Value of Digital Radiography in Expiration in Detection of Pneumothorax

Wertigkeit der digitalen Röntgenaufnahme in Exspiration zum Nachweis eines Pneumothorax

Authors L. Thomsen[1], O. Natho[1], U. Feigen[1], U. Schulz[2], D. Kivelitz[1]

Affiliations
[1] Department of Radiology, Asklepios Klinik St. Georg, Hamburg, Germany
[2] Medical statistics, medistat GmbH, Kiel, Germany

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Correspondence
Priv.-Doz. Dr. Dietmar Kivelitz
Albers-Schönberg Institut für Strahlendiagnostik,
AK St. Georg
Lohmühlenstr. 5
20099 Hamburg
Tel.: ++ 49/40/18 18 85 23 60
Fax: ++ 49/40/18 18 85 41 92
d.kivelitz@asklepios.com

Abstract

Purpose: The purpose of this study was to find out whether pneumothorax detection and exclusion is superior in expiratory digital chest radiography.
Materials and Methods: 131 patients with pneumothorax with paired inspiratory and expiratory chest radiographs were analyzed regarding localization and size of pneumothorax. Sensitivity, specificity, negative (npv) and positive predictive value (ppv) as well as the positive (LR+) and negative likelihood ratio (LR-) were determined in a blinded randomized interobserver study with 116 patients. The evaluation was performed by three board-certified radiologists.
Results: In 131 patients, there were 139 pneumothoraces, 135 (97.1 %) were located apical, 88 (63.3 %) lateral and 33 (23.7 %) basal. Sensitivity was 99 % for inspiratory and 97 % for expiratory radiographs. The interobserver study yielded a mean sensitivity of 86.1 %/86.1 %, specificity of 97.3 %/93.4 %, npv of 88.7 %/88.5 % and ppv of 96.7 %/92.1 % for inspiration/expiration. For inspiratory radiographs the LR+/LR- were 40.2/0.14 and for expiration 13.9 and 0.15. McNemar-Test showed no significant difference for the detection of pneumothoraces in in-/exspiration.
Conclusion: Inspiratory and expiratory digital radiographs are equally suitable for pneumothorax detection. Inspiratory radiographs are recommended as the initial examination of choice for pneumothorax detection, an additional expiratory radiograph is only recommended in doubtful cases.
Key Points:
- Basal pneumothoraces during inspiration demonstrate a greater width than during expiration.
- There is statistically no difference between inspiration/expiration for the diagnosis of pneumothorax.
- An image taken during inspiration is recommended to confirm or rule out a pneumothorax.

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Zusammenfassung

Ziel: Das Ziel der Studie ist es zu klären, ob der Nachweis und Ausschluss eines Pneumothorax mittels einer Röntgenaufnahme des Thorax in Exspiration einer Aufnahme in Inspiration überlegen ist.
Material und Methoden: Es wurden anhand von 131 Patienten mit einem sicheren Pneumothorax mit gepaarten Röntgenaufnahmen des Thorax in In- und Exspiration die Lokalisation und Ausdehnung des Pneumothorax sowie die Atemexkursion gemessen. Eine geblindete randomisierte Interobserverstudie mit 116 Patienten ermittelte die Sensitivität, Spezifität, negativen (NPV) und positiven prädiktiven Wert (PPV) sowie den positiven (LH+) und negativen Likelihood-Quotienten (LH-). Die Beurteilung der Bilder erfolgte durch drei radiologische Fachärzte.
Ergebnisse: Es fanden sich bei den 131 Patienten 139 Pneumothoraces, davon 135 (97,1 %) apikale sowie 88 (63,3 %) laterale und 33 (23,7 %) basale Pneumothoraces mit einer Sensitivität von 99 % für Aufnahmen in Inspiration sowie für Exspirationsaufnahmen von 97 %. Die Interobserverstudie ergab für die Aufnahme in Inspiration/ Exspiration eine mittlere Sensitivität von 86,1/ 86,1 %, Spezifität von 97,3/93,4 %, NPV von 88,7/ 88,5 % und PPV von 96,7/92,1 %. Für die Aufnahme

in Inspiration lagen der LH+/LH- bei 40,2/0,14 und für Aufnahmen in Exspiration bei 13,9 und 0,15. Der McNemar-Test zeigte für die Aufnahmen in In-/Exspiration keine signifikanten Unterschiede für den Nachweis eines Pneumothorax.
Schlussfolgerung: Röntgenaufnahmen des Thorax in Inspiration erweisen sich bei der Diagnostik des Pneumothorax als gleichwertig gegenüber Aufnahmen in Exspiration. Inspirationsaufnahmen sind daher empfohlen, eine zusätzliche Exspirationsaufnahme ist nur im Einzelfall bei entsprechender bzw. sich verändernder klinischer Symptomatik und/oder bei diagnostischen Unsicherheiten gerechtfertigt.

Introduction

The first scientific descriptions of pneumothorax as a pathological accumulation of air between the lungs and internal chest wall were published by Jean Marc Gaspard Itard (1803) and René Théophile Hyacinthe Laënnec (1819) [1 – 3]. Itard considered pneumothorax as a complication of pulmonary tuberculosis with partial or complete collapse of the lung [4, 5]. Nowadays, as a complication of various interventional measures [6 – 12], iatrogenic pneumothorax requires monitoring using imaging technology. Different methods are used for imaging diagnosis of pneumothorax [6-9]. X-ray images of the chest with the patient standing are primarily used to demonstrate or exclude pneumothorax [1, 3, 5, 13 – 16]. Digital projection radiography using various detector systems has largely replaced the formerly common analog cassette with X-ray film and intensifying screen [13, 17, 18]. Numerous authors [13, 15 – 17, 19 – 23] prefer an X-ray image taken during expiration in the case of pneumothorax. This is the current general standard. This standard is based on experience with similar conventional X-ray film-screen systems, and was applied to digital systems. During expiration the pneumothorax gap appears wider in relation to the inflated lung than during inspiration. However, under some circumstances, X-ray images acquired during expiration can hide other pathological findings. Therefore, some authors question the need for acquisition of images acquired during expiration [1, 3, 14, 24 – 27].
In the age of digital radiography with findings using high-resolution monitors with digital tools (e. g. magnifier/zoom, contour enhancement, inversion), this study should therefore investigate the question of whether an expiration image is still required to prove/exclude pneumothorax and whether it can continue as a standard.

Materials and Methods

Patient Selection and Study Population

For the time frame 10/01/2009 to 01/31/2012, the RIS system ("Radiology Information system"; Medora Centricity RIS 4i, General Electric Medical Systems) was used to find patients with paired X-ray images of the thorax (of inspiration and expiration in posterior/anterior beam projection) related to the clinical issue of pneumothorax. In total, 1634 patients between 13 and 96 years of age (average 63.02 years) meeting these prerequisites were found. Of these, 153 (9.4 %) patients had a diagnosis of pneumothorax or high suspicion of pneumothorax.
A maximum interval of 2 hours between the images was allowed. Since 4 patients did not meet this criterion, they were excluded from the study.

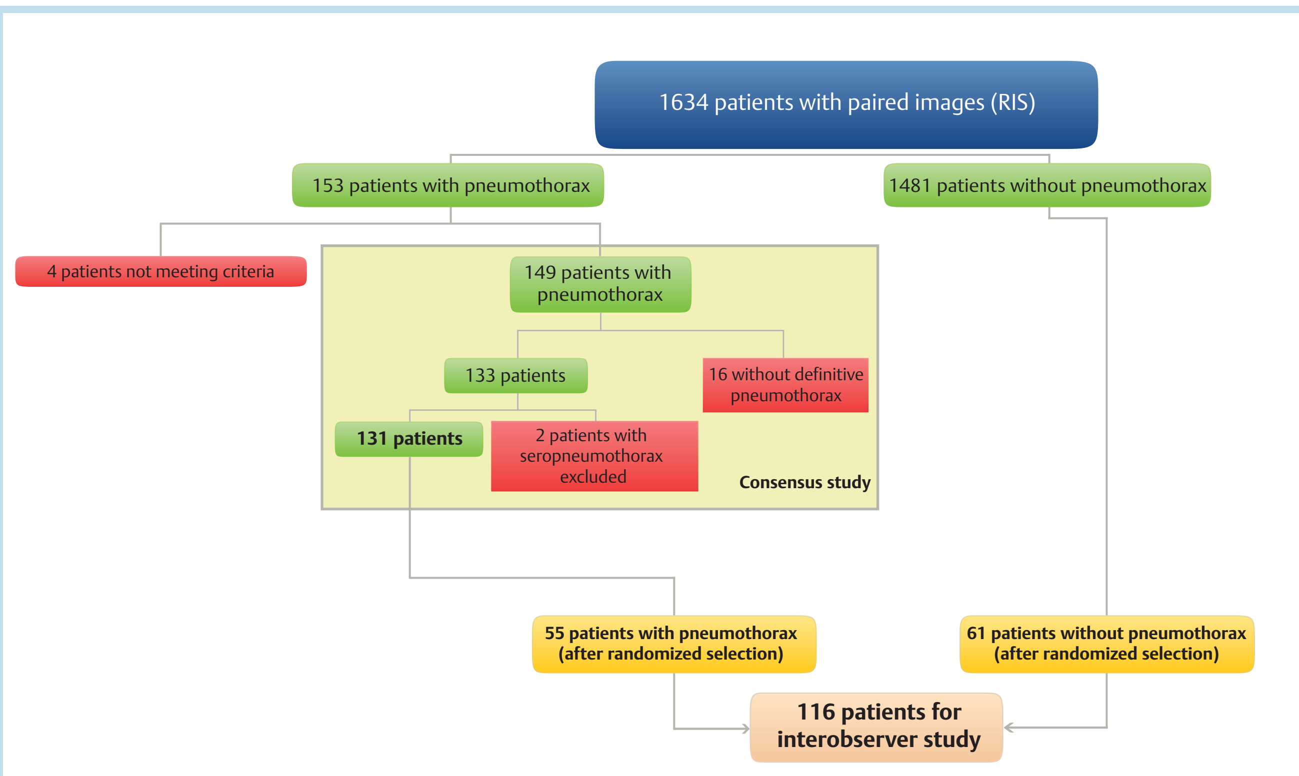

Fig. 1 Various patient groups.

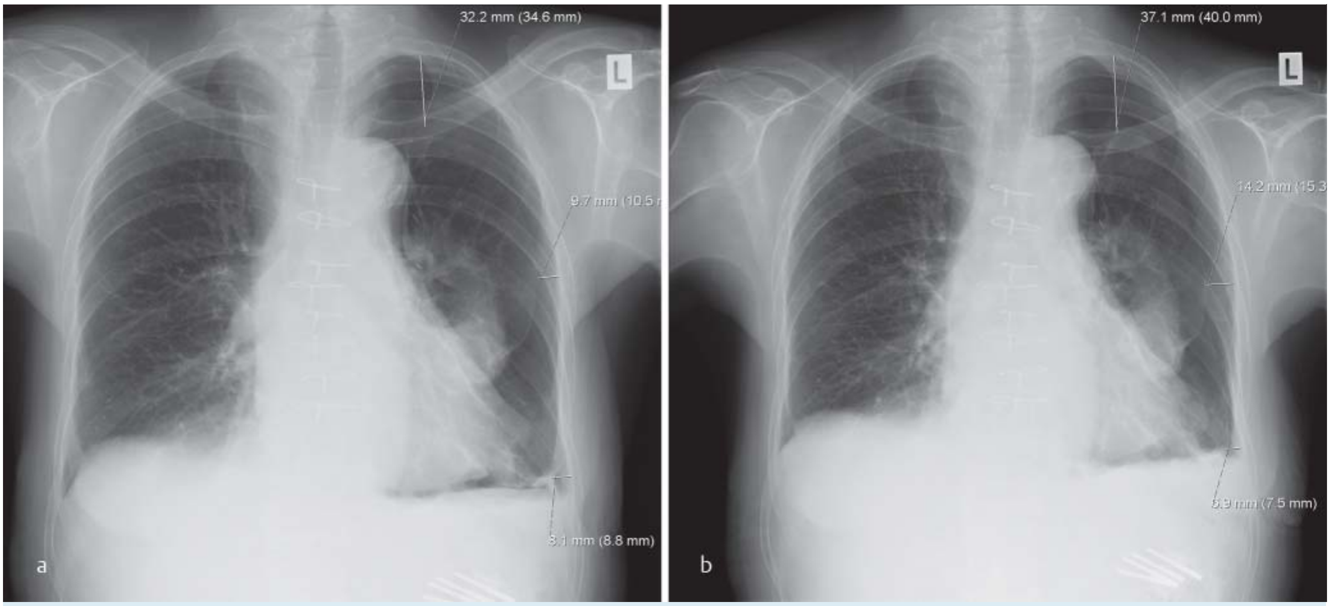

Fig. 2 Measurement of pneumothorax width comparing inspiration **a** and Expiration **b**.

After re-evaluation by a specialist in diagnostic radiology who was also one of the readers in the interobserver study, another 16 patients were excluded due to not clearly detectable pneumothorax.

In the case of two of the 133 remaining patients, existing seropneumothorax made the presence of pneumothorax undetectable. Likewise, these patients were excluded from the study.

In the end, 131 patients with 139 pneumothoraces (8 patients had bilateral pneumothorax) who were diagnosed in at least one respiratory position were included in the study. Based on the work of Seow et al [27], 55 of the 131 patients were randomly assigned to this interobserver study. In addition, another 61 patients were also reevaluated by a medical specialist and randomly selected from the group of patients without pneumothorax (1481 patients = 90.6 % of the entire group) (**Fig. 1**). Randomization was performed taking into consideration sex and age.

The 232 chest images of these 116 selected patients were evaluated in the interobserver study by 3 specialists in diagnostic radiology. This patient group was composed of 36 women (31.03 %) and 80 men (68.97 %) between the ages of 14 and 87 (average age: 63.4 years). Common radiological criteria for the diagnosis of pneumothorax were used [17, 18, 20].

All X-ray examinations were performed on a Proteus XR/a® digital X-ray work station with a direct flat image detector system (General Electric Medical Systems). The standard parameters were: 120 kV, 100mA, FFA: 182cm; detector size 41 × 41 cm, detector matrix 2022 × 2022 pixels.

Image Analysis

A separate work list in PACS Sectra® (Picture Archiving and Communication System, Firma Philips Medical Systems Netherlands B. V.) of the Institute as well as a database recorded the selected patients. The images were anonymized, all annotations and information on the respiratory position were removed electronically. The presence, location and

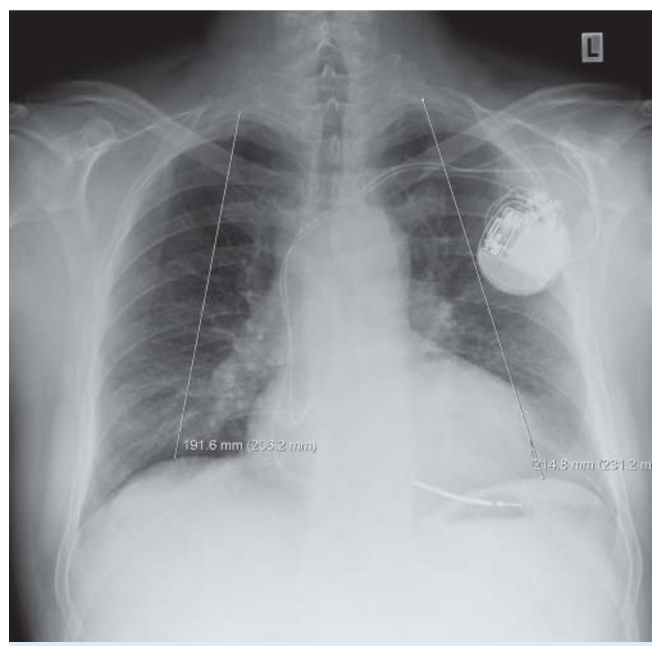

Fig. 3 Craniocaudal thoracic diameter during expiration.

width of the pneumothorax were documented. The width of each pneumothorax gap was measured standardized to the maximum apical, lateral (at hilus height) and basal extent (in maximum extent laterally, since basal pneumothoraces are frequently not detectable by measurement during expiration). The change in the gap (Δ width of pneumothorax gap) is defined as the difference between the measured values during inspiration and expiration. Two high-resolution grayscale monitors (5k; Totoku Electric CO LTD, model: monochrome LCD monitor ME 551i2) set up parallel to one another were used to access the anonymized X-ray images (n = 232) from the randomized work list stored in the PAC system. The PACS electronic tools (digital ruler, contrast reversal, magnifier, zoom, image contrast and brightness, etc.) were available for diagnostic analysis as well as measurements. Fig. 2 illustrates an example of the documented measurements of the width of the pneumothorax.

Measurements of the craniocaudal diameter of each side of the thorax from the highest apical point to the highest point of the diaphragm dome on each side during inspiration and expiration were used to assess the depth of inspiration and respiratory position (Fig. 3).

Statistics

Correlation analyses according to Spearman ranking provided statistical evaluations of the results [28]. The essential conditions for correlation analysis – quantitative characteristics, probability of a linear relationship, independent observation units – according to the requirements of Weiss [28] had been met for this study.

Only independent and no mutually dependent characteristics were present. Consequently, the width of the pneumothorax gap during expiration was assigned to the x-axis; inspiration values were assigned to the y-axis. Using a regression line (method according to Weiss [28]), the correlation between the width of pneumothorax during inspiration and expiration could be defined apically, laterally and basally for both respiratory positions.

Statistical assessment of the data provided each reader with values for sensitivity and specificity as well as mean values for the entire study [28]. Calculation of positive and negative predictive values supported the statistical description of the diagnostic significance of inspiration and expiration images for the diagnosis of pneumothorax. The chi square test according to McNemar [28] tested the dependency of the diagnosis of pneumothorax on the respective respiratory position. The likelihood quotient (LH) defined the validity of the diagnostic test. The positive likelihood quotient (LH+) indicated the magnitude of the likelihood of a diagnosis of pneumothorax in the case of an ill patient compared to a healthy patient [28]. The negative likelihood quotient (LH-) indicated the likelihood of a diagnosis of "no pneumothorax" of a patient with pneumothorax compared to a patient without pneumothorax [28]. During interpretation a value for LH+ below 0.3 is considered "poor"; a LH+ between 0.3 and 3 is considered "good". LH+ values above 10 are considered "very good" [28]. For LH-, the correlation is reversed [28].

Results

During observation of 131 with a total of 139 definitively diagnosed pneumothoraces (74 left-side, 65 right-side), in 134 of the 139 cases (96.4 %) pneumothorax was demonstrated during both inspiration and expiration. In 4 cases (2.88 %), pneumothorax was visible exclusively on the inspiration image. Only one pneumothorax (0.72 %) was visible solely during expiration. Images of inspiration yielded a sensitivity of 99 % for this studied patient population, and 97 % for expiration images. It is not possible to indicate specificity, since this assessment only includes patients with verified pneumothorax.

In addition, the location of a visible pneumothorax gap on inspiration and expiration images was compared. Without taking respiratory position into account, in 135 cases (97.1 %) there was an apical pneumothorax gap; in 88 cases (63.3 %) it was laterally measurable, and in 33 instances (23.7), the gap was basally measurable (total pneumothoraces: 139) (Fig. 4).

Of the 135 apically visible pneumothoraces, 133 (98.5 %) were apparent during inspiration; 130 (96.3 %) were recognizable during expiration. Of the 33 basally detectable pneumothoraces, 32 (97.0 %) were more frequently recog-

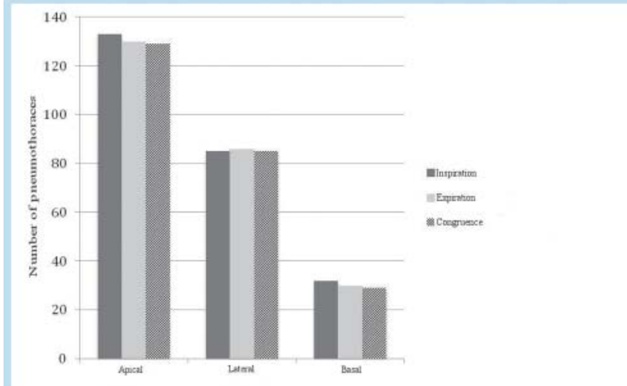

Fig. 4 Location of pneumothorax during inspiration and expiration.

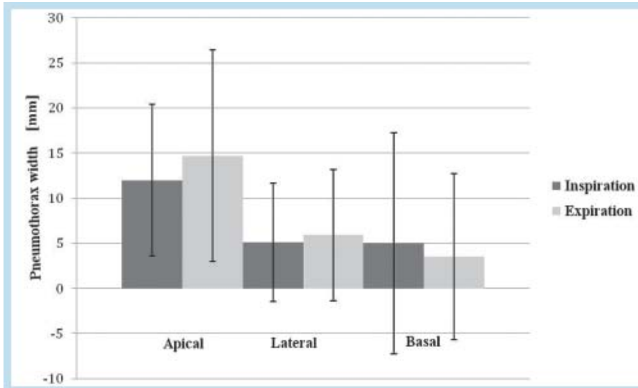

Fig. 5 Mean pneumothorax width during inspiration and expiration.

Table 1 Changes in the width of the pneumothoracic gap.

location	Δ width of pneumothoracic gap[1]	n	mean Δ width of pneumothoracic gap ± standard deviation
apical n = 135	≤ 0 mm	32	2.4 mm ± 5.9
	= 0 mm	25	
	≥ 1 – 10 mm	65	
	≥ 10 mm	13	
lateral n = 88	≤ 0 mm	27	0.9 mm ± 3.0
	= 0 mm	16	
	≥ 1 – 10 mm	43	
	≥ 10 mm	2	
basal n = 33	≤ 0 mm	21	–1.4 mm ± 5.9
	= 0 mm	2	
	≥ 1 – 10 mm	10	
	≥ 10 mm	0	

[1] Δ width of pneumothoracic gap = width of pneumothoracic gap during expiration – width of pneumothoracic gap during inspiration, n = 139 pneumothoraces.

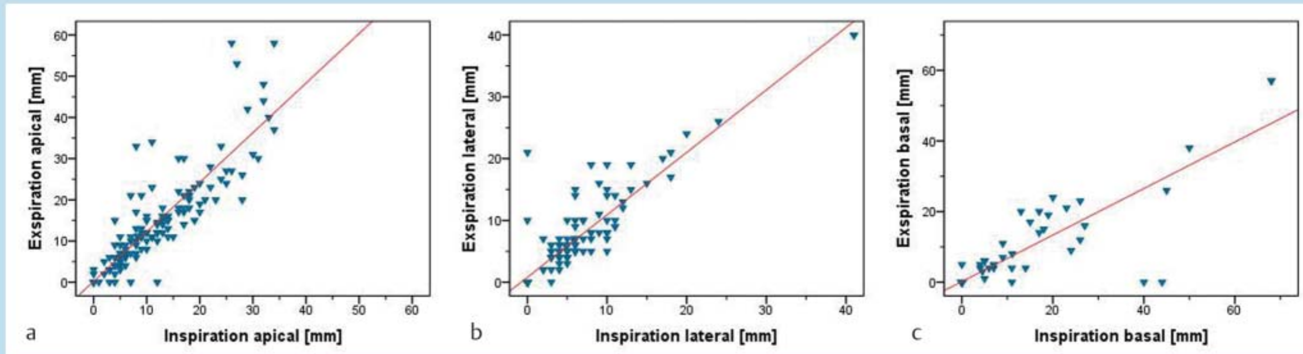

Fig. 6 **a** Correlation of apical pneumothorax width during expiration/inspiration, n = 135 Strong and significant correlation (Spearman correlation, R = 0.885, p < 0.001) **b** Correlation of the width of lateral pneumothoraces during expiration/inspiration, n = 88 Strong and significant correlation (Spearman correlation, R = 0.902, p < 0.001) **c** Correlation of the width of basal pneumothoraces during expiration/inspiration, n = 33 Strong and significant correlation (Spearman correlation, R = 0.910, p < 0.001).

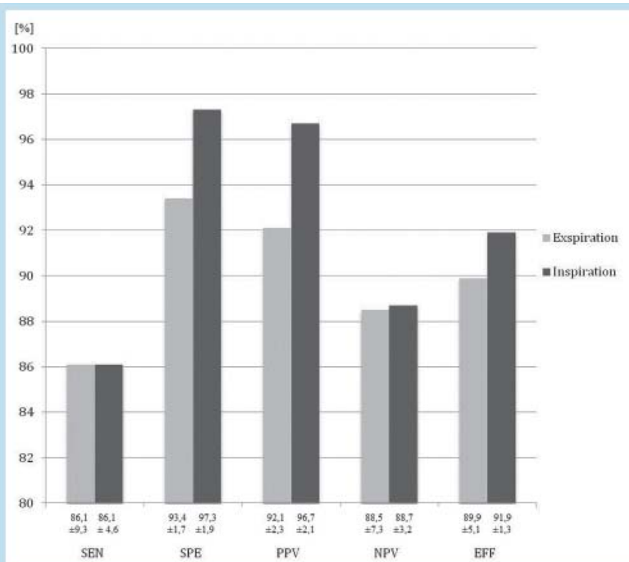

Fig. 7 Sensitivity, specificity as well as predictive values of the interobserver study.

Table 2 Change in craniocaudal thoracic diameter in respiratory positions after localization of side.

Δ in craniocaudal thoracic diameter [1]	right n =	left n =
≤ 0 mm	24	29
1 mm to 10 mm	31	28
11 mm to 20 mm	34	28
21 mm to 30 mm	33	29
31 mm to 40 mm	15	16
more than 41 mm	12	19
mean Δ width of craniocaudal thoracic diameter [mm]	17.4	19.2
standard deviation (s)	14.6	18

[1] Δ width of craniocaudal thoracic diameter = craniocaudal thoracic diameter during inspiration – craniocaudal thoracic diameter during expiration, n = 149 patients.

nizable during inspiration than expiration (30 cases/90.9 %). Among the 88 laterally measurable cases, one case appeared more frequently in the expiration respiratory position (86 cases/97.7 %) than in the inspiration position (85 cases/96.6 %) (Fig. **4**). Disregarding location and respiratory position, in the majority of cases a pneumothorax width up to 20 mm was demonstrated.

Depending on respiratory position, the average width varied with the location. Apical pneumothorax, with a mean value of 14.7 mm ± 11.73 (absolute 2 – 58 mm) during expiration, appeared wider than during inspiration (12.0 mm ± 8.39; absolute: 1 – 35 mm). This was likewise true with respect to lateral pneumothorax, with an average of 5.9 mm ± 7.27 (absolute: 2 – 40 mm) during expiration and 5.1 mm ± 6.55 (absolute: 2 – 41 mm) during inspiration. In contrast, basal pneumothorax demonstrated during inspiration on average 5.00 mm ± 12.23 (absolute: 4 – 86 mm) wider than during expiration (3.5 mm ± 9.19; absolute: 1 – 57 mm). (**Fig. 5**) Basal pneumothoraces, in 21 of 33 cases (63.6 %) measured significantly larger during inspiration than during expiration (**Table 1**).

As a mean value, basal pneumothoraces during inspiration likewise demonstrated a greater width than during expiration (–1.4 mm ± 5,9) (**Table 1**).

Fig. 6a–c show the correlation of the width of apical, lateral and basal pneumothoraces during inspiration and expiration. The positive slope of the calculated regression lines indicates a concordant relationship of values measured during inspiration and expiration. The R-squared value is 0.7379 for apical, 0.8151 for lateral and 0.738 for basal pneumothoraces.

The results of the craniocaudal thoracic diameter differed on average by 17.4 mm during right inspiration and expiration, and on the left, by 19.2 mm (**Table 2**). Specifically, some paradoxical diaphragmatic excursions were demonstrated.

The results of the analysis of anonymized radiographs of the thorax during inspiration and expiration in the interobserver study of the 116 patients are shown in **Fig. 7** for the three readers. For expiration images, the positive likelihood quotients for the three readers in the interobserver study lie between 10.2 and 19.6 (mean: 13.9 ± 5.0). LH+ for inspiration is calculated with values between 18.5 and 52.1 (mean: 40.2 ± 18.8). For expiration, LH- is indicated as 0.04 to 0.23 (mean: 0.15 ± 0.101); for inspiration, it lies between 0.09 and 0.19 (mean: 0.143 ± 0.045) (**Fig. 8**). Assuming bi-

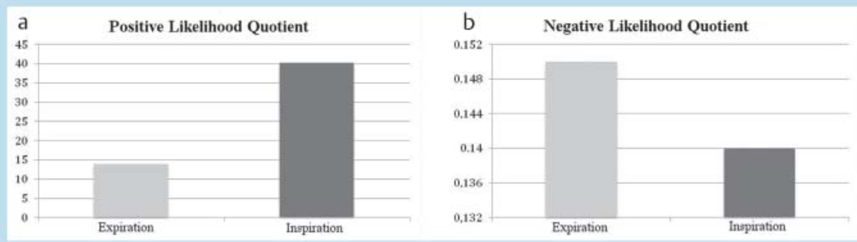

Fig. 8 Positive **a** and negative **b** Likelihood quotient in interobserver study.

nomial distribution and an alpha level of 0.05 for the paired thoracic radiographs in the interobserver study, the McNemar test shows no significant differences between inspiration/expiration for the detection of pneumothorax.

Analysis

When considering the interobserver study population, there is statistically no significant difference (McNemar test alpha = 0.05) between inspiration/expiration for the diagnosis of pneumothorax. This, as well as a mean sensitivity of 86.1 % for the diagnosis of pneumothorax in both respiratory layers, is consistent with the study by Seow et al [27].

During observation of all 139 evaluated pneumothoraces (131 patients) it was demonstrated in the majority of cases – contrary to the generally accepted view [13, 15 – 17, 19 – 23] – the pleural space is greater during inspiration than during expiration. A possible explanation is that the pneumothorax increases proportionally with the increase in thoracic volume during inspiration. The cause may be communication of the pleural space with intrapulmonary or outside air; the gap increases during inspiration due to trapped air and the elastic restoration force of the healthy lung.

It has also been demonstrated that on the whole, pneumothoraces are more frequently detected during inspiration than during expiration; this is likewise congruent with the results of Seow et al [27].

If one takes location into account, apical and lateral pneumothoraces on average are wider during expiration (by 2.7 mm ± 0.8 mm) than during inspiration.

In contrast, it is striking that basal pneumothoraces are more easily detected during inspiration. This may be due to the fact that the basal parts of the lung and pleural structures are generally easier to evaluate due to the lower position of the diaphragm.

Considerations with respect to location, in particular basal pneumothorax, have yet to appear in the literature.

Sharing the conventional wisdom, many authors are of the opinion that pneumothorax is more widely demarcated during expiration than during inspiration. This is due to the relatively larger proportion of air in the pleural space with respect to the intrapulmonary air during expiration compared to inspiration [13, 15 – 17, 19 – 23].

The hitherto unexamined thesis that pneumothorax presents more broadly during expiration has limited relevance to our results. Likewise, our study does not confirm the opinion of Klopp et al [16] that the pleural contour in the case of a small pneumothorax is more easily detected during expiration.

A fact that speaks for the general investigation into inspiration is that normal and pathological structures are better represented during inspiration and thus more likely to be detected. Numerous authors share this opinion [1, 3, 17, 20, 22, 24, 26, 27, 29, 30]. If we apply this knowledge to the possible occurrence of secondary diagnoses in cases of suspected pneumothorax, then it can be presumed that they can be more reliably diagnosed during inspiration. For example, in the study by Bradley et al [26], lung contusions were detected only during inspiration in 2 patients with post-traumatic pneumothorax.

With respect to the literature [1, 5, 19, 26, 27, 31, 32], our study population is on the whole representative; however, the average age is slightly older in comparison, primarily due to the higher proportion of patients with post-interventional or postoperative pneumothorax (after pacemaker implantation, defibrillation or cardiac surgery).

Another finding of our analysis is that many patients could hardly follow or comply with the breathing commands. This might be based on the fact that patients could not continue their breath long enough during expiration, since our study population had a large number of patients with cardiovascular disease. Another possibility is a lack of acoustical comprehension of the breathing commands or because of a language barrier. In such cases, reproducibility and extent of expiration is limited.

The results of this study demonstrate the high diagnostic value of thoracic images during inspiration and expiration in the presumptive diagnosis of pneumothorax. Nevertheless, thoracic CT is considered the gold standard for imaging for the detection or exclusion of a pneumothorax [33, 34].

Ideally a correlation with thoracic CT examinations would optimize the design of the study.

A further study is planned involving a review of the interobserver results as well as possible optimization of the study design with additional inclusion of CT examinations.

It should also discuss the disadvantages of the use of digital X-ray equipment. In the comparison studies, analog film screen systems were used [22, 23, 26, 27], which compared to digital technology, provide higher local resolution [31, 35]; this is particularly important for the identification of fine structures such as pleural contours. Recognition of these structures depends also upon the degree of contrast with their surroundings [35]; in this respect an equivalent [36] or superior capability of digital radiography systems could be demonstrated compared to analog film exposures [37]. Advantages of digital radiography include a wider dynamic range and better quantum efficiency which can reduce image retakes and radiation dose [35, 38]. The aforementioned advantages of digital imaging and the possibility of digital image enhancement can compensate for the disadvantages compared to analog technology [35]. In this sense, the comparability of the results can be interpreted using the results of the comparative studies [22, 23, 26, 27].

Conclusions

▼

Different respiratory positions do not significantly affect the diagnostic exclusion or detection of pneumothorax. The hypothesis that a pneumothorax is basically demonstrated wider during expiration than during inspiration has not been confirmed. Rather, when observing the exact location, it can be shown that in particular with respect to basal pneumothorax, and to pneumothoraces in general, inspiration images provide optically better results when compared to expiration images.

Further, analysis of the craniocaudal diameter in both respiratory positions as well as the estimation of the readers in the interobservational study indicated that many patients could hardly follow or comply with the breathing commands.

For the reasons mentioned, we are in agreement with Seow et al [27] that an image taken during inspiration is recommended to confirm a possible pneumothorax. An additional expiration image is justified for diagnostic, radiation hygiene and economic considerations only in individual cases with related and changing clinical symptoms and/or diagnostic uncertainty.

Acknowledgement

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This manuscript is dedicated to Professor Bernd Hamm for his 60th birthday.

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