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Validation of the qCO Cardiac Output Monitor during Valsalva Maneuver

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Abstract— **Monitoring cardiac output for a variety of patient conditions is essential to ensure tissue perfusion and oxygenation. Cardiac output can be measured either invasively using a pulmonary artery catheter or non-invasively using impedance cardiography (ICG). The objective of the present study was to validate a cardiac output monitor, the qCO (Quantium Medical, Barcelona, Spain). The qCO is based on the ICG principle. Twenty-five volunteers (18-75 years) were enrolled in the study. The duration of the study was 10 min. The subjects were asked to rest quietly in an armchair for a duration of 5 min. At 5 min they were asked to do a Valsalva maneuver which is known to decrease the cardiac output. The baseline value of the normalized cardiac output (qCO index) was compared with the minimum value during the Valsalva maneuver. The results showed (t-test, p<0.0005) significant difference between the cardiac output estimated at baseline and during the Valsalva maneuver. In conclusion, the qCO was able to indicate trend changes of the cardiac output in volunteers.**

I. Introduction

There is a solid and growing body of knowledge advocating inclusion of Cardiac Output (CO) monitoring in various treatment algorithms which could pertain to millions of patients each year worldwide. However, the implementation of this procedure has proven difficult in an economically challenged climate. The main objective of hemodynamic therapy is the oxygenation achieved by adequate tissue perfusion. In the case of critically ill patients who are particularly predisposed to cardiocirculatory failure, the hemodynamic treatment might benefit from advanced cardiovascular monitoring [1]. Apart from cost issues, one of the main features that should present the CO monitors in order to achieve a greater acceptance is to be noninvasive, which is not always the case with the currently available CO technology. The relevant publications in this field typically use the Swan Ganz catheter as reference method while this technique is totally invasive and therefore poses a considerable risk for the patient, such as infection thrombosis and emboli, besides being time-consuming to position [2]-[4].

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The objective of the present study was to validate a new noninvasive Cardiac Output Monitor, the qCO (Quantium Medical, Barcelona, Spain), using the thoracic impedance cardiography (ICG) principle. This method has been applied previously by a number of authors, among others Kubicek and later modified by Sramek and Bernstein [5]-[9]. The precision of these methods is not optimal, hence there is room for new thinking for optimisation of the hardware and the algorithms by which the data are recorded and processed. A number of commercial devices have been sent to the market among which the BIOz (Sonosite, WA, USA) [10] and the more recent NICOM (Cheetah Medical, Tel Aviv, Israel) [11]. The advantage of the ICG is that it is totally noninvasive and is harmless to the patient as the procedure only incorporates the positioning of four wet gel electrodes on the thorax of the patient. The measurement is continuous, hence a more detailed trend can be provided to the physician.

II. Method

The qCO measures the ICG by 4 electrodes, one pair injects a constant current, 400 µA RMS, at a frequency of 50 kHz, while a second pair of electrodes measures the resulting voltage, as shown in the Fig 1. The voltage is amplified and digitized with a sampling frequency of 250 Hz and converted to an isolated (complying with ISO 60601 standard) USB signal transmitted with a proprietary communication protocol. The impedance plethysmographic curve (Z curve) is displayed on a standard laptop supplied with a medical grade power supply, to ensure patient safety. The qCO monitor uses the information from the Z curve and the maximum of its first derivative dZ/dt to provide a unitless

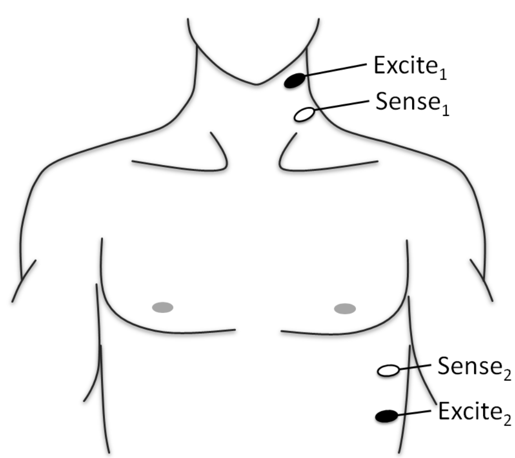

Figure 1. The qCO electrode positions.

estimate of the cardiac output, the qCO index, which allows tracking changes in cardiac output.

The study was carried out at the 21st Century Specialized Clinic, Mazatlan, Mexico, including 25 volunteers (17 men, 8 women). The duration of the study was 10 min. The subjects were asked to rest quietly in an armchair for a duration of 5 min. At 5 min they were asked to do a Valsalva maneuver [12] which is known to decrease significantly the cardiac output. The qCO index was normalized to its baseline value for each volunteer. A Lilliefors test was applied to assure that the data belong to a normal distribution, then a t-test was carried out to establish whether there was significant difference between the baseline (average value of the 15 seconds before start of the Valsalva maneuver) and the minimum achieved during the maneuver.

III. RESULTS

An example of the evolution of the Cardiac Output during the Valsalva maneuver can be found at Fig. 2. The upper curve shows the impedance (Z) versus time, the middle curve is the first derivative while the lower curve is the qCO index, the unitless estimate of the cardiac output. On the upper curve a lower frequency is present, arising from the respiratory curve, which disappears during the Valsalva maneuver as the patient is in apnea. This can also be appreciated from Fig. 3 and Fig. 4, where a respiration frequency around 0.3 Hz is observed, while during the Valsalva maneuver the main frequency is due to the Z changes over each heartbeat, in this example approximately 1.5 Hz or 90 BPM.

Five subjects were rejected for failing to perform the Valsalva maneuver correctly: in one case no Valsalva maneuver was performed at all and in four cases the subject was moving during the maneuver. The age range was 18-75 years. Fig. 5 shows the evolution of all volunteers included in the study. Time 0 is the start of the Valsalva maneuver and the curve is drawn for each volunteer until the interruption of the maneuver. In several subjects there is a minor increase immediately after start, while the minimum occurred at 20-60s. Table 1 shows the change of each subject. The mean change was 15.8 % (standard deviation 9.7%), which was significantly different from the baseline value (p<0.0005).

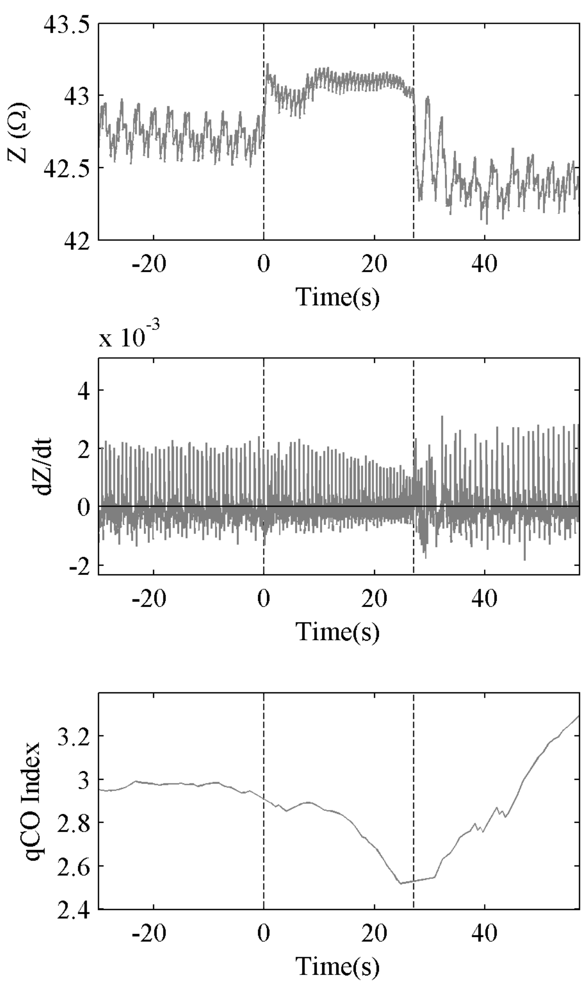

Figure 2. Volunteer #15 around the Valsalva maneuver.
The two dashed vertical lines represent the beginning and the end of the Valsalva maneuver, respectively.

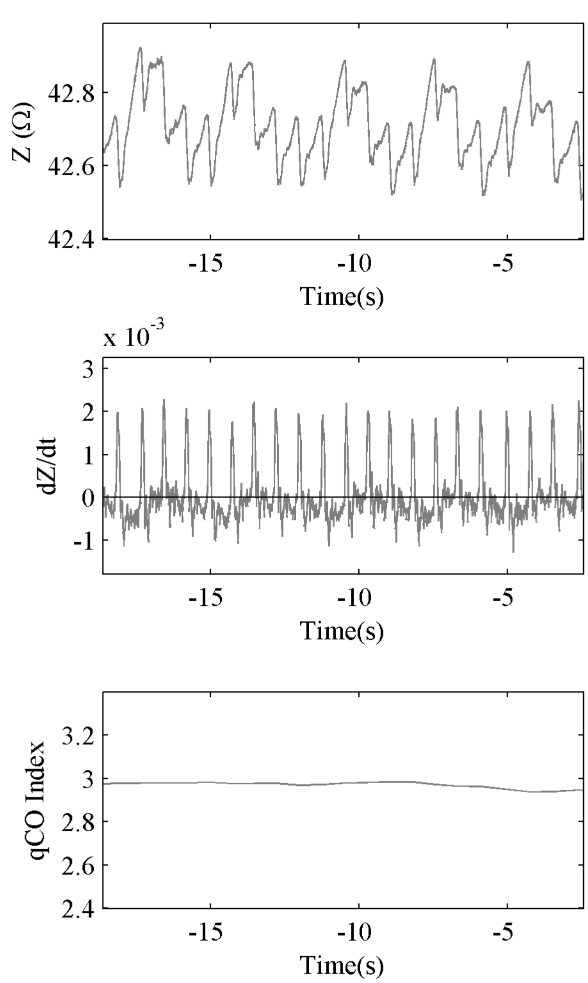

Figure 3. Volunteer #15 at baseline.
A clear respiratory pattern is observed in the Z curve. The qCO index is stable.

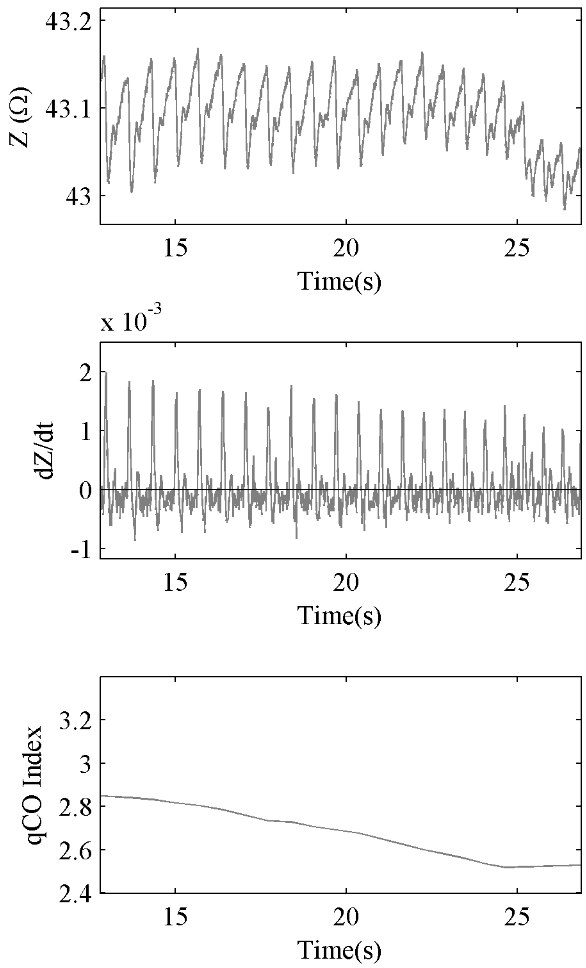

Figure 4. Volunteer #15 at the end of the Valsalva maneuver. The Z curve is flatter and the qCO index is decreasing.

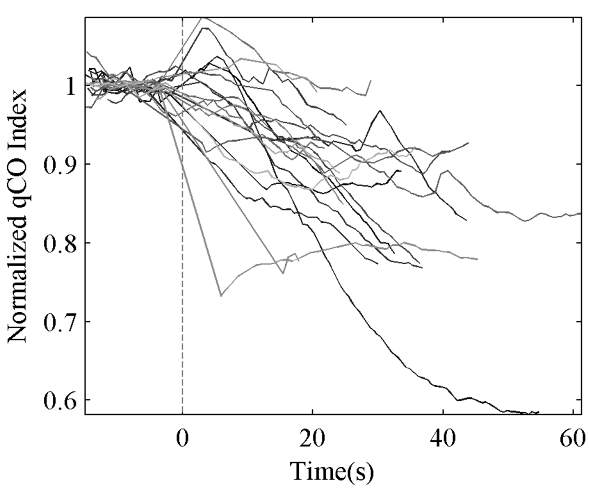

Figure 5. Normalized qCO index 15s before and during the Valsalva maneuver for all volunteers included in the study.

TABLE I. CARDIAC OUTPUT DECREASE DURING VALSALVA MANEUVER

Subject ID	**qCO index decrease (%)**
1	21.4
2	13.7
3	41.8
4	17.1
5	22.7
6	23.2
7	5.0
8	22.6
9	11.3
10	6.9
11	9.8
12	17.2
13	9.4
14	1.2
15	15.1
16	23.9
17	26.7
18	1.7
19	11.1
20	13.2
Mean ± Std	**15.8 ± 9.7**

Std = Standard Deviation

IV. DISCUSSION

The results show that the qCO was able to detect a change in cardiac output during the Valsalva maneuver. The present version of the device and the algorithm does not give an absolute value of cardiac output, rather it gives a trend of the changes in cardiac output that the patient has experienced. This information is useful during surgery where the patient might experience blood loss, if the patient suffers cardiovascular problems or any other reason that causes the patient to experience changes in cardiac output. The qCO is easy to use by attaching four electrodes to thorax of the patient. A number of limitations to the study should be mentioned. First of all this study was carried out in volunteers, the signal integrity might be affected by the electrical noise and other artifacts present in the operating room. Hence more studies in the operating room environment should be carried out. On the other hand, the Valsalva maneuver could be affected as well, some subjects might not collaborate fully, hence the expected change in cardiac output will not occur. It was noted in this study that not all subjects completed the Valsalva maneuver. Some authors have found that variations in the technique of the Valsalva maneuver in terms of prestrain final breath and strain pressure may interfere with the response in cardiac output [12]. Both tachycardic response observed during the strain and bradycardic behavior following the strain decrease proportionally to an increase in the lung volume and a decrease in strain pressure. In some cases, a bradycardic response may even be observed during the strain instead of the typical tachycardia. The cardiovascular response is higher when the Valsalva maneuver is started at the end of expiration and correlates with the strain length. It would thus be useful to take into account these considerations in future studies involving Valsalva maneuvers. In conclusion, it was found that the Valsalva maneuver was a useful method for an initial validation of a cardiac output monitor.

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