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A preliminary efficacy evaluation performed by opto-electronic plethysmography of asymmetric respiratory rehabilitation

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***Abstract*—The aim of present work is to test an opto-electronic system as diagnostic device to preliminary assess the efficacy of asymmetric respiratory rehabilitation.**

The respiratory rehabilitation efficacy, in terms of tidal volume variations, has been assessed for 14 patients undergone left or right superior lobectomy. Tidal volume variations of six torso compartments have been measured in pre-surgery, post-surgery and post-rehabilitation phases. Significant difference of total chest wall tidal volume has not been observed between the three phases. Tidal volume differences have been observed between paretic and healthy side. Significant tidal volume increase has been observed for non-operated side between pre-surgery and post-rehabilitation phases during quiet breathing, mean tidal volume increases of about 32%. Measurement results indicate that respiratory rehabilitation is more effective on non-operated side which, in turn, compensates the operated one. The opto-electronic plethysmograph appears to be a suitable instrument for evaluation of respiratory rehabilitation in case of respiratory volumes asymmetry.

I. Introduction

LUNG cancer is one of the most prevalent types of cancer in the western population. Lobectomy is a lung cancer treatment consisting of lung lobe surgical excision [1], [2]. Usually, respiratory rehabilitation is performed to accelerate physiological recovery after lung lobectomy [3].

Recent literature shows positive results in terms of quality of life, physical performance, exercise capacity and also positive effects in patient's daily life after respiratory rehabilitation, but not in terms of respiratory functionality improvement [4], [5]. Other studies show that a period of rehabilitation improves functional and peak exercise capacity in patients with restrictive pulmonary function but they do not improve pulmonary function [2], [6], [7].

In another study, the efficacy of respiratory rehabilitation has been investigated on patients divided in rehabilitation and no-rehabilitation groups and their tidal volume has been measured by spirometry; significant differences in total tidal volume have not been observed between the groups [8].

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Indeed, total chest wall tidal volume measured in these studies does not show significant change since post-surgery until post-rehabilitation.

Therefore, there are no significant results about respiratory rehabilitation efficacy so far and, probably, this is partially due also to the limited sensitivity and specificity of the instrumentation utilized.

The aim of present work is to test an opto-electronic system (OEP System®; BTS, Milan, Italy) as diagnostic device to preliminary assess the efficacy of respiratory rehabilitation.

An Opto-Electronic Plethysmograph (OEP) for motion analysis of a large number of markers (89), fixed on the body, is able to detect the movements of chest wall occurring during respiration [9]. Special television (TV) cameras [solid-state charge-coupled devices (CCDs)] are operating up to 100 frames per second syncronized with coaxial infrared flashing light-emitting diodes. The three-dimensional (3D) coordinates of the different markers are computed using stereo-photogrammetric methods. The next step is to compute the volume closed surface obtained by connecting the points to form triangles (using Gauss's theorem). Volume accuracy, accordingly to manufacturer's specifications, can be between 0,02 and 0,2 l in according to patient's placement and calibration process. Starting from the measured points a special geometrical modelling of the chest wall is developed to describe the surface of the whole chest wall and its different compartments [10], [11]. Indeed, OEP system can provide a tidal volume independent measurement of six different compartments of the chest wall as opposed to spirometers and pneumotachographs [12], [13], which are only able to measure the overall tidal volume.

In this work, total chest wall has been analyzed in pre-surgery, post-surgery and post-rehabilitation phases. Moreover, single compartments tidal volume has been measured to evaluate possible asymmetries between operated on side and non-operated on side in order to obtain more information about respiratory rehabilitation efficacy.

II. Description of Methodology

A group of 14 patients (10 men and 4 women), undergone left or right superior lobectomy and then respiratory rehabilitation, has been enrolled for this study. Rehabilitation time lasted two weeks for every patient. Rehabilitation program consisted of the following

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exercises: (1) quiet diaphragmatic, thoracic and low costal respiration; (2) exercises to recovery shoulder and thorax mobility; (3) gym bicycle exercises to improve cardiovascular fitness.

Torso and single compartment tidal volumes have been measured in three different phases: pre-surgery, post-surgery and post-rehabilitation, afterwards called phase 1, 2 and 3 respectively. The evaluated compartments are: the pulmonary rib cage (RCp) defined as extending from the markers placed at the clavicular line, the abdominal rib cage (RCa) and the abdomen (AB). Each compartment axially splits into right and left side (Fig.1). The separation between left and right was obtained using the axial column of markers placed on the sternum.

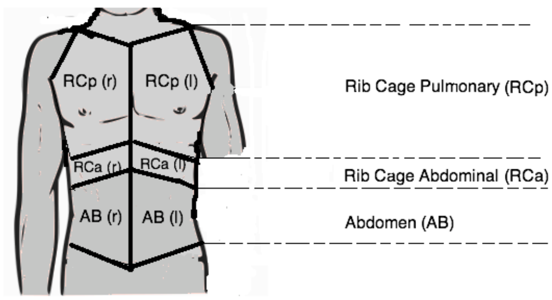

Fig. 1. Patient's torso splits in three compartments (RCp= Rib Cage pulmonary, RCa= Rib Cage abdominal, AB= Abdomen) which, in turn, split in left and right side.

This division allows to measure single compartment tidal volumes as a function of time and to obtain information about any asymmetries between sides in patients.

Torso (To), RCp, RCa and AB mean patients' tidal volume have been compared in the three phases to evaluate changes between pre-surgery, post-surgery and post-rehabilitation phase.

Torso tidal volume (V_{To}) is obtained by adding the contributions of all compartments V_{RCp},V_{RCa}, V_{AB} where V_{RCp} is pulmonary rib cage tidal volume, V_{RCa} is abdominal rib cage tidal volume and V_{AB} is abdomen tidal volume.

Finally, RCp has been split in healthy and paretic side, i.e. non-operated and operated side, to evaluate differences among the three phases. This analysis has been carried out on only RCp tidal volume because partial lobectomy surgery removes lung lobes placed in that compartment and it could be more significant than other compartments.

All measurements have been performed by OEP in order to record chest wall displacement during respiration. Trials have been carried out recording chest displacement during two minutes of quiet breathing.

III. Results and Discussion

A. *Torso tidal volume measurements*

Figure 2 shows torso tidal volume (V_{To}) measurements of every patient during quiet breathing as mean ± standard deviation (SD).

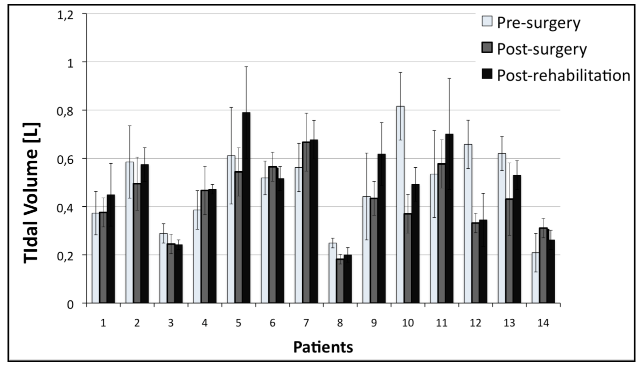

Fig. 2. Torso mean tidal volume ± SD in three different phases for every patient.

Percent mean tidal volume variation between two different phases has been calculated by the following equation:

$$\Delta V_X^{n-m}\% = \frac{V_X^m - V_X^n}{V_X^n} \cdot 100 \qquad (1)$$

where:

the X pedix defines the compartment,

n-m apex is 1-2 to compare pre-surgery and post-surgery phases, 2-3 to compare post-surgery and post-rehabilitation and 1-3 to compare pre-surgery and post-rehabilitation.

TABLE I
PERCENT TORSO MEAN TIDAL VOLUME VARIATION BETWEEN TWO DIFFERENT PHASES

	Phases		
	1-2	2-3	1-3
$\Delta V_{To}\%$	-12%	+13%	+1%

Table 1 shows that from pre-surgery to post-surgery phase there is a torso tidal volume decrease (only for 50% of patients), V_{To} increases from post-surgery to post-rehabilitation for 70% of patients and for 50% of patients from pre-surgery to post-rehabilitation too, but this percent increment is very poor.

Thus, torso tidal volume appears not to give enough information about improvement from pre-surgery to post-rehabilitation.

B. *Compartments tidal volume measurement*

RCp, RCa and AB tidal volumes have been measured in pre-surgery, post-surgery and post-rehabilitation in order to have more detailed information. These measurements cannot be obtained by a spirometer or pneumotachograph (Fig.3).

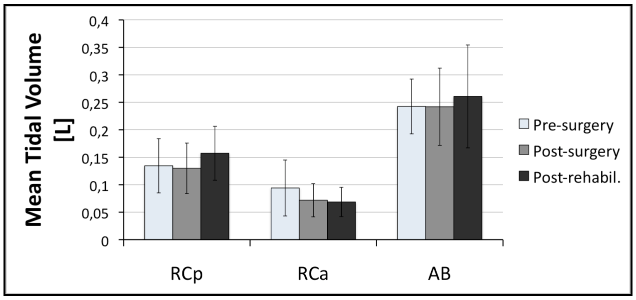

Fig. 3. Mean tidal volume ± SD for three compartments in the three different phases

Figure 3 shows mean V_{RCa} decreases between post-surgery and post-rehabilitation, in opposite to V_{RCp} and V_{AB}, and so abdominal rib cage ventilation does not improve after rehabilitation. Moreover, mean AB tidal volume is always higher than RCp and RCa ones.

TABLE II
PERCENT MEAN TIDAL VOLUME VARIATION FOR THREE DIFFERENT COMPARTMENTS BETWEEN TWO PHASES

	Phases		
	1-2	2-3	1-3
$\Delta V_{RCp}\%$	-2%	+23%	+21%
$\Delta V_{RCa}\%$	-24%	-4%	-28%
$\Delta V_{AB}\%$	-0.3%	+7%	+7%

Results obtained from experimental trials show that surgery causes a tidal volume decrease for every compartment, but especially for RCa. Positive increases are more significant in RCp both from post-surgery to post-rehabilitation and from pre-surgery to post-rehabilitation, so rehabilitation improves meanly RCp ventilation.

C. Healthy and paretic side of pulmonary rib cage tidal volume measurement

Finally, RCp tidal volume of paretic $\left(V_{RCp}^{P}\right)$ and healthy $\left(V_{RCp}^{H}\right)$ side has been analyzed in order to obtain more information about respiratory rehabilitation efficacy (Fig. 4).

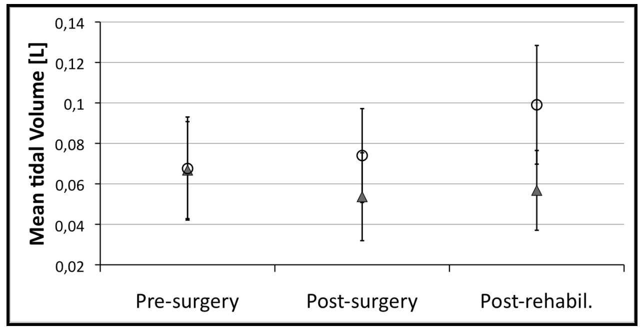

Fig. 4. Mean tidal volume ± SD for RCp healthy (circle) and paretic (triangle) side.

Figure 4 shows that mean V_{RCp}^{H} and V_{RCp}^{P} are similar in pre-surgery phase (68±20 mL and 67±20 mL respectively). Mean tidal volume difference increases between healthy and paretic side from pre-surgery phase (1%) to post-rehabilitation phase (43%). This result shows that healthy side compensates the operated side tidal volume decrease.

TABLE III
PERCENT MEAN TIDAL VOLUME VARIATION FOR HEALTY AND PARETIC SIDE BETWEEN TWO PHASES

	Phases		
	1-2	2-3	1-3
$\Delta V_{RCp}^{H}\%$	+8%	+25%	+32%
$\Delta V_{RCp}^{P}\%$	-20%	+5%	-15%

Table III shows that after surgery mean V_{RCp}^{P} decreases of about 20% (54±20mL) while mean V_{RCp}^{H} increases of about 8% (74±20mL). Thus, non-operated side compensates operated side ventilation.

V_{RCp}^{H} increases of about 25% (99±30mL) and V_{RCp}^{P} of only about 5% (57±20mL) from post-surgery to post-rehabilitation. Respiratory rehabilitation mainly increases the non-operated side tidal volume.

V_{RCp}^{H} increases is of 32% from pre-surgery to post-rehabilitation and V_{RCp}^{P} decrease is of 15 %.

D. Total results

Table IV resumes the results.

TABLE IV
TIDAL VOLUME VARIATION SINCE PRE-SURGERY UNTIL POST-REHABILITATION

Compartments	Tidal volume variation (%)
Torso (To)	+1%
Pulmonary rib cage (RCp)	+21%
Abdominal rib cage (RCa)	-28%
Abdomen (AB)	+7%
RCp no-operated side	+32%

RCp, RCa and AB tidal volume allows a more detailed analysis about respiratory rehabilitation efficacy as compared with overall tidal volume. Results show that RCp non-operated side compensates RCp operated side, in which tidal volume decrease. Trials have been carried out to obtain quantitative results that confirm qualitative results presented in some studies [6], [7].

Moreover, results confirm asymmetry absence between V_{RCp} healthy and paretic side in pre-surgery phase [14], whereas in post surgery after partial lobectomy OEP appears to be a valid instrument for these kind of studies.

Indeed, results of present work show that there is RCp tidal volume asymmetry between non-operated and operated side. This result might be more useful than total chest wall changes to evaluate patient's improvement and to establish rehabilitation exercises efficacy.

Finally, OEP is useful to measure patient pulmonary volumes to underline differences between healthy and paretic side, before and after respiratory rehabilitation.

IV. CONCLUSION

Rib cage pulmonary, abdominal rib cage, abdomen and torso tidal volume have been measured to analyze respiratory rehabilitation efficacy. Three compartments analysis shows that V_{RCa} decreases above all in post-surgery. V_{RCp} increases of 21%, V_{To} increases of 1% between pre-surgery and post-rehabilitation phase. With this compartmental analysis, it is possible to evidence compartment volumes that have undergone the greatest changes; in this way, rehabilitation program can be customized for every patient in accord to their personal ventilation problems. Results show the importance to divide chest wall in different compartments, in order to evaluate respiratory rehabilitation efficacy.

RCp healthy side improves its ventilation after rehabilitation (tidal volume increase 32%) in order to compensate paretic side tidal volume decrease (-15%). OEP measures single compartment tidal volume and thus, it allows to obtain a more detailed information about respiratory rehabilitation.

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