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Original Article

Effect of diaphragmatic breathing training with visual biofeedback on respiratory function in patients with multiple rib fractures: A randomized-controlled study

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ABSTRACT

Objectives: The aim of this study was to investigate the effect of diaphragmatic breathing training with visual biofeedback on respiratory function in patients with multiple rib fractures.

Patients and methods: Between June 2021 and October 2021, a total of 16 patients (15 males, 1 female; mean age: 49.50±11.85 years; range, 25 to 66 years) who were diagnosed with multiple rib fractures were randomly assigned into two groups as the control group (CG, n=8) and the visual biofeedback group (VBG, n=8). The effect of each diaphragmatic breathing training on respiratory function was evaluated before and after eight interventions. For respiratory function, pulmonary function test was used to measure pulmonary function and respiratory muscle strength, and the Pain, Inspiratory capacity, Cough (PIC) score was used to evaluated pain, inspiratory capacity, and cough ability.

Results: In both groups, the pulmonary function representing the ratio of measurements to predicted values of both forced vital capacity (CG mean difference=25.37±4.58, p=0.002, VBG mean difference=24.25±3.96, p=0.007) and forced expiratory volume in 1 sec (CG mean difference=32.38±5.7, p=0.002, VBG mean difference=26.15±5.73, p<0.001) increased significantly. The maximal inspiratory (CG mean difference=14.00±0.35, p=0.002, VBG mean difference=20.5±6.26, p=0.009) and expiratory pressure (CG mean difference=43.72±29.44, p=0.034, VBG mean difference=25.76±6.78, p=0.015), the indicators of respiratory muscle strength, increased significantly in both groups. The PIC score, which evaluated pain, inspiratory capacity, and cough ability, also increased significantly in both groups (CG mean difference=1.63±0.26, p≤0.001, VBG mean difference=3.13±0.19, p<0.001). The change of PIC score after intervention did not significantly differ between the groups (F=1.439, p=0.250); however, there was a significant difference over time (F=38.476, p<0.001). The change of PIC scores differed over time between the groups (F=2.806 p=0.011).

Conclusion: Diaphragmatic breathing training and diaphragmatic breathing training with visual biofeedback can improve pulmonary function, respiratory muscle strength, pain, inspiratory capacity, and cough ability in patients with multiple rib fractures.

Keywords: Biofeedback, breathing exercises, diaphragm, respiratory muscles, rib fractures.

Rib fractures occur in 10% of patients with trauma and are common injuries, accounting for 39% of patients with chest trauma.[1] Even a single fractured rib can cause severe pain and trigger deep breathing difficulties, leading to pulmonary complications, such as atelectasis or pneumonia.[2] Pulmonary complications are experienced by 35% of patients with rib fractures.[3] Three or more fractured ribs, that is, multiple rib fractures, can cause shallow breathing due to pain, decrease endotracheal secretion, and increase the length of hospital stay and recovery period due to poor prognosis, which is correlated with mortality.[3]

Respiratory exercise during hospitalization, a conservative treatment for multiple rib fractures, is very important to increase respiratory strength, coughing ability, chest wall mobility, and pulmonary ventilation.[4] Diaphragmatic breathing training is a breathing method that induces maximum exhalation, improves lung ventilation, and promotes the discharge

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of secretions from the trachea. This method can be easily applied to daily life, as it has no side effects, and the training is easy to perform.[5] In addition, it causes relatively little pain and can be performed routinely by the patient on their own.[6] Despite such clinical advantages, it is difficult for the elderly or patients to recognize the exact contraction of the diaphragm while applying breathing exercises due to unfamiliarity with the method.[5] Furthermore, during diaphragmatic breathing training, there are many cases in which only the upper abdomen moves, and the lower abdomen has limited movement, or the abdominal wall contracts while inhaling and relaxes while exhaling.[7]

To compensate for such challenges, previous studies have applied biofeedback through ultrasound, respiratory apparatus, virtual reality based game, and surface electromyography (sEMG).[7-11] Among the several methods applying real-time biofeedback during diaphragmatic breathing training, sEMG has been reported to improve selective control of muscles.[12-14] In addition, sEMG has been used as a biofeedback method for training patients to self-regulate muscle contraction and tension. This is achieved through training to decrease the recruitment of overactive muscles during exercise or to increase the recruitment of underactive muscles during exercise.[15]

Although there have been many studies on diaphragm damage caused by multiple rib fractures,[16-18] there are insufficient studies on pulmonary function and respiratory muscle strength in patients with multiple rib fractures. In addition, there is no study showing changes in respiratory function, such as pulmonary function and respiratory muscle strength, through early respiratory exercise in patients with multiple rib fractures. Many studies have been conducted on the effects of diaphragmatic breathing training on various diseases.[19-22] Moreover, diaphragmatic breathing training using visual feedback has been conducted in healthy participants. However, there are insufficient studies on changes in respiratory function through the application of diaphragmatic breathing training with visual biofeedback in patients with multiple rib fractures.

In the present study, we aimed to investigate the effect of diaphragmatic breathing training with visual biofeedback on pulmonary function, respiratory muscle strength, pain, inspiratory capacity, and coughing ability in patients undergoing respiratory rehabilitation for post-traumatic multiple rib fractures.

PATIENTS AND METHODS

This single-center, prospective, randomized-controlled study was conducted at P Hospital, Busan Metropolitan City between June 2021 and October 2021. The sample size was determined using G*Power version 3.1.9 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), and the Pain, Inspiratory capacity, Cough (PIC) score results of the two groups obtained from the preliminary experiment were applied to the G*Power program. The effect size, statistical power, and alpha level were estimated as 0.8, 0.8, and 0.05, respectively. As a result of the analysis, the sample size was calculated as 16, and 20 participants were selected considering a drop-out rate of 20%.

A total of 16 patients (15 males, 1 female; mean age: 49.50±11.85 years; range, 25 to 66 years) who voluntarily consented to participate after the study was explained to them were randomly assigned to the control group (CG, n=8) who received diaphragmatic breathing training and the visual biofeedback group (VBG, n=8) who received diaphragmatic breathing training with visual biofeedback. This study performed randomization for the block of all participants via a computer random-number generator.

Among hospitalized patients diagnosed with multiple rib fractures, those who met the following criteria were included in the study: *(i)* receiving respiratory rehabilitation due to decreased respiratory function; *(ii)* having had multiple rib fractures within one week; and *(iii)* consented to participate in the study. Those were excluded if they met the following criteria: *(i)* limited treatment due to wounds or medical devices attached to the electrode attachment site and *(ii)* cognitive impairment due to brain damage or pre-existing brain diseases, or communication disorders due to other reasons. This study followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines.[23] A flow diagram of the study procedures is shown in Figure 1.

The participants were randomly assigned to two groups and the intervention was provided by a physical therapist with more than five years of experience. The two groups each received diaphragmatic breathing training for 30 min, once a day, eight times over three weeks. Only diaphragmatic breathing training was performed in the CG, and diaphragmatic breathing training with visual biofeedback was performed in the VBG. Both groups were educated on the diaphragmatic breathing training method before the intervention, and the

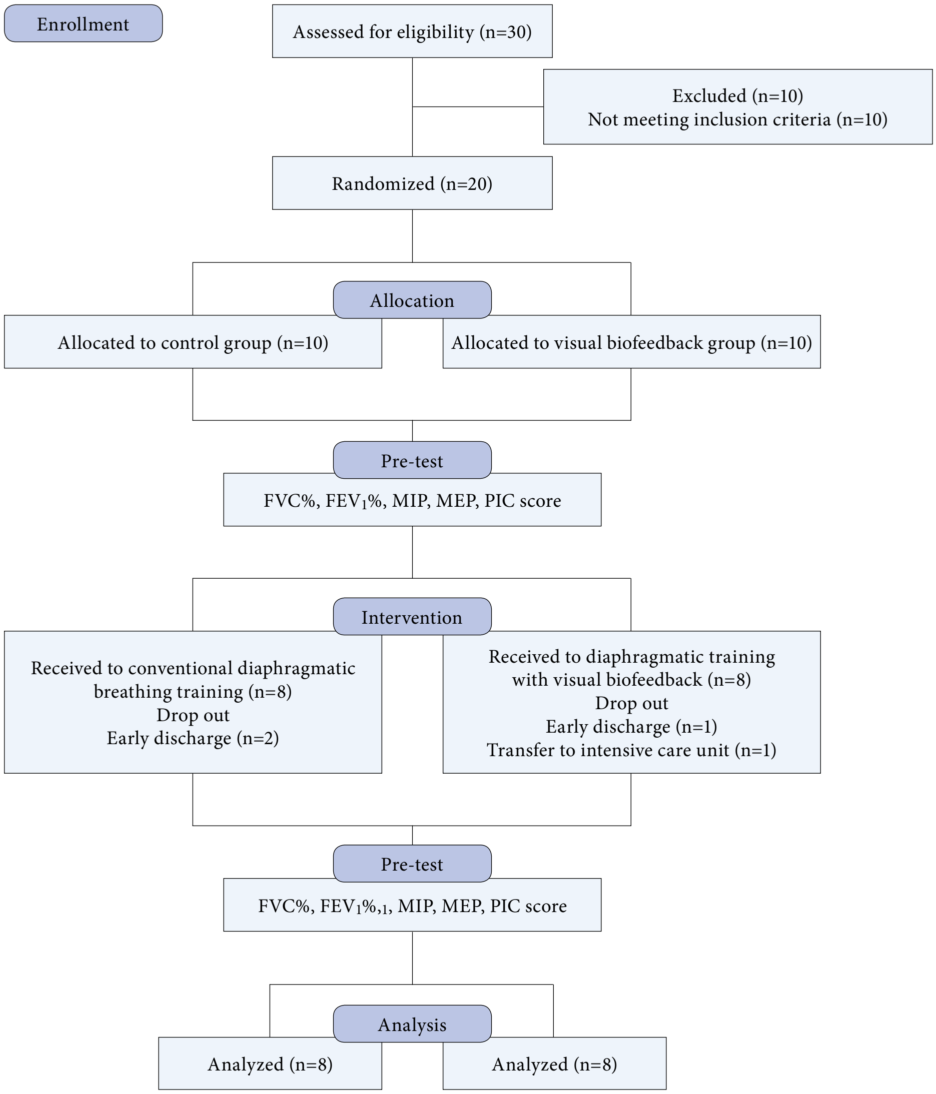

Figure 1. Flow chart of patient participation in the study.

FVC%: Percentage forced vital capacity; FEV%: Percentage forced expiratory volume in 1 second; MIP: Maximum inspiratory pressure; MEP: Maximum expiratory pressure; PIC: Pain, inspiratory capacity, and cough score.

training was performed when the participants were fully familiar with it.

Diaphragmatic breathing training was performed in the sitting position with one hand on the rectus abdominis muscle and the other hand on the chest to feel the movement of the abdomen while minimizing movement of the upper chest. One set consisted of four to five times of diaphragmatic breathing per minute followed by 30-sec rest. Four sessions were performed, with one session consisting of 1-min rest after five sets.

Diaphragmatic breathing training with visual biofeedback was conducted using EMG equipment (MOT10, PhysioLab Co., Ltd., Busan, Korea) and software (MoTive-Rs, version 1.0, PhyoLab Co., Ltd., Busan, Korea) (Figure 2). To minimize skin resistance to the sEMG signal, the electrodes were attached after shaving the skin in the corresponding area (if necessary) and cleansing it with an alcohol swab. The EMG electrodes (AgCl electrode, 3M Inc., Seoul, Korea) were attached on both sides at a point 1 cm from the superior anterior iliac spine

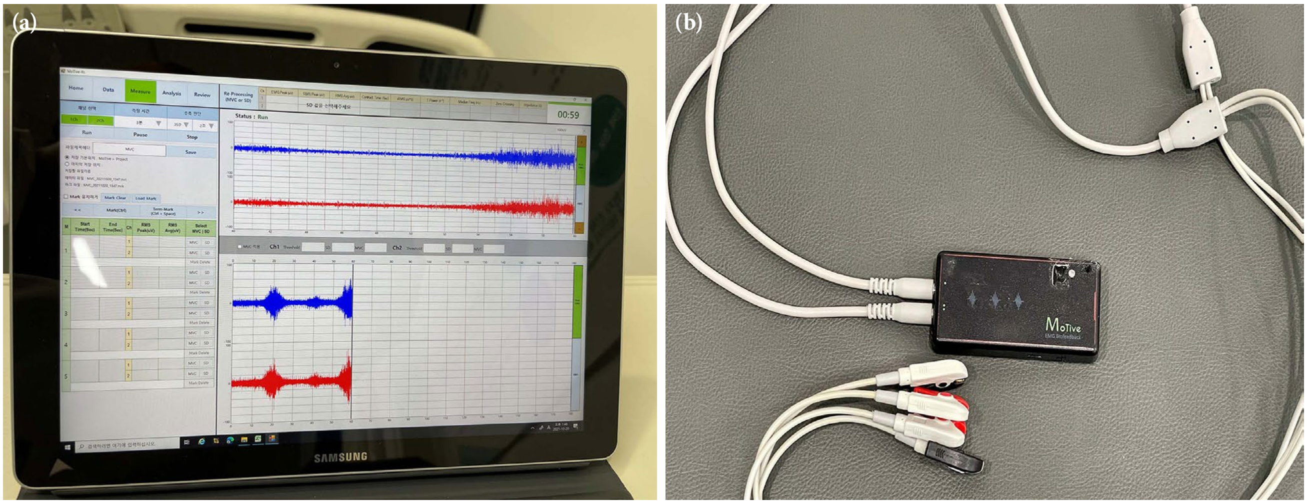

Figure 2. The surface electromyography (sEMG) **(a)** User interface of sEMG software (MoTive-Rs, version 1.0). **(b)** Bluetooth sEMG device (MOT10).

to the umbilicus with a distance of not more than 2 cm between the electrodes.[7] The diaphragm is a deep muscle, from which it is difficult to receive sEMG signals. In addition, this study did not aim to examine the muscle activity of the diaphragm during diaphragmatic respiration. Instead, we investigated the change in respiratory function upon application of visual biofeedback. Thus, based on previous studies, an attachment site that received the most signals during diaphragmatic breathing training and was not affected by gauze or chest tube drainage in case of surgery patients was determined.[7]

After attaching the electrodes, the therapist verbally instructed the patient to keep an eye on the monitor screen while performing diaphragmatic breathing in an upright sitting position. The monitor was positioned for the patient's convenience. During exhalation, the abdominal wall muscles were contracted to flatten the abdomen, and the real-time muscle contraction graph was viewed on the monitor to confirm abdominal contraction. The patients were instructed to remember the size of their maximal effort inspiratory and expiratory graphs on the monitor, and to inhale and exhale targeting those values. The patients were instructed to breathe by distinguishing between abdominal wall relaxation and diaphragm contraction during inhalation and abdominal wall contraction and diaphragm relaxation during exhalation.

To confirm the change in respiratory function according to each intervention, lung capacity, respiratory muscle strength, pain, inspiratory capacity, and coughing ability were measured in that order. Pulmonary function was evaluated using a spirometer (Pony Fx, Cosmed, Italy) that produced the maximal effort expiratory spirogram. The spirogram was used to determine forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV_1) to confirm lung capacity. The highest value was recorded so that the difference between the highest and second highest values was within 5% or 200 mL.[24,25] The measured values of pulmonary function tests were compared with the normal predicted values, considering race, age, sex, height, weight, and history of smoking. The ratio was analyzed to determine the percentage of predicted FVC (FVC%) and the percentage of FEV_1 (FEV_1%).

For respiratory muscle strength, maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP) were measured using a differential pressure gauge (Pony Fx, Cosmed, Italy). After three measurements, the value with the highest reproducibility was selected and recorded.[24]

The PIC score, developed at WellSpan York Hospital, USA, is a tool for evaluating pain, inspiratory capacity, and coughing ability in patients with rib fractures.[3] In this study, changes were continuously monitored by daily measurements during the eight-round intervention period. The total score was calculated by summing the scores for pain, inspiratory capacity, and coughing ability, with 10 being the maximum score and 3 being the minimum score. A higher score indicates a better respiratory function prognosis in patients with multiple rip fractures.[24]

Statistical analysis

Statistical analysis was performed using IBM SPSS for Windows version 22.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were presented in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The normality of each variable measured in the CG and VBG was confirmed using the Kolmogorov-Smirnov test. To analyze the association between two variables, the chi-square test was used. A paired t-test was performed to compare the FVC%, FEV_1%, MIP, and MEP before and after intervention within each group. An independent t-test was performed to compare the FVC%, FEV_1%, MIP, and MEP before and after intervention between the groups. A two-way repeated analysis of variance (ANOVA) was used to examine the change and interaction effects of pain, inspiratory capacity, and coughing ability measured repeatedly during the intervention period between each group at each time point. The Bonferroni post-hoc test was performed, when a significant main effect was observed for a group, time, or group-by-time interaction effect. A one-way repeated ANOVA was used to confirm the time-dependent differences in pain, inspiratory capacity, and coughing ability measured repeatedly during the intervention period within each group. A contrast test was performed for comparison between time points. A *p* value of <0.05 was considered statistically significant.

RESULTS

The participants included in the final analysis consisted of 16 patients with multiple rib fractures, with eight in patients in the CG, eight in patients in the VBG (Table 1).

In terms of pulmonary function, FVC% was significantly increased for both the CG and VBG before and after the intervention in a within-group comparison (CG mean difference=25.37±4.58, p=0.002, VBG mean difference=24.25±3.96, p=0.007). The FEV_1% was significantly increased for both the CG and VBG before and after the intervention in a within-group comparison (CG mean difference=32.38±5.7, p=0.002, VBG mean difference=26.15±5.73, p<0.001) (Table 2).

The MIP (CG mean difference=14.00±0.35, p=0.002, VBG mean difference=20.5±6.26, p=0.009) and MEP (CG mean difference=43.72±29.44, p=0.034, VBG mean difference=25.76±6.78, p=0.015),

TABLE 1
General characteristics of the subjects

	CG (n=8)		VBG (n=8)		
	n	Mean±SD	n	Mean±SD	*p*
Age (years)		50.75±11.94		48.25±12.44	0.313
Sex					0.302
Male	7		8		
Female	1		0		
Height (cm)		169.75±4.24		169.13±9.08	0.249
Weight (kg)		65.38±5.76		72.37±13.07	0.364
State of smoking					0.614
Non	3		4		
Current	5		4		
Injury mechanism					0.74
Fall down	3		3		
Crush injury	1		0		
Traffic accident	4		5		
Number of rib fracture		7.00±2.27		6.38±1.51	0.540
Site of rib fracture					0.614
Right	3		4		
Left	5		4		
Injury severity score		18.75±8.92		15.75±6.11	0.189

SD: Standard deviations; CG: Control group; VBG: Visual biofeedback group; p-Value from independent t–test.

TABLE 2
Comparison of FVC%, FEV_1%, MIP and MEP after the intervention

	CG (n=8)		VBG (n=8)		
	n	Mean±SD	n	Mean±SD	p
FVC%					
Pre (%)	8	42.88±17.49	8	51.75±18.34	0.339
Post (%)	8	68.25±12.91	8	76.00±14.38	0.276
p-value		0.002 *		0.007 *	
FEV_1%					
Pre (%)	8	44.00±21.06	8	55.25±19.53	0.287
Post (%)	8	76.38±15.36	8	81.40±13.80	0.494
p-value		0.002 *		<.001 *	
MIP					
Pre (cmH_2O)	7	44.00±23.87	8	37.25±10.25	0.507
Post (cmH_2O)	7	58.00±23.52	8	57.75±16.51	0.733
p-value		0.002 *		0.009 *	
MEP					
Pre (cmH_2O)	7	46.14±13.72	8	49.62±21.04	0.715
Post (cmH_2O)	7	89.86±43.16	8	75.38±27.82	0.665
p-value		0.034 *		0.015 *	

SD: Standard deviations; CG: Control group; VBG: Visual biofeedback group; FVC%: Percentage forced vital capacity; FEV_1%: Forced expiratory volume in 1 second; MIP: Maximum inspiratory pressure; MEP: Maximum expiratory pressure; * Paired t-test; p<0.05; p-value from independent t–test and paired t-test.

the indicators of respiratory muscle strength, were significantly increased before and after intervention in the CG and VBG, respectively, in a with-in-group comparison (Table 2).

Two-way repeated ANOVA to confirm that the change in PIC score did not significantly differ according to the groups (F=1.439, p=0.250), although there was significant difference over time (F=38.476, p<0.001). The change of PIC score over time differed between groups (F=2.806 p=0.011) (Table 3). In other words, there was no significant difference in the effect on pain, inspiratory capacity, and coughing ability between diaphragmatic breathing training with and without visual biofeedback. On the other hand, as the number of days of intervention increased, the effect on pain, inspiratory capacity, and coughing ability showed a difference (Figure 3).

In the CG, the PIC score showed no significant change through rounds 1, 2, 3, and 4; maintained in rounds 5 (M=8.25) and 6 (M=8.25); and increased in

TABLE 3
Effect within groups following the intervention

Source of variation	F	*p*
Intervention period	38.476	<0.001*
Group	1.439	0.250
Intervention period* group	2.806	0.011*

* Two-way repeated ANOVA; p<0.05

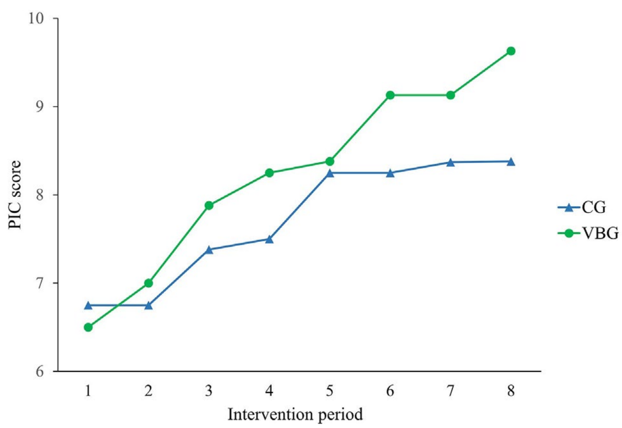

Figure 3. Comparison of the PIC score according to intervention.

CG: Control group; VBG: Visual biofeedback group; PIC: Pain, inspiratory capacity, and cough score.

TABLE 4
Comparison of the PIC score according to intervention

	CG (n=8)	VBG (n=8)	
Period	Mean±SD	Mean±SD	*p*
1	6.75±1.04	6.50±0.93	0.619
2	6.75±1.16	7.00±0.53	0.593
3	7.38±1.06	7.88±0.64	0.273
4	7.50±1.20	8.25±1.04	0.201
5	8.25±1.17	8.38±0.92	0.815
6	8.25±1.16	9.13±0.99	0.128
7	8.37±1.30	9.13±0.99	0.213
8	8.38±1.30	9.63±0.74	0.038 *

SD: Standard deviations; PIC score: Pain, inspiratory capacity, and cough score; * Two-way repeated ANOVA; p<0.05.

round 7 (M=8.37) followed by round 8 (M=8.38). In the VBG, the PIC score increased significantly in rounds 2 (M=7.00), 3 (M=7.88), 4 (M=8.25), 5 (M=8.38), and 6 (M=9.13); maintained in round 7 (M=9.13); and increased in round 8 (M=9.63) (Table 4 and Figure 3).

DISCUSSION

Diaphragmatic breathing training is being used in clinical practice as a respiratory rehabilitation method that can be applied in the early stages of hospitalization by effectively preventing pulmonary complications.[26,27] It has been reported that surface diaphragm EMG, which has been proven to be sufficient sensitive and reproducible enough to assess diaphragm function, can evaluate the level and pattern of diaphragm activation and, along with other physiological measures, can support the management of respiratory diseases.[28] Real-time visual biofeedback using sEMG has been reported to target the selective activation of muscles and potentially improve muscle control ability.[13] In addition, diaphragmatic breathing training using sEMG was reported to be useful for abdominal or thoracic surgery, rehabilitation after pregnancy, and breathing retraining for patients with hyperventilation.[7]

A recent study has shown that the effect of diaphragmatic breathing training on the improvement of pulmonary function and diaphragm contraction rate is statistically significant. Furthermore, it is important to recognize the correct contraction of the diaphragm while performing breathing exercises.[5] In a study examining the correlation between pulmonary function and diaphragm movement, diaphragm motility and FVC% showed a positive correlation.[29] These studies are consistent with the results of the present study in which diaphragmatic breathing training with and without visual biofeedback showed a significant increase in FVC%, an indicator of pulmonary function. In the present study, pulmonary function is thought to have improved due to improved ventilation by the increased strength and endurance of the diaphragm through diaphragmatic breathing training with and without visual biofeedback. These mainly involve contraction of the diaphragm, a major muscle involved in inhalation.

Respiratory retraining using biofeedback was reported to have a positive effect on pulmonary volume, blood oxygen saturation, respiratory muscle strength, and subjective pain when applied to patients with adult lung diseases, such as chronic obstructive pulmonary disease, emphysema, and cystic fibrosis.[30-32] When visual biofeedback was applied to diaphragmatic breathing training using sEMG in patients with cystic fibrosis in a previous study, FVC and FEV_1 were significantly improved. This finding indicates that diaphragmatic breathing training using biofeedback has a positive correlation with improved pulmonary function.[31] This supported the results of the present study which showed significant improvements in FVC% and FEV_1% after the application of diaphragmatic breathing training.

Although there have been no previous studies on respiratory muscle strength in patients with multiple rib fractures, many studies have reported on spinal cord injury due to trauma and respiratory muscle strength. It has been reported that inspiratory and expiratory muscle training in athletes with quadriplegia due to spinal cord injury have a significant effect on respiratory muscle strength and pulmonary volume.[33] A similar study reported that respiratory muscle strength could be improved, and the incidence of pulmonary complications could be reduced, when respiratory muscle training was performed in adults with quadriplegia.[34] Based on previous studies reporting that the mobilization of the diaphragm can be substantially increased during diaphragmatic breathing training, the results of this study are believed to be due to the increased mobilization of the diaphragm during diaphragmatic breathing training which, in turn, increased the strength of the respiratory muscles.[35]

Nonetheless, FVC%, FEV_1%, and respiratory muscle strength were significantly improved in both the diaphragmatic breathing training group and the diaphragmatic breathing training group using visual biofeedback. This may be because the average age of the participants in this study was middle age; therefore, there was no difficulty in recognizing the contraction and relaxation of the diaphragm during diaphragmatic breathing, and the simple trauma patient group without nervous system damage had high compliance with the training.

As a result of repeated measurements of PIC score during the eight rounds of intervention in this study, the diaphragmatic breathing training group and the diaphragmatic breathing training group using visual biofeedback both showed a significant increase, while comparing the first and eighth rounds of intervention. When compared over time, there was a significant increase in round 5 compared to round 1 in the CG, but a significant increase was confirmed in round 2 in the VBG. In addition, both groups showed an interaction effect between the PIC score and time. However, the PIC score was significantly higher in the VBG than in the CG in round 8, the final evaluation date. This finding suggests that the VBG shows improvements in pain, inspiratory capacity, and coughing ability faster than the CG.

Diaphragmatic breathing training with visual biofeedback helps recognize diaphragmatic contraction and relaxation in real time. A recent study compared normal diaphragmatic breathing training, diaphragmatic breathing training using a sandbag and applying resistance to the abdomen, and diaphragmatic breathing training with visual biofeedback in normal participants. The results of the diaphragmatic breathing training with VBG are consistent with those of the present study, with significant improvements in pulmonary function.[5] Therefore, when visual biofeedback was used, the paradoxical diaphragmatic respiration was immediately corrected by receiving visual feedback on the degree of contraction of the expiratory muscles of the abdomen. Thus, the correct diaphragmatic respiration method was recognized, thereby allowing respiration with maximal effort.

Although there have been no clinical studies confirming the prognosis using the PIC score, many studies have reported on the effect of pain, inspiratory capacity, and coughing ability on respiratory function. A recent study reported that pain in patients with rib fractures is subjective, but is an appropriate measure of the patient's overall condition.[36] In addition, a positive correlation between pain relief and return to daily life of patients with rib fractures was found in a study on the effect of pain on the prognosis of patients with rib fractures using a visual pain scale.[37] The incentive spirometry used to evaluate the inspiratory capacity in the PIC score measurement is one of the most used methods to improve pulmonary ventilation.[38] It is a method to continuously promote maximum inspiratory capacity to prevent the occurrence of postoperative pulmonary complications in patients undergoing surgery for chest trauma. Evaluating inspiratory capacity using incentive spirometry, a simple breathing training method that the patient can apply in bed, is a simple and quick method. The maximal expiratory velocimetry used to evaluate coughing ability is utilized to examine the relationship between the degree of pain relief and maximal expiratory velocity in patients with rib fractures.[39] Based on these previous studies, the PIC score, which evaluates pain, inspiratory capacity, and coughing ability, is a clinically useful measure that can be used to evaluate prognosis for the prevention of pulmonary complications in patients with multiple rib fractures and to easily determine changes in respiratory function.

The current study showed no significant difference in the effects of diaphragmatic breathing training with and without visual biofeedback on pulmonary function and respiratory muscle strength. However, considering that the PIC score increased significantly from the second round of intervention in the diaphragmatic breathing training group using visual biofeedback, visual biofeedback is thought to be effective in more rapidly improving pain, inspiratory capacity, and coughing ability in patients with multiple rib fractures.

A review of previous studies on the respiratory function of patients with multiple rib fractures confirmed that pulmonary complications caused by multiple rib fractures increased the length of hospital stay and recovery period. The effect of diaphragmatic breathing training on physical function in patients with stroke, spinal cord injury, and lower back pain has been confirmed.[22,40] However, it is difficult to find a study that conducted rehabilitation treatment for patients with multiple rib fractures with high trauma severity scores at catchment area trauma centers. It is confirmed that the diaphragmatic breathing training with and without visual biofeedback conducted in this study are helpful interventions to improve the respiratory function of patients with multiple rib fractures. Diaphragmatic breathing training with visual biofeedback was particularly effective in the early improvement of pain, inspiratory capacity, and coughing ability. Therefore, the application of diaphragmatic breathing training with visual biofeedback in patients hospitalized for multiple rib fractures due to trauma would contribute to the prevention of pulmonary complications by improving pain, inspiratory capacity, and coughing ability at an early stage. Although multiple rib fractures are common traumatic injuries, there is a lack of research on breathing interventions. Therefore, based on this study, various studies on breathing exercises using visual biofeedback should be conducted.

Since this study included patients in the acute stage within one week after trauma, there were missing values due to the difficulty in measuring the maximal inspiratory and expiratory pressures due to pain in the first evaluation. In addition, due to the repeated measurement design, participants dropped out midway due to transfer to the intensive care unit or early discharge over the intervention period. The eight interventions were conducted for a total of three weeks, a relatively short intervention period; therefore, there is a limitation in generalizing the study results. Therefore, a long-term study is necessary to investigate the effect of long-term intervention using diaphragmatic breathing training and visual biofeedback in the future. Furthermore, a study on the effect of diaphragmatic breathing training with visual biofeedback on long-term prognosis, such as quality of life and daily living ability, after discharge of patients with multiple fractures and on various application methods of diaphragmatic breathing training that can be applied in bed during hospitalization are needed for the rapid improvement of respiratory function in patients with multiple rib fractures.

Additionally, sEMG is a non-invasive method that cannot accept only signals from specific muscles, and irregular noise may appear depending on the electrode position or the surrounding environment. Consequently, during diaphragmatic breathing training using visual biofeedback, the surrounding environment should be maintained so that sEMG signals can be collected in a state with as little noise as possible, and research to eliminate noise is needed in the future. More research is needed on proper signal processing of sEMG and how to remove irregular noise.

In conclusion, both the diaphragmatic breathing training group and the diaphragmatic breathing training with VBG showed significant improvement in respiratory function. In the diaphragmatic breathing training group using visual biofeedback, pain, inspiratory ability, and coughing ability improved from the next day of training. Based on the results of this study, diaphragmatic breathing training with visual biofeedback is expected to improve patient participation and help the patients to understand the goal of rehabilitation treatment. It would be an effective treatment method that can be easily applied in the inpatient ward particularly, when movement to the treatment room and high-level exercise therapy are restricted due to trauma, such as multiple rib fractures.

Ethics Committee Approval: The study protocol was approved by the Bioethics Review Committee of the Catholic University of Korea (date: 06.01.2021. no: CUPIRB-2021-013). The study was conducted in accordance with the principles of the Declaration of Helsinki. The study was followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept, data collection, literature search, writing manuscript; H.J.S.; Analysis, concept, critical review, design, materials, supervision; H.H.S.

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