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STERNUM SUPPORT MAY PREVENT MAJOR ATELECTASIS AFTER MEDIAN STERNOTOMY

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Abstract

OBJECTIVES: Atelectasis and other pulmonary complications are common after cardiac surgery. A new type of sternum support vest (Posthorax®) has been shown to lower the risk of deep mediastinitis after median sternotomy. Clinical observations at the department of thoracic surgery at the Karolinska university hospital indicated that the vests also lowered the risk of atelectasis. We therefore designed a study aimed at testing if sternum support vest could be shown objectively to lower the risk of a number of pulmonary complications after median sternotomy.

METHODS: Two groups of patients were selected for inclusion. Group A (n = 67) were operated upon in September 2011, before the vest was introduced. Group B (n = 80) were operated upon in March 2012, after the introduction of the vest. The median age and ratio of men to women was similar in both groups, with 70% men. Scoring systems (0-4) were created to quantify the degree of atelectasis in each lung lobe and pleural effusion on each side on the post operative chest x-ray images. The severity of atelectasis was compared between groups. Information was also gathered from medical records.

RESULTS: A significantly lower ($p = 0.02$) prevalence of complete or near complete lobar atelectasis was seen in group B. This difference was seen only among men ($p = 0.01$). There were no other significant differences in complications between group A and group B.

CONCLUSIONS: This study provided the first evidence that a sternum support vest could lower the risk of complete atelectasis among men who have undergone median sternotomy.

Keywords: atelectasis, pulmonary complications, median sternotomy, sternum support vest

OBJECTIVES

Pulmonary complications following cardiothoracic surgery are a major cause of morbidity and mortality (1). These complications include atelectasis, pleural effusion, pneumonia, and acute respiratory distress syndrome (2). Several methods have been proposed to reduce the incidence of these complications (3). Unpublished clinical observations indicated that a recently introduced sternum support vest (Posthorax®), designed to prevent wound infection after cardiac surgery may also lower the risk of pulmonary atelectasis. This study investigated if the support vest can be shown to lower the risk of pulmonary complications in cardiac surgery, with a focus on atelectasis.

In cardiac and mediastinal surgery median sternotomy is often performed to provide access (4). 0.5% to 5% of the patients develop postoperative mediastinal complications (5), one of the most serious being mediastinitis, affecting 1% to 3% of patients, with a mortality between 10% and 25% (6). Pulmonary complications are also common, atelectasis and pleural effusion are often seen after CABG (7,8), and atelectasis occurs in 90% of anesthetized patients (9,10). Atelectasis increases the risk of hypoxemia, pneumonia and inflammatory response (11), major risk factors for the development of postoperative pulmonary dysfunction, and may play a greater role than lung vascular injury (12). Pneumothorax occurs in 1.4% of patients after cardiac surgery (13). Pneumonia affects 2% of patients after CABG (14) and significantly increases the risk of mortality. Pulmonary complications contribute significantly to in-hospital time, morbidity, and mortality after cardiac surgery (15).

A range of factors affect the risk for pulmonary complications (11). Surgical factors include the method of surgery, time available for preparation, and if reoperation was necessary.

Anesthetic factors include anesthesia-induced atelectasis, fluid balance, and the need for blood transfusion. Among patient factors, age, chronic obstructive pulmonary disease, and a bodymass index over 27 increase the risk (3).

Atelectasis can be defined as the collapse of alveoli, leading to a reversible loss of aerated lung, and reduced gas exchange (9). How it is caused during surgery is not well understood. Anesthesia is thought to play a large part, as the normally coordinated activity of the respiratory muscles is disrupted and respiratory muscle tone is diminished (11). Animal studies suggest that cardiac surgery itself play a role. Pigs that underwent CABG had significantly more atelectasis compared to pigs where only sternotomy was performed (16). Three contributing mechanisms are suggested (17).

Compression atelectasis is believed to be the most important mechanism in postoperative patients (17). Anesthesia causes relaxation and displaces the diaphragm into the thorax and reduces intercostal muscle tone (9), compressing lung tissue (10). It also shifts blood volume from thorax (18), increasing pressure on diaphragm. These factors allincrease pressure on lung tissue, leading to atelectasis.

Absorption atelectasis develops distally to blocked airways. Oxygen is rapidly absorbed into the blood, leading to collapse (19).

Surfactant, that covers the surface of alveoli and serves to reduce the surface tension and herby preventing alveolar collapse, may be impaired. In vitro experiments show that anesthesia results in impairment, leading to loss of compliance and risk of atelectasis (20).

Prevention of atelectasis improves postoperative outcome (9). Continuous positive airway pressure ventilation (CPAP), pre-surgery and postoperative respiratory physiotherapy decreases postoperative atelectasis (21-23). Early postoperative mobilization and kinetic beds, changing in body position, has also showed some effect but incidence remain high (24).

A sternum support vest is designed to hold the sternum together while healing, it restricts maximal expansion of the ribcage and has been shown to reduces hospital stay and sternal wound complications after sternotomy (25) (26). Since January 2011, the support vests have been offered to all patients after median sternotomy at the Department of Thoracic Surgery at Karolinska University Hospital in Stockholm. Clinical observations suggested less extensive atelectasis on chest x-rays in patients using the vest.

The purpose of this study was to investigate if use of the Posthorax® sternum support vest could lower the risk of lung complications among patients who have undergone cardiac surgery via median sternotomy.

METHODS

Patients

Two groups of patients were included in the study. Group A included all patients at the department of thoracic surgery at the Karolinska university hospital who had undergone thoracic surgery via median sternotomy during September 2011, prior to the introduction of the vest, defined as the control group. Group B included all patients at the department who had undergone median sternotomy during March 2012. March was selected after discussions with staff at the department. By this time, vests were available to all patients as part of routine postoperative care, and all staff were trained and familiarized with the vests. Patient care was otherwise identical, with patients from both groups receiving the same pain management, chest physiotherapy, early mobilization, upper limb and thorax exercises, and breathing exercises with positive expiratory pressure.

Data from a total of 166 patients was initially collected (76 in group A, 90 in group B). Patients were excluded if no chest x-rays was available from either the third, fourth or fifth postoperative day. This led to the exclusion of 16 patients (9 from group A, 7 from group B). Patients from group B were excluded if staff at the department determined that they had not used the vest as directed. This led to the exclusion of 3 patients.

Patient characteristics from the two groups are shown in Table 1. The median age for patients was similar. The ratio of men to women was the same, with men making up 70% of patients in both groups. The two groups did not differ significantly in the time elapsed from surgery until chest x-rays were performed, with an average duration of 3.5 days in both groups. There was, however, a significant difference ($p = 0.04$) in the ratio of bedside x-rays performed, as opposed to upright x-rays.

Both groups included patients who had undergone a range of different surgical procedures. The distribution of procedures is shown in Table 2. These all involved surgery of the heart, aorta or other structures in the mediastinum, requiring median sternotomy. These cases included the following conditions: aortic aneurysm, coronary artery occlusion, endocarditis, atrial septal defect, ventricular septal defect, aortic valve stenosis or insufficiency, mitral valve stenosis or insufficiency, and tricuspid valve stenosis or insufficiency. A number of patients underwent combination procedures, for example CABG and aortic graft, during the same operation. The number of procedures is therefore greater than the number of individuals in each group.

Group A included a significantly higher ratio of aortic graft procedures. There was also a higher ratio of combination procedures (defined as two or more different procedures performed during the same operation) in group A, though this difference did not reach statistical significance. The study was approved by the Regional Ethical Review Board, Stockholm, Sweden.

The sternum support vest

A sternum support vest of mainly cotton fabric (Posthorax®, EppleInc, Vienna, Austria) was fitted to the patients in group B. The vest is shown in Figure 1. Two foam pads on each side of sternum provide stabilization of the sternum halves and in anterio posterior direction. It is fitted prior to surgery and is worn postoperatively for at least six weeks.

Selection of x-ray images

Chest x-rays for each patient were obtained from the electronic archives at the department of thoracic radiology at Karolinska university hospital. Chest x-rays taken on the third day after operation were selected when available, as this is the standard interval at the hospital for when postoperative x-rays are performed. In cases where an x-ray was not performed on the third day after operation, x-rays from the fourth or fifth postoperative day were selected. Whenever available, upright x-rays were examined. However, for some patients only bedside x-rays could be found. Frontal x-rays were available for all patients. When lateral x-rays were available, these were included in the analysis.

Assessment of x-ray images

All chest x-rays from both groups were placed in a random order, and arranged for viewing on electronic displays. To achieve maximal blinding during analysis, images were retrieved and placed in order by a staff member not involved in the analysis. All identifying information was removed from the images, including personal details such as age and gender. The date the x-ray was obtained was also made inaccessible to the examiner. Images were then analyzed by an experienced thoracic radiologist (S.N. 22 years of experience).

The following variables were assessed for each patient:

- Degree of atelectasis in each lobe of the lungs, as defined by atelectasis score
- Degree of pleural effusion, as defined by pleural effusion score
- Presence of pneumothorax
- Signs of congestion

It was also noted if the clasps from a sternum support vest were visible on the image. These plastic clasps are somewhat opaque to x-rays and could often be seen on a chest x-ray image. This was seen as a complication for the blinding of the study.

Atelectasis score

In order to assess the degree of atelectasis for each patient, an atelectasis scoring system was designed. This system was based on scoring systems for atelectasis used in previous studies (25-26), but with modifications to present more detailed information on the degree of atelectasis. In this system, a score was given to each lobe individually, as opposed to scoring the lungs as a whole. This expanded scoring system has the advantage of conveying more specific information on the presence of atelectasis in each lobe. The score can easily be translated to less detailed scoring systems. Each lobe was given a score from 0 to 4, according to its degree of atelectasis; 0 - no sign of atelectasis, 1 - plate-like atelectasis or < 25% atelectasis, 2 - 25% to 50% atelectasis, 3 - 50% to 75% atelectasis (if lower lobe: diaphragm partially obscured), 4 - > 75% atelectasis (if lower lobe: diaphragm completely obscured).

The scores for each of the five lobes were recorded separately. Two examples are shown in Figure 2.

Pleural effusion score

A scoring system was implemented to quantify the degree of pleural effusion, by measuring how far the fluid extended in each lung cavity. Each hemithorax was scored from 0 to 4; 0 - no sign of fluid in the lung cavity, 1 - fluid in pleural sinus, but not above the level of the diaphragm, 2 - fluid level above the diaphragm, but under the hilum, 3 - fluid level extending up to the hilum or above, 4 - fluid in the entire hemithorax.

Postoperative pneumonia

Postoperative pneumonia was defined as a clinical diagnosis of pneumonia within six weeks after surgery. Hospital records from the entire Stockholm district area were examined for each patient to see if such a diagnosis had been made. The electronic records were examined to see if pneumonia was one of the diagnoses recorded for the patient during the six weeks following surgery. Further, final patient reports from the department of thoracic surgery were examined, to see if a diagnosis of pneumonia had been made during the hospital stay. Finally, other patient reports (when available) were studied, up to six weeks after surgery.

Statistical analysis

All data was entered into a Microsoft Excel® spreadsheet as a part of the data collection process. Distribution of categorical variables, such as atelectasis scores and pleural effusion scores, were compared using Pearson's chi-squared test. Distributions of continuous variables were compared using a Student's t-test. When comparing atelectasis scores and pleural effusion scores, the maximal value recorded for each patient was used. P-values < 0.05 were considered significant. Statistical analyses were performed using StatsDirect® software.

Results

Atelectasis

The vast majority of patients in both groups showed signs of atelectasis, with only 2 patients in each group receiving an atelectasis score of 0 for all lobes of the lungs. The highest median score in both groups was observed in the left inferior lobe. The median atelectasis score for each lobe is shown in Table 3.

When comparing the degree of atelectasis between the two treatment groups, the study focused on the highest atelectasis score observed in any lobe of the lungs. There were no statistically significant differences in the occurrence of a maximal atelectasis score from 0 to 3. However, an atelectasis score of 4 was significantly more common in group A ($p = 0.02$). The distribution of maximal atelectasis scores across both groups is shown in Figure 3.

Gender differences

An atelectasis score of 4 was significantly more common among men in group A than among men in group B ($p = 0.01$). There were no significant differences in the distribution of atelectasis scores from 0 to 3. The distribution of the highest scores is shown in Figure 4. There were no significant differences in the distribution of atelectasis scores between women in group A and women in group B. Gender differences remained significant when comparing men and women in group B, with an atelectasis score of 4 being significantly more common among women ($p = 0.04$). There were no other statistically significant differences in atelectasis scores between men and women in group B. There were no statistically significant differences when comparing men in group A with women in group A.

Pleural Effusion and other complications

Pleural effusions were seen in a majority of cases in both groups. This analysis focused on the highest score recorded for each patient, for either hemithorax. There were no statistically significant differences between the two groups.

Table 4 summarizes other findings. There were no statistically significant differences in the occurrence of pneumothorax, venous congestion or in the diagnosis of pneumonia within six weeks after surgery.

Visibility of vests on x-ray images

Structures of the support vests were visible on 91% of chest x-rays in group B. Table 5 shows how a number of these variables differed between cases within group B where vests were visible, and where vests were not visible. There were no statistically significant differences within these two subgroups of group B.

Analysis including non-vest users in group B

In group B, 3 patients were excluded for not having used the vest as instructed. Additional analyses were performed to test results when these patients were included. Differences in the prevalence of grade 4 atelectasis remained statistically significant (p-value 0.04). Other differences were not found to be statistically significant. Distribution of atelectasis and pleural effusion scores including these 3 patients are shown in Table 6.

Discussion

A lower prevalence of grade 4 atelectasis (complete or near complete atelectasis) was seen among patients who used the Posthorax® sternum support vest after median sternotomy, as compared to patients who underwent surgery before the vest was introduced. Dividing the groups by gender, the difference was significant only among men. For other lung complications, there were no statistically significant differences between the two groups.

Effect of vests on atelectasis

At present, the main method of combating postoperative atelectasis after uncomplicated median sternotomy is chest physical therapy, often in combination with breathing excercises, (27). While the use of incentive spirometry appears to be of no use against respiratory complications (28), there is evidence supporting the use of positive expiratory pressure devices. In a randomized clinical trial, patients who had performed breathing exercises using a positive expiratory pressure device were shown to have half as large areas of atelectasis as the control group (29). While the effect seen in the present study cannot be compared to the effect of breathing exercises, the thorax vest may be a treatment that can be used in addition to these interventions.

There are several mechanisms by which the vest could affect respiration, and thereby lower the risk of pulmonary complications. One could be altered breathing mechanics. As the vests restrict the mobility of the sternum and ribs, it may alter which muscle groups are used during respiration. Breathing while wearing the vest may be more dependent on the diaphragm, shifting ventilation to the lower lobes. This may prevent atelectasis of the lower lobes, where it has been shown to occur most frequently following surgery (17). Movement of the ribcage after sternotomy may be painful, as this can cause movement of the two halves of the sternum. Such pain has been well documented and may persist for years (22,30). Because the vest restricts expansion and movement of the ribcage, breathing while wearing the vest may be less painful for the wearer. This may increase the effectiveness of chest physiotherapy, including deep breathing exercises, and may facilitate early mobilization. This, in turn, may lead to deeper respiration when using the vest, with improved ventilation of the lungs leading to a lower occurrence of atelectasis.

Gender differences

Women accounted for approximately 30% of patients in both groups. While a lower prevalence of grade 4 atelectasis was seen among men in group B compared to men in group A, no such difference was seen among women. Within group B, a significantly lower prevalence of grade 4 atelectasis was seen among men, compared to women.

Recent studies have shown significant gender differences in chest wall kinematics. In a study of 34 healthy men and women, a greater contribution of the muscles of the rib cage was found among women during respiration, and a greater abdominal contribution to tidal volume was found among men (31). A study similarly showed a greater contribution of the inspiratory rib cage muscles in women compared to men, with women having on average a 9% shorter diaphragm compared to men (32). The authors speculate that the function of these anatomical differences may be to allow for the abdominal distension during pregnancy. As the sternum support vest limits the maximal expansion of the rib cage, these gender differences in respiration may have decreased the effectiveness of the vest in preventing atelectasis among women.

Another possible explanation is the design of the vest itself. The model used for women is slightly different, in order to accommodate the breasts. This may affect the function of the vest in such a way that it provides less stability than the male model. The female model of vest may also require more care when being fitted and adjusted for wearing, which may increase the risk that it is used in a suboptimal way. Since women are in the minority among cardiac surgery patients, staff may have had less training and experience in how to apply the vest effectively on women.

Limitations of the study

Differences among study groups

While the two groups in our study were similar in most respects, there were certain differences. The two groups were separated by six months, with group A consisting of patients treated in September 2011 and group B patients treated in March 2012. During the time period between the collection of the two groups, slight differences in staff and/or treatment may have occurred at the department. However, such changes were judged to be minimal.

There were significant differences in the type of surgery performed on patients in the two groups, with more aortic grafts performed in group A. There were also more combination procedures in group A, though not to a significant degree. There was also a significant difference in the ratio of bedside x-rays (25% in group A compared to 13% in group B). As a bedside x-rays may be an indication that the patient is not well enough to stand, this may be seen as an indication of higher morbidity among group A. However, this difference may also conceivably have been secondary to the effect of the vest. The use of a retrospective study design does not allow meaningful conclusions in this regard.

Blinding

Clasps and other structures of the support vests were visible on 91% of chest x-rays in group B. This was a problem in the blinding of the study, as a visible vest made it immediately clear which of the two groups the patient belonged to. This information can conceivably have influenced the assessment of atelectasis, pleural effusions, and venous congestion.

It is not clear why some patients in group B did not have visible vests on their chest x-rays. Staff may have temporarily removed the vest while the x-ray was performed, or clasps from the vests may have been obscured by structures on the x-ray image. Table 5 summarizes how a number of variables differed between patients within group B where the vest was seen, compared to patients where it was not seen. There were no significant differences between these subgroups of group B. This points to the lack of blinding not being a significant factor.

The gender differences in distribution of atelectasis scores also indicates that incomplete blinding may not have significantly affected study results. If the decrease in grade 4 atelectasis among men in group B was due to bias, the bias would have been applied selectively to men. This seems unlikely.

Subjectivity of analysis of x-ray images

X-ray images were analyzed by an experienced thoracic radiologist. Yet the use of our scoring systems for atelectasis and pleural effusion does leave some room for subjectivity in assessments, and it is possible that for each lobe, other radiologists would apply a different score. Several studies have demonstrated that there may be considerable differences in how different radiologists interpret the same images, although experienced observers were less prone to errors (33, 34). In the present study, additional analyses performed by a second or third radiologist would strengthen the results. However, the significant difference noted between groups in the prevalence of atelectasis was limited to grade 4 atelectasis (complete or near complete atelectasis). A lobe with this degree of atelectasis is markedly different from a normal lobe, leaving less room for interpretation.

Further research

This study presents the first evidence that atelectasis can be prevented by restricting the expansion of the rib cage using a sternum support vest. If these results are replicated in larger studies, this may open up a new strategy in combating a common and often serious complication of surgery and anesthesia. An effective prevention of atelectasis would be of benefit not only to patients who have undergone median sternotomy, but to patients undergoing a large number of different treatments.

Designing such a strategy may depend on a better understanding of the physiology of respiration while wearing a sternum support vest. Magnetic resonance imaging of test subjects wearing the vest would be of benefit in this regard. Such studies may also shed light on gender differences in the effectiveness of the vest.

Conclusions

This is the first study that has investigated if use of a sternum support vest is associated with a lower prevalence of lung complications. The study focused on the prevalence of postoperative atelectasis, among patients who had undergone cardiac surgery via median sternotomy. The results showed a significantly lower prevalence of atelectasis of grade 4 (complete or near complete atelectasis) among men who were issued the support vest as a part of their postoperative care. This suggests that use of the support vest may be beneficial to patients recovering after cardiac surgery, not only in preventing sternal wound infection, but also in preventing atelectasis.

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Table 1. Patient characteristics

	Group A (n = 67)	Group B (n = 80)	p-value
Age (years)	64.1 (+/- 12.6)	65.5 (+/- 11.6)	0.42
Men (n)	47 (70 %)	57 (71 %)	0.97
Women (n)	20 (30 %)	23 (29 %)	0.97
Time from surgery to chest x-ray (days)	3.5 (+/- 0.66)	3.5 (+/- 0.69)	0.99
Bedside x-rays (n)	17 (25 %)	10 (12.5 %)	0.04

Table 2. Procedures (numbers of patients)

	Group A (n = 67)	Group B (n = 80)	p-value
CABG	25	36	0.37
Aortic graft	12	4	0.01
Aortic valve replacement	37	38	0.35
Mitral valve replacement	7	10	0.67
Tricuspid valve replacement	1	2	0.67
Cryoablation	1	2	0.67
Pulmonary thromboendarterectomy	2	1	0.46
Atrial septal defect	1	2	0.67
Ventricular septal defect	1	0	0.27
Tumor	0	3	0.11
Combination procedures	22	16	0.08

Abbreviations: CABG - Coronary Artery Bypass Graft

	Group A (n = 67)	Group B (n = 80)
Right superior lobe	0	0
Middle lobe	1	1
Right inferior lobe	0	0
Left superior lobe	0	0
Left inferior lobe	2	2

Range: 0 – 4 for each lobe

Table 4. Other pulmonary complications (number of patients)

	Group A (n = 67)	Group B (n = 80)	p-value
Pneumothorax	5	6	1.00
Venous congestion	10	8	0.36
Pneumonia within six weeks of surgery	2	0	0.11

Table 5. Visibility of vests within group B (number of patients)

	Vest visible (n = 73)	Vest not visible (n = 7)	p-value
Highest atelectasis score 0	2	0	0.66

Highest atelectasis score 1	32	2	0.44
Highest atelectasis score 2	21	2	0.80
Highest atelectasis score 3	14	3	0.14
Highest atelectasis score 4	4	0	0.53
Pleural effusion grade 2 - 4 in either hemithorax	19	3	0.34
Venous congestion	6	2	0.09
Pneumothorax	6	0	0.43

Table 6. Results including non-vest users in group B (number of patients)

	Group A (n = 67)	Group B (n = 83)	p-value
Highest atelectasis score 0	2	2	0.83
Highest atelectasis score 1	27	35	0.14
Highest atelectasis score 2	16	24	0.49
Highest atelectasis score 3	11	17	0.53
Highest atelectasis score 4	11	5	0.04

Table 7. Results by gender including non-vest users in group B (number of patients)

	Group A	Group B	p-value
Men with highest atelectasis score 4	7	1	0.011
Women with highest atelectasis score 4	4	4	0.26

Figure 1.The Posthorax sternum support vest, from the front and from the side. Image used with permission from Epple Inc.

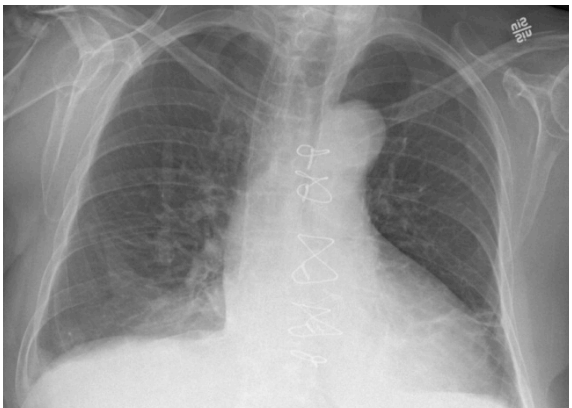

Figure 2a. Example of a patient with an atelectasis score of 1 in the middle lobe and in the lower left lobe.

Figure 2b. Example of a patient with an atelectasis score of 4 in the lower left lobe.

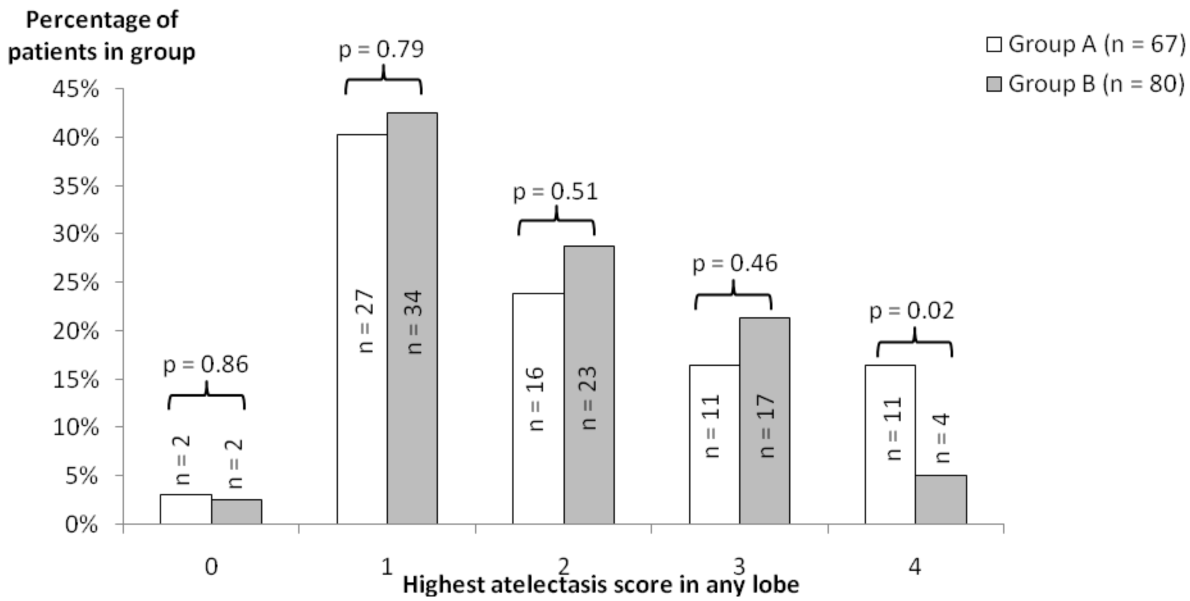

Figure 3. Distribution of the highest atelectasis score among patients in the two groups.