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A Continuous Monitoring Software of the Vision Based Incentive Spirometer: Experimental Validation*

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ABSTRACT

A continuous observation is required to check as to whether the patient uses the incentive spirometer (IS) properly, and it is difficult to quantify the extent of its use. This study aimed to develop a software to recognize the IS and to check as to whether it is possible to evaluate if the patient uses the IS properly through this software. A flow-oriented IS consisted of the three colored floating balls with inspiratory flows of 700 cc/s, 1200 cc/s, and 1900 cc/s was used. The software was consisted of the IS and its components were recognized in real time from the video recorded by the webcam. It was prepared to recognize yellow, red, and blue, which were the ball colors of the spirometer, and green, which represented the start and end lines of the ball. When the balls and green markers were recognized, the height of the IS was measured. Furthermore, the speed of inhalation was calculated as the ratio of the moving distance of the ball. Lastly, this speed was recorded every 0.02 s. The 500, 1000, and 1500 cc syringes were used to simulate inhalation. After pulling the syringes, the movements of the balls were identified, and the volume of inhaled air was calculated. The calculated volume was statistically compared to the actual volume. When the movement of the ball recognition line in the video was compared with the last moving ball, the software exactly tracked each of the three balls of the IS, and identified as to whether the IS was used and the extent of inhalation. However, it did not exactly reflect the actual inhalation volume. We developed a vision-based monitoring software to measure whether the patients used the IS well and experimentally verified it. The software can be used as a contactless modality for preventing respiratory complications after surgery.

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1. Introduction

The incentive spirometer (IS) is a manual function recovery device, which is a disposable medical device, and which is used to check on the extent of breathing exercise and recovery. The IS was included for the enhanced recovery after the surgery (ERAS) protocol of many institutions. In addition, it can be used for functional recovery for the patients with respiratory failure (Eltorai et al., 2018a; Shetty et al., 2020). However, while educating the patients on the use of the IS, medical staffs fail to verify if the patients are actually using it properly. To check as to whether the patients use the IS properly, a continuous observation is required, yet it is difficult in reality. Thus, it is also difficult to quantify the extent of its use.

Recently, the methods for automatically recognizing a specific object or human face from an image, while continuously shooting with a camera have been developed. The equipment for which this technology is applied has already been commercialized and used in real life. In particular, during the recent coronavirus disease pandemic, the use of such equipment has increased as it can replace human work. Similar to this method, we assumed that it would be possible to check as to whether the patients use the IS properly; hence, we devised a related software. The purpose of this study was to check as to whether it is possible to evaluate if the patients use the IS properly through this software.

2. Research Method

2.1 Type of the IS and the modeling of inhalation

A plastic flow-oriented IS consisted of the three floating balls with the inspiratory flows of 700 cc/s, 1200 cc/s, and 1900 cc/s was used. The balls were yellow, red, and blue. To check on the exact position of the balls, green markers were attached to the baseline and highest point of the area where the ball moved. Syringes were used to simulate the quantitative inhalation. The volume of inhalation was 500 cc, 1000 cc, and 1500 cc, and inhalation was performed by pulling the piston of the syringe of each volume.

2.2 Software configuration

The software was consisted of the following algorithms: First, to correct the webcam images, a Gaussian filter was applied to convert the red-green-blue color space into a hue-saturation-value color space. Thereafter, it was prepared to recognize yellow, red, and blue, which were the ball colors of the spirometer, and green, which represented the start and end lines of the ball. The positions of the three balls of the IS were identified by color, and the boundaries were drawn (Figure 1). The order of recognizing the ball was set to ensure that the first moving ball was recognized first, regardless of the color. Subsequently, the program was designed to recognize the ball in the middle and recognize the last remaining ball moving.

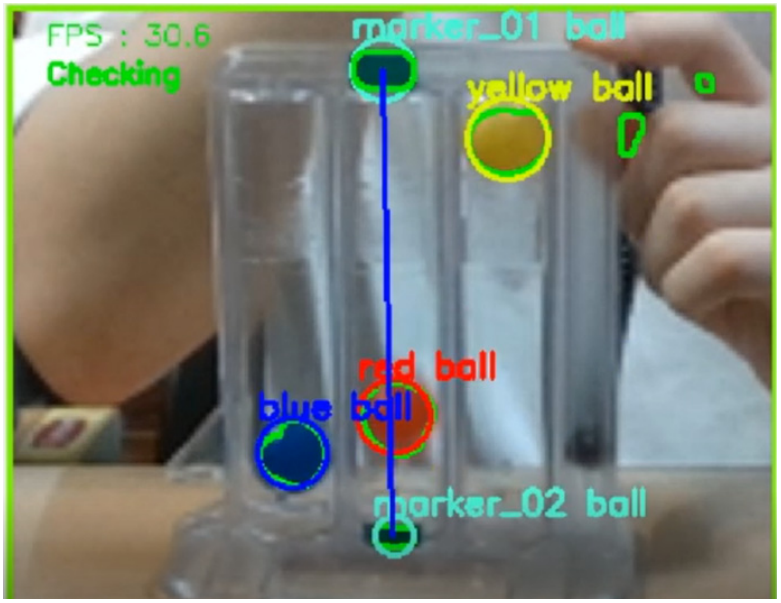

Fig. 1. Picture of the software captured from the video. The markers that identify the starting and ending points and each balls are automatically identified in the picture

When the balls and green markers were recognized, the height of the IS was measured using green markers on the start and end lines. Then, when the inhalation began and the balls moved, the moving distance of the balls was measured from the green marker on the starting line. The ratio of the moving distance of the ball at the total height was calculated, and the speed of inhalation was calculated by multiplying the maximum speed value in the cylinder. This process was performed once every 0.02 s. Furthermore, by multiplying the calculated speed value and 0.02 s, the volume sucked in 0.02 s was calculated. This process was repeated while the inhalation was continued, and the final inhalation volume was calculated by adding up all the measured volumes.

2.3 Data collection

After connecting the syringe to the IS inlet, we ran the software. After adjusting the webcam to show the IS fully, we checked as to whether the green markers and balls were recognized on the screen. When everything was recognized, we pulled the syringe as hard as possible and sucked the air. Subsequently, on the software execution screen, it was checked as to whether the recognition range moved along with the movement of the balls caused by air intake. Then, the volume measured using the software was recorded and compared with the volume of the syringe (Figure 2). This process was performed 100 times with one type of syringe, and the consistency of the measured values obtained each time was evaluated. As mentioned earlier, three types of syringes were used: 500 cc, 1000 cc, and 1500 cc, and a total of 300 measured values were obtained.

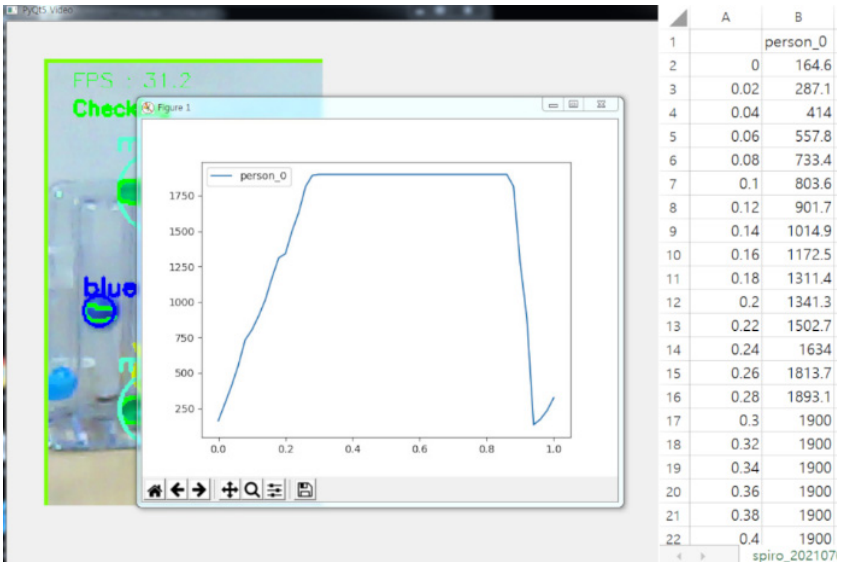

Fig. 2. The velocities of flow that was measured in the picture after pulling the syringe once. The velocity was measured once every 0.02 s. The volume of each sections was measured by multiplying the corresponding velocity of flow by 0.02 s, and the total volume was calculated by calculating the cumulative sum of volumes

2.4 Statistical analysis

A bias was calculated, and the Student's t-test was performed to confirm the difference between the measured and actual values. The coefficient of variation was calculated for the reproducibility evaluation. The R software version 4.0.5 was used for all statistical analyses.

3. Results

When using the 500 cc syringe, the first and middle balls moved, and the last ball did not move at all. There were 33 cases in which only the first ball moved, and among the remaining 67 cases, the second ball moved. When the 1000 cc and 1500 cc syringes were used, all of the balls, including the last ball, moved. When the movement of the ball recognition line in the video was compared with the last moving ball, it was consistent in all cases.

The average air volume calculated using the software was 135 ± 11.11 cc when the 500 cc syringe was used. The calculated air volume was 427.86 ± 48.84 cc when the 1000 cc syringe was used, and 1101.63 ± 156.77 cc when the 1500 cc syringe was used. The measured volume and actual volume showed a statistically significant difference ($p<0.001$), and the average bias between them was -364.1, -572.14, and -398.37. The coefficient of variation when using the 500 cc, 1000 cc, and 1500 cc syringes was 8.17%, 11.41%, and 14.23%, respectively (Table 1).

Table 1. Difference between the actual volume and the measured volume.

Actual (Syringe) volume (cc)	Measured volume (cc)			Mean bias (cc)	CV (%)
	Mean±SD	Min	Max		
1500	1101.63±156.77	670.8	1495.2	-398.37 (26.56%)	14.23
1000	427.86±48.84	308.6	527.8	-572.14 (57.21%)	11.41
500	135.9±11.11	101.9	160.4	-364.1 (72.82%)	8.17

CV, coefficient of variation; SD, standard deviation; Min, minimum; Max, maximum

4. Discussion

The use of the IS after surgery may reduce pulmonary complications (Soh et al., 2019; Sum et al., 2019; Bilyy et al., 2020). Therefore, some institutions have adopted the use of the IS for the ERAS. However, according to the American Association for Respiratory Care's guidelines, the routine use of the IS after surgery has not yet been recommended (Strickland et al., 2013; Eltorai et al., 2018b). The reasons for the negative results in the previous studies on the use of the IS after surgery are the poor study methodology and the low patient adherence (Eltorai et al., 2018b). The methodological faults include many factors, such as the imprecise procedure descriptions and the lack of appropriate control comparisons (Eltorai et al., 2018b). Among these methodology faults is the lack of a quantification method for the extent of the actual IS use. In the previous studies, the patient was instructed to use the IS for a few seconds at a time, several times a day, but the researcher was often unable to directly confirm how accurately it was performed (Sum et al., 2019). Through the method that we have presented, we can quantify the extent of movement of the ball and time it has moved. Thus, a more reliable evaluation is possible by comparing the time or intensity of use, rather than the evaluation based on the presence or absence of use.

In many hospitals, after first educating the patients on the IS, the medical staffs cease to supervise as to whether the patients are using it properly. This reduces the patients' motivation and adherence, and makes it very difficult to evaluate as to whether they are using it properly (Eltorai et al., 2018b). To compensate for which, adherence can be increased by automatically monitoring the IS through a webcam or camera and set an alarm off to use the IS at a set time. We devised a method to measure the inspiratory volume using the flow-oriented IS. However, when it is actually applied, its accuracy or reproducibility is not high, and hence, it would be difficult to use the IS in practice. This may be so because the ball hardly moves in an air flow that is too low. When the air flow is low, there is a flow of air. Hence, there is a volume to be sucked in, yet it is not measured. Therefore, it is measured less than the actual volume. At a high air flow of 1900 cc/s or more, it was calculated as 1900 cc. Therefore, this may also be why the measured volume was lower than the actual volume. Therefore, the overall volume is measured to be lower than the actual volume, which is similar to the result we obtained.

5. Conclusion

We developed a vision-based monitoring software to measure as to whether the patients used the IS well and experimentally verified it. While the software did not accurately measure the inhaled volume, it accurately tracked on the movement of the IS's three balls over time. Therefore, the software will be useful for preventing the respiratory complications after surgery by monitoring as to whether the patients actually use the IS properly contactlessly. A study to actually apply this for the post-operative patients will have to be conducted in the future. It could also be developed as a digital therapeutic by adding educational functions to the software.

Conflicts of Interest

The authors declare to have no conflict of interest.

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