peripheral oximetry to detect desaturation ($S_pO_2 \geq 90\%$) in our study. In fact, the long delay from ventilation disconnected to S_pO_2 decreasing to 90% doesn't represent an actual response time of oximetry. Because oximetry measures the pulse oxygen saturation rather than oxygen partial pressure (P_aO_2), the value of oxygen saturation will be above 90% till the P_aO_2 decreases to less than 60 mm Hg. Therefore, the decrease of oxygen saturation is not the sensitive sign for detecting the ventilator or circuit problems, especially for ventilation with high oxygen concentration. Furthermore, the oxygen saturation readings of peripheral oximetry might obviously overestimate the S_aO_2 values during the rapid P_aO_2 decrease due to response delay.

There are two limitations in this study. First, the reflectance tracheal oximetry sensor is simply reformed by an unfolding transmittance pediatric oximetry sensor, and this may affect the measurement. However, this reformed oximetry sensor has been used successfully in studies of S_tO_2 measurement and trans-esophageal right and left ventricular oxygenation monitoring under guide of transesophageal echocardiograph [18, 19], and this similar reform performed well in our previous trans-tracheal monitoring of pulmonary arterial oxygen saturation [20]. Second, it is difficult to absolutely control the time point of arterial blood sampling.

In summary, the performance of trachea oximetry to rapid desaturation, both the response time and accuracy are better than peripheral oximetry.

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