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Evaluation of Respiration Reproducibility of Chest General X-ray Examination using Self-made Respiratory Synchronization Device

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ABSTRACT

The purpose of this study was to develop a respiratory synchronization device for X-ray (X-RSD) to increase the reproducibility of inspiration when examining the Chest X-ray of a patient who difficulty in breathing coordination. The X-RSD was self-made using an air pressure sensor and air was injected by connecting a ventilator to the mannequin for CPR. At this time, the amount of injected air was quantified using the SkillReporting device. After placing the X-RSD on the chest of the mannequin, the amount of air was tested in 6 steps from 200 to 700 cc by 100 cc increased. For the accuracy evaluation, the sensitivity of X-RSD was measured by repeating a total of 80 measurements, and the sensitivity was 100%, and very precise results were obtained. After that, the images examined while viewing the X-RSD of the chest lateral examination and the images obtained by the blind examination were compared and evaluated. The lung volume of X-RSD was larger than that of the blind test, and the deviation was smaller. Overall, the use of X-RSD can help with chest X-ray examination of patients who have difficulty in cooperating, and it is thought that it will be possible to contribute to the reduction of exposure dose by reducing the repeat rate of general X-ray examinations.

Keywords: General X-ray, Exposure dose, Pediatric X-ray, Chest X-ray, Respiratory Synchronization Device

I. INTRODUCTION

General imaging is a simple, non-invasive test for viewing internal organs, often performed for the purposes of check-ups or diagnostics. According to statistics from the Health Insurance Review and Assessment Service (HIRA), the frequency of general imaging in Korea has increased by approximately 22% in 3 years, from 2016 to 2019[1,2]. Chest radiography is a test used to diagnose lesions through the examination of the rib cage, which includes the lungs, trachea, bronchial tubes, heart, and major blood vessels. X-ray irradiation is performed at the end of deep inspiration while the lungs are expanded. The Source to Image Receptor Distance is set to 180 cm to prevent distortion and expansion of cardiac shadows[3]. Among the types of chest radiography, general imaging is a low-cost, highly efficient option that is widely used in clinics due to the considerable amount of information obtained given its short duration[4,5]. On the other hand, the presence of overlapping lung shadows from the various organs located in the chest or images not taken during inspiration may pose challenges to obtaining accurate readings[3]. Thus, in order to prevent the overlapping of lung shadows with the ribs, high tube voltage should be used, and in order to minimize the overlapping of lung shadows and obtain images

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favorable for lesion detection, images must be taken at an inspiratory state when the lung field is enlarged[3,6]. However, the patient's breathing state cannot be controlled arbitrarily by the radio-technologists, so the patient's cooperation must be performed to examine the inspiratory state. For patients with whom there are challenges in communication, however, such as pediatric or unconscious patients, there are barriers in following the instructions of the radio-technologists, in which case the images are taken based on visual observation of inspiration[7]. This may be a limitation as it heavily depends on the technique of the radio-technologists and lacks a standard inspiration state during imaging, which leads to increased repeat rates. In examinations using other devices such as CT, in chest imaging, the respiratory synchronization device is already used to standardize and examine the patients respiratory status. Therefore, it is possible to obtain an image of high diagnostic value even form a patient who has difficulty in communication. However, there is a problem in that the quality of the image varies depending on the patient's breathing cooperation because a breathing synchronization device is not used in general X-ray. As such, this study aimed to develop a respiratory synchronization device and examine whether radiography with standardized inspirations is possible in general imaging.

II. MATERIALS AND METHODS

1. Development of Sensor

The respiratory synchronization device used in this study (X-ray respiratory synchronicity, X-RSD) is a plastic container 13 (W) × 9 (L) × 5 (H) cm^3 in size. A red LED lamp, green LED lamp, gain adjuster, and power button were installed on the exterior of the container, while the main controller connected to the MPU was developed inside the container. The main controller and pressure sensor were connected using a sensor connector. The pressure sensor used was an FSR402 pressure sensor, in which the resistance value changed upon pressure.

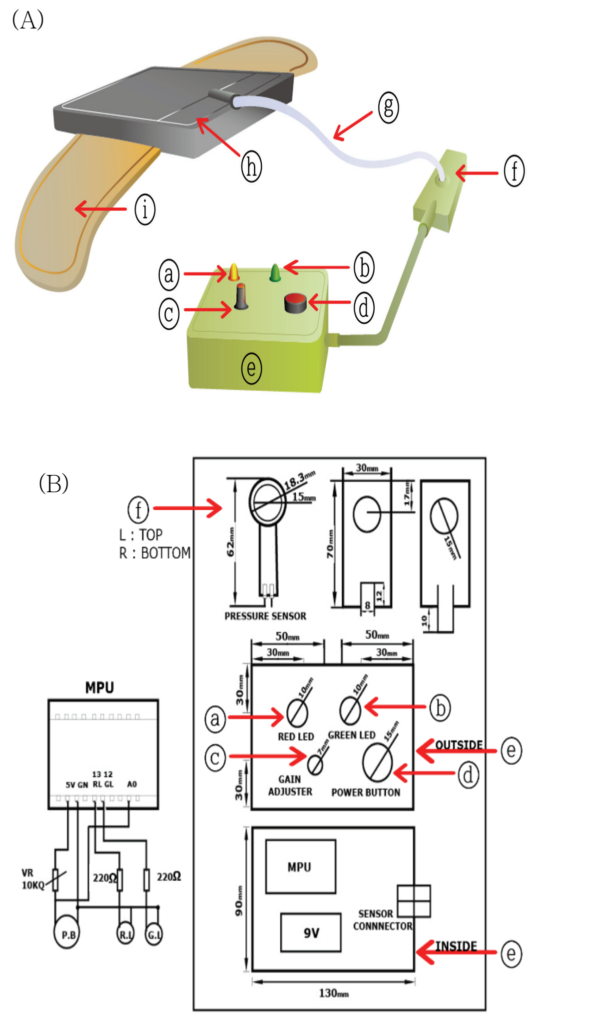

Fig. 1. (A) Minetic diagram of X-RSD (There are red LED lamp(ⓐ), green LED lamp(ⓑ), gain adjuster(ⓒ) and power button(ⓓ) in main controller(ⓔ) that is connected with pressure sensor(ⓕ). Applying pressure to pressure pad(ⓗ) fixed by Velcro belt(ⓘ), the pressure sensor senses incoming air by air injection tube(ⓖ). The red LED lamp turns on when the pressure is applied, and the green LED lamp turns on when the pressure isn't applied. The reference value of pressure sensor can be set through the gain adjuster.) and (B) drawing of X-RSD

The pressure pad was made of a square radioactive material of 24 (W) × 14 (L) cm^2 in size, and for ease of air injection, the connecting parts of the pad were made detachable. The pressure sensor and pressure pad were connected using a rubber tube measuring

145 cm in length[Fig.1].

The pressure pad of the X-RSD can thus be secured onto the patient pad were connected using Velcro belt and air in the pressure pad travels through the rubber tube based on changes in the patienting a rubber. Once the pressure caused by air traveling through the rubber tube reached the pressure sensor, the resistance value of the sensor changes, and the change in resistance value is recognized and converted to data by the MPU. An arbitrary reference point is set for the data, and the change in pressure is displayed using an LED lamp. The Gain adjustment device can be used to change the reference value of the data. The red LED lamp turns on when pressure is applied, while the green LED lamp turns on in the absence of pressure.

2. Materials and Equipment

In this study, a CPR mannequin (Resusci Anne QCPR mannequin, Laerdal, Norway) was used to conduct the experiment in a human-like environment. Air was injected into the mannequin using a ventilator (EVA-900M, NBMt, Korea) and the Laerdal Wireless Skill Reporting System (Simpad PLUS, Laerdal, Norway) was used to determine the amount of air injected, and an X-ray tube (E7239X, DK medical systems, Korea) was used to take chest lateral images[Fig.2].

3. Procedure

3.1. Determining X-RSD Sensitivity

In order to determine the sensitivity of X-RSD, a pressure pad was secured in between the nipples of the mannequin using a Velcro belt. Based on the average human respiratory volume, 500 cc, a ventilator was used to inject 200 cc, 300 cc, 400 cc, 500 cc, 600 cc, and 700 cc of air into each respective mannequin. Checks were completed on the function of the X-RSD for each injection volume. In consideration of mechanical error, the sensitivity of the X-RSD was determined through 80 repeated measurements for each respiratory volume.

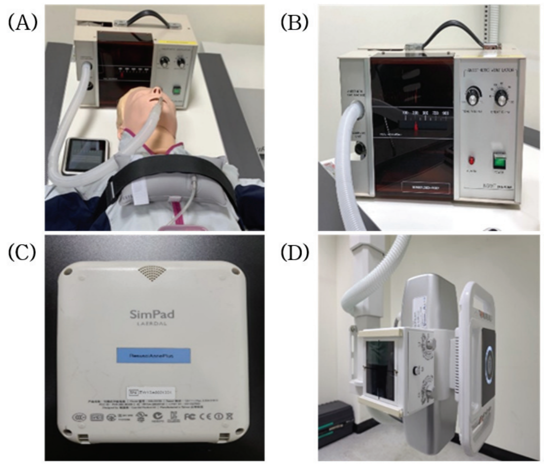

Fig. 2. Connecting (B) the ventilator to (A) the mannequin to inject air and checking the amount of air through (C) the simpad. Imaging chest lateral is performed with (D) X-ray tube.

3.2. Application of X-RSD in General Imaging

In order to examine the usefulness of the application of X-RSD in general imaging, chest lateral images were taken in a blind condition, where the device was not used, and an intervention condition in which the X-RSD was used. Although the mannequin looks similar to the human body, it was incompatible with PA or AP imaging as the internal structure was comprised of metal parts. Furthermore, as the top of the device is designed to inflate when air is injected, it is impossible to observe changes in the airbag through PA or AP imaging. In order to overcome this limitation, the airbag was examined laterally, which enabled observations of height. The ventilator was set to a breathing cycle of 20 breaths/min with a respiratory volume of 500 cc, similar to that of a human. A 14 x 17 inch cassette was used, and the X-rays were incident toward the center of the airbag on the mannequin. All images were taken under the following conditions, 110 kV tube voltage, 12.5 mAs tube current and 180 cm SID. In the blind condition, 5 images were taken with a naked-eye observation of breathing state without the X-RSD. In the intervention condition, 5 images were taken based on the indication of breathing status as observed using the red LED lamp. The images were taken by 5 researchers who each took one image for the blind and intervention conditions, respectively.

3.3. Analysis of Images

10 images were collected in total, as 5 images were taken in the blind and intervention conditions, respectively. The airbag portion of the images was classified into upper, middle, and lower parts, depending on the position of each part in relation to the chest springs of the mannequin.

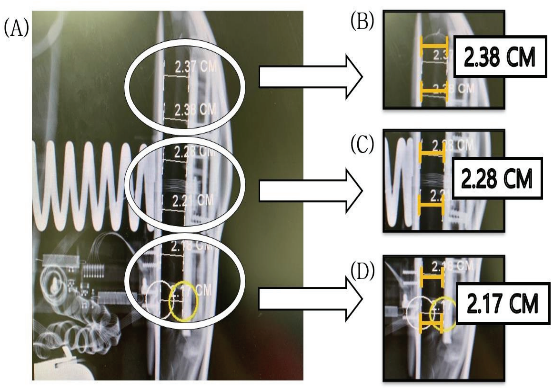

Fig. 3. Imaging for measuring data (A) by upper (B), middle (C), and lower (D) of chest lateral X-ray imaging.

The upper part was defined as the portion of the airbag positioned above the chest springs, the middle part was defined as the portion of the airbag positioned in line with the chest springs, and the lower part was defined as the portion of the airbag positioned below the chest springs. At each position, the length from the beginning of the shadow of the airbag to the end was measured twice, for a total of 6 measurements for each image. 30 measurements were obtained in the images taken in the blind condition, as well as in the intervention condition involving the X-RSD, respectively, for a total of 60 measurements[Fig.3].

3.4. Statistical Analysis

An independent sample t-test was performed to derive the average of the measurements taken from the chest image using a statistical program (SPSS 18.0, IBM, USA). Here, a p-value less than 0.05 indicated statistical significance.

III. RESULT

1. Comparison of X-RSD sensitivity based on the amount of air injected

80 measurements were taken for each respiration volume from 200 cc to 700 cc. 480 measurements were taken in total, of which 100% were recognized without error[Table.1].

Table 1. Sensor Recognition according to Tidal Volume

Tidal Volume(cc)	n	Average(cc)	Sensor (n)	Recognition (%)
200	80	215.16 ± 16.35	80	100
300	80	333.58 ± 6.40	80	100
400	80	414.70 ± 7.08	80	100
500	80	500.00 ± 7.04	80	100
600	80	586.00 ± 7.04	80	100
700	80	709.51 ± 27.09	80	100

2. Measurement values of the mannequin chest images based on X-RSD use

The lengths of the upper part of the images taken in the blind condition were measured to be the longest at 2.38 cm and the shortest at 0.57 cm. In the middle part, the measurements ranged from 2.28 cm to 0.61 cm. In the lower part, the measurements ranged from 2.18 cm to 0.57 cm. Measurements in the intervention (X-RSD) condition ranged from 2.37 cm to 1.5 cm in the upper part, 2 cm to 1.25 cm in the middle part, and 1.6 cm to 1.14 cm in the lower part. The length of images taken blindly was 1.06 ± 0.62 cm, and the length of the images taken using X-RSD was 1.65 ± 0.32 cm. Therefore, when using X-RSD, the mean vlaue was higher than that of the blind test($p<0.05$)[Table.2].

Table 2. Compare of the image measurements according to using X-RSD

Type	n	Average(cm)
Blind	30	1.06 ± 0.62
X-RSD	30	1.65 ± 0.32
p		0.000

IV. DISCUSSION

With an increase in the use of general imaging tests, the use of chest X-rays has also increased[1,2]. For images taken with an expanded lung field, which have a high diagnostic value, it is particularly important to perform the procedure with a close observation of the patient part a human chest[8]. Nevertheless, patients who have difficulty communicating are more likely to require repeats as it is more difficult for them to control their breathing[9]. The X-RSD was developed as a means to alleviate such challenges in general imaging and its usefulness in the clinical application was evaluated.

First, the recognition of 100% of the 200-700 cc air injections performed to test the sensitivity of the X-RSD demonstrated that the X-RSD had excellent sensitivity. Afterwards, it was demonstrated that measurement taken during inspiration, upon lung field expansion, for chest lateral general imaging was more commonly observed in the intervention (X-RSD) condition compared to the blind condition.

According to the Standard Imaging Guidelines for Pediatric General Imaging Guidelines developed by the Ministry of Food and Drug Safety, it is recommended that chest X-ray be taken following two rounds of deep inhalation and exhalations, at a pause following the second inhalation. However, chilidren do not follow the instructions of radio-technologists well because their cognitive abilities and communication are not accurate[10]. Therefore, it is difficult to standardize the respiratory status of children because the above examination method is taken by judging with the naked eye of a radio-technologists. Such factors decrease the quality of the radiograph and increase the frequency of repeats[7]. Not only are children sensitive to radiation due to actively dividing cells, but they also have a longer life ahead of them, which increases the risk of cancer following an incubation[7]. As such, in order to reduce radiation exposure due to repeats among children, it is important to standardize their breathing status. Moreover, it is essential to have parents accompany children into the examination room during pediatric examinations to prevent movement and relieve anxiety[7]. In such circumstances, the parent may also be subject to secondary exposure. An increased number of repeats not only increases radiation exposure in children, but also the second exposure of parents, which highlights the importance of reducing repeats and acquiring high-quality images with minimal imaging[7].

Aside from children, patients who could benefit from an X-RSD during general imaging can also include those in the intensive care unit (ICU). Imaging in ICU patients may be of low quality as they often find it difficult to take a position or hold their breath[11]. Among ICU patients, there also may be those who are unconscious. Unconscious patients may have irregular or abnormal breathing patterns, which makes it difficult to standardize their breathing status[12]. In addition, since communication between the patient and radio-technologist is impossible, it is difficult to perform the examination in a sufficiently inspiratory state in the chest X-ray. Nonetheless, there is yet to be X-RSD available for standardizing breathing in unconscious patients during imaging of the chest X-ray, which requires the examinations to be exposured in a state of inspiration. The implementation of an X-RSD in general imaging will enable chest images of ICU patients, who face difficulties in communication or have irregular breathing, to be taken in a state of inspiration.

As such, this study aimed to develop an X-RSD with a main control based on Arduino and apply the X-RSD in general imaging. In the recent transition into the 4th Industrial Revolution, largely thanks to the development of technology, Arduino gained attraction following the incorporation of Inter of Things (IoT) as one of the core concepts of the 4th Industrial Revolution. Arduino refers to an open-source computing platform and software development environment that is based on a microcontroller board. It carries advantages of low cost, easy programming that is suitable for beginners, and enabling users to add functions to suit their needs[13]. Moreover, it provides a suitable environment for the development and research of IoT devices required in various industries regardless of expertise. Based on these characteristics, there has been promotion of research on incorporating Arduino into medical devices, befitting the 4th Industrial Evolution. Indeed, in the United States, Zach Taylor developed a portable ultrasound imaging device based on Arduino, while in England, Steven Reynolds developed an MR contrast agent autoinjector[14,15].

In Korea, however, there is a paucity of research on Arduino-based medical devices, indicating a need for active research efforts on the application of Arduino in medicine. Thus, the X-RSD developed in this study, which is based on Arduino, may serve as preliminary data for research on Arduino medical devices in Korea.

A limitation of this study is that the patietnt’s respiratory status can be recognized when X-RSD is used, but the moment of exposure must be determined by the radio-technologists. Nevertheless, future research on automatic imaging systems interlocking X-RSD and an X-ray irradiation device through the development of Arduino functions will help alleviate this issue.

V. CONCLUSION

The X-RSD developed in this study confirmed that standardized respiration control tests are possible in general imaging circumstances where respiratory coordination is not possible. It is anticipated that future research interlocking X-RSD and X-ray irradiation devices will lead to more accurate testing, for which this study will serve as preliminary data.

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자체 제작한 호흡 동기화 장치를 통한 흉부 일반촬영 검사의 호흡 재현성 평가

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요 약

본 연구의 목적은 일반촬영용 호흡 동기화 장치를 개발하여 호흡 협조가 어려운 환자의 가슴 검사를 할 때 들숨의 재현성을 높이는 것이다. 공기압 센서를 이용하여 호흡 동기화 장치를 자체 제작(X-RSD)하였고, 심폐소생술용 마네킹에 벤틸레이터를 연결하여 공기를 주입하였다. 이때 주입한 공기의 양은 SkillReporting 장치를 이용하여 정량화하였다. 마네킹의 가슴에 X-RSD를 위치한 후 공기의 양을 200-700 cc까지 100 cc 씩 총 6 단계를 나눠서 검사하였다. 오차 평가는 총 80회씩 반복 측정하여 X-RSD의 민감도를 측정하였고 민감도는 100%로 매우 정교한 결과 값을 얻을 수 있었다. 이후 가슴 측면검사를 X-RSD를 보면서 검사한 영상과, 암맹 검사한 영상을 비교평가 하였고, X-RSD의 폐 용적이 암맹 검사보다 용적도 크게 측정되고, 편차도 적게 측정되었다. 종합적으로 X-RSD를 이용하면 협조가 어려운 환자의 가슴검사에 도움을 줄 수 있으며, 일반촬영의 재촬영률을 줄여 전체적인 피폭선량 감소에 기여가 가능할 것이라 사료된다.

중심단어: 일반촬영, 피폭선량, 소아 X-선 검사, 가슴 X-선 검사, 호흡 동기화

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