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Objective: Endoluminal visualization in virtual and video bronchoscopy lacks information about the surrounding structures, and the traditional 2D axial, coronal and sagittal CT views can be difficult to interpret. To address this challenge, we previously introduced a novel visualization technique, Anchored to Centerline Curved Surface, for navigated bronchoscopy. The current study compares the ACCuSurf to the standard ACS CT views as planning and guiding tools in a phantom study.

Material and methods: Bronchoscope operators navigated in physical phantom guided by virtual realistic image data constructed by fusion of CT dataset of phantom and anonymized patient CT data. We marked four different target positions within the virtual image data and gave 12 pulmonologist the task to navigate, with either ACCuSurf or ACS as guidance, to the corresponding targets in the physical phantom.

Results: Using ACCuSurf reduced the planning time and increased the grade of successful navigation significantly compared to ACS.

Conclusions: The phantom setup with virtual patient image data proved realistic according to the pulmonologists. ACCuSurf proved superior to ACS regarding planning time and navigation success grading. Improvements on visualisation or display techniques may consequently improve both planning and navigated bronchoscopy and thus, contribute to more precise lung diagnostics.

Keywords: navigated bronchoscopy; virtual bronchoscopy; ACCuSurf visualization; lung diagnostics; image guided intervention

Introduction

Diagnostic success rates using bronchoscopy vary from 40-60% for all central lesions visible within the airway lumen [1, 2]. For peripheral lesions, meaning outside the respiratory tract, the diagnostic success rate has been reported to be as low as 9% [3]. These rates are diagnostics without the use of navigation in bronchoscopy. Published studies using navigated bronchoscopy indicate an increase in the diagnostic success for centrally and peripheral located tumours up to 80% [2]. Navigated bronchoscopy (NB) in lung medicine can potentially improve these low success rates, but the use of navigated bronchoscopy has not increased significantly since the introduction [4]. Existing technology in navigated bronchoscopy is expensive and has technically complex set up for the operation room. According to a literature study made by our group, the visualisation mode and display approaches have not changed significantly in video navigated bronchoscopy (Fig 1A) for the last 20 years [5]. In this study, we suggest a new visualization approach instead or in addition to the established virtual endoluminal view (see Fig 1B). This method will provide anatomical view information around the airways. In a recent paper, we published a new imaging modality that visualize a route to target display for navigating a bronchoscope from the patient's mouth to a selected target in the lungs [6]. With this method, the airway data is sliced in half along the centerline route to target (see Fig 1C) making the surrounding anatomical structures more visible to the operators, compared to endoluminal view. The method is called Anchored to Centerline Curved Surface (ACCuSurf). A similar and established visualization technique in the medical community is Curved Planar Reformatting (CPR) [7]. With ACCuSurf, our goal is for the pulmonologists to have a 3D perception of direction and location of the instrument relative to the path (direction) and target. With the CPR method, this 3D understanding would not be accessible.

This mode is used for display and analysis of tubular structures like blood vessels. It enables the visualization of lumen, wall and surrounding tissue in one 2D slice and is used for investigation of stenosis, occlusions, aneurysms and calcifications. However, to our knowledge it has not been applied to bronchoscopy applications.

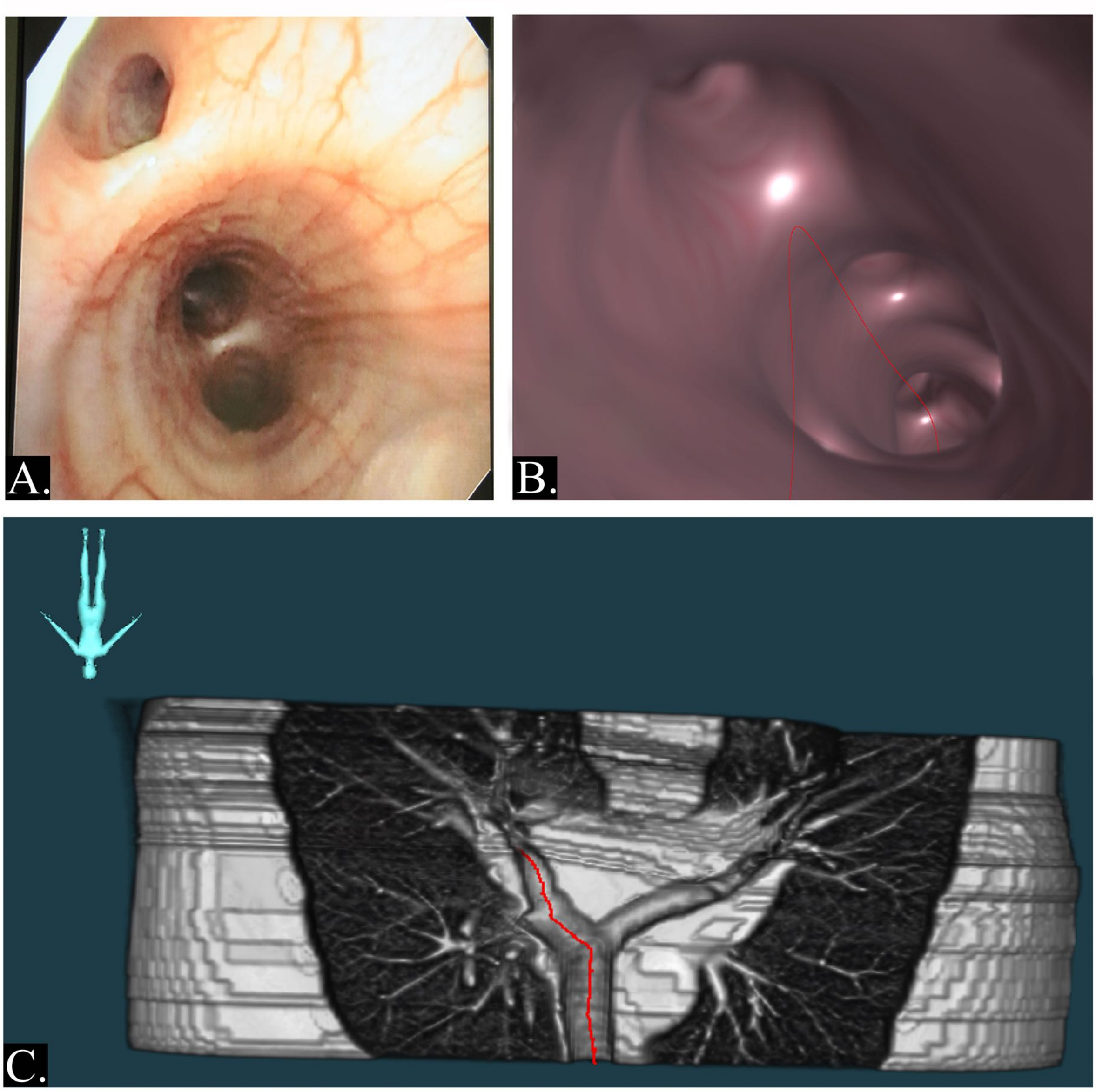

Figure 1. *A) Video bronchoscope image; B) Virtual bronchoscope view based on CT of a pig (unpublished material); and C) ACCuSurf overview from back of patient, the patient data is sliced in half along the route to target.*

We performed an evaluation of ACCuSurf as a planning and guiding tool for lung doctors using an airway physical phantom with image CT data fused with real patient image data.

Methods

Our aim in this study is to investigate the effect on bronchoscopy operator performance when using either the ACCuSurf visualization method or the conventional visualization method consisting of axial slices (ACS). The experiment was performed with 12 operators doing a bronchoscopy procedure in a realistic phantom setup. Each operator targeted four pre-defined targets in the physical phantom, using the navigation system for both planning and guidance during the procedure. The navigation system display showed either ACS or ACCuSurf visualization of the image data. Each operator was assigned equal use of the two visualization methods, using ACS for two targets and ACCuSurf for two targets.

The following parameters were measured (24 samples for ACS and 24 samples for ACCuSurf) and were used to compare the two methods

- Planning time (s)
- Procedure time (s)
- Successful navigation grade (%)

Phantom data preparation

The experiment was performed on a silicon lung phantom (Ultrasonic Bronchoscopy Simulator LM-099 from KOKEN CO., LTD, Tokyo, Japan). A CT scan of the phantom was merged with an anonymized high-resolution CT scan of a patient to construct a realistic image data set for presentation to the operators. Both CT datasets were acquired on a Siemens CT scanner (Siemens Healthineers, Erlangen, Germany) – image matrix 512x512, resolution 0.756 × 0.756 mm/pix with 0.5 mm slice distance.

The x-ray density in the CT pixel data, represented by its numerical Hounsfield Unit (HU) [-1000 to +3000], were processed to construct the new merged realistic dataset.

The anonymized patient data (Fig 2.1A) was processed as follows; first the airways were segmented (Fig 2.1B). Secondly, to remove the original airways from the patient CT data, the CT voxels inside the airways were assigned random HU values between 1-160, which corresponds to HU values in the surrounding tissue (lung and heart) (Fig 2.1C). Next, an airway model was created from the CT phantom data (Fig 2.2A). The airway lumen (Fig 2.2B) from the phantom was assigned Hounsfield values of air (-1024 HU) and then fused back into the phantom data (Fig 2.2C). Finally, the patient data and the phantom data were fused in a manner that the trachea and the carina were aligned together in the two datasets, using a centerline based registration method (Fig 2.3) [8].

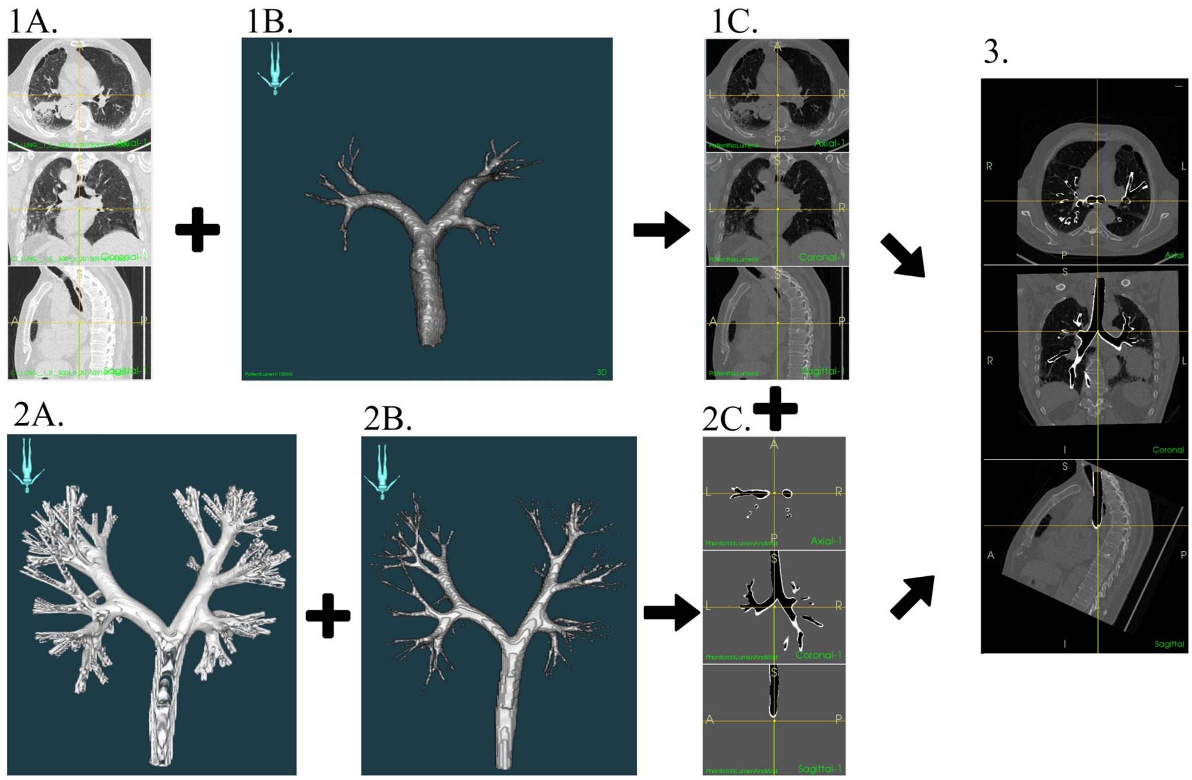

Figure 2. *1A. Patient dataset, 1B. Patient airways, 1C. patient lung data without airways. 2A phantom airway model, 2B phantom lumen. 2C. Phantom airway model with air lumen. 3. New patient phantom.*

Bronchoscopy Phantom Trial

A user comparison was made with ACCuSurf and ACS views as planning and guidance tools during the intervention, by testing the visualizations on 12 pulmonologists manoeuvring through the physical phantom. The pulmonologists were given four different targets to reach (Fig 3A), two for each side in the phantom patient lungs. The virtual targets were all placed at the end of the airways in the phantom and visualized as a mark indicator in the ACCuSurf and ACS views (Fig 3C-D). The bifurcations along the navigation path for one of the targets is illustrated on Figure 3B. Both ACCuSurf and ACS views were made for each of the four targets. Views for target no. 1 is illustrated in figure 3 (C-D). The order of operation on targets and visualisation were different for all 12 pulmonologists, giving no target or visualisation method an advantage. All 12 pulmonologists performed bronchoscopy on four targets each using two on ACS and two on ACCuSurf. There were 48 samples in total, 24 for ACS and 24 for ACCuSurf. The ACCuSurf display had additionally the correspondent opposite airways (half of the airways augmented in blue colour above the ACCuSurf, see Fig 3C).

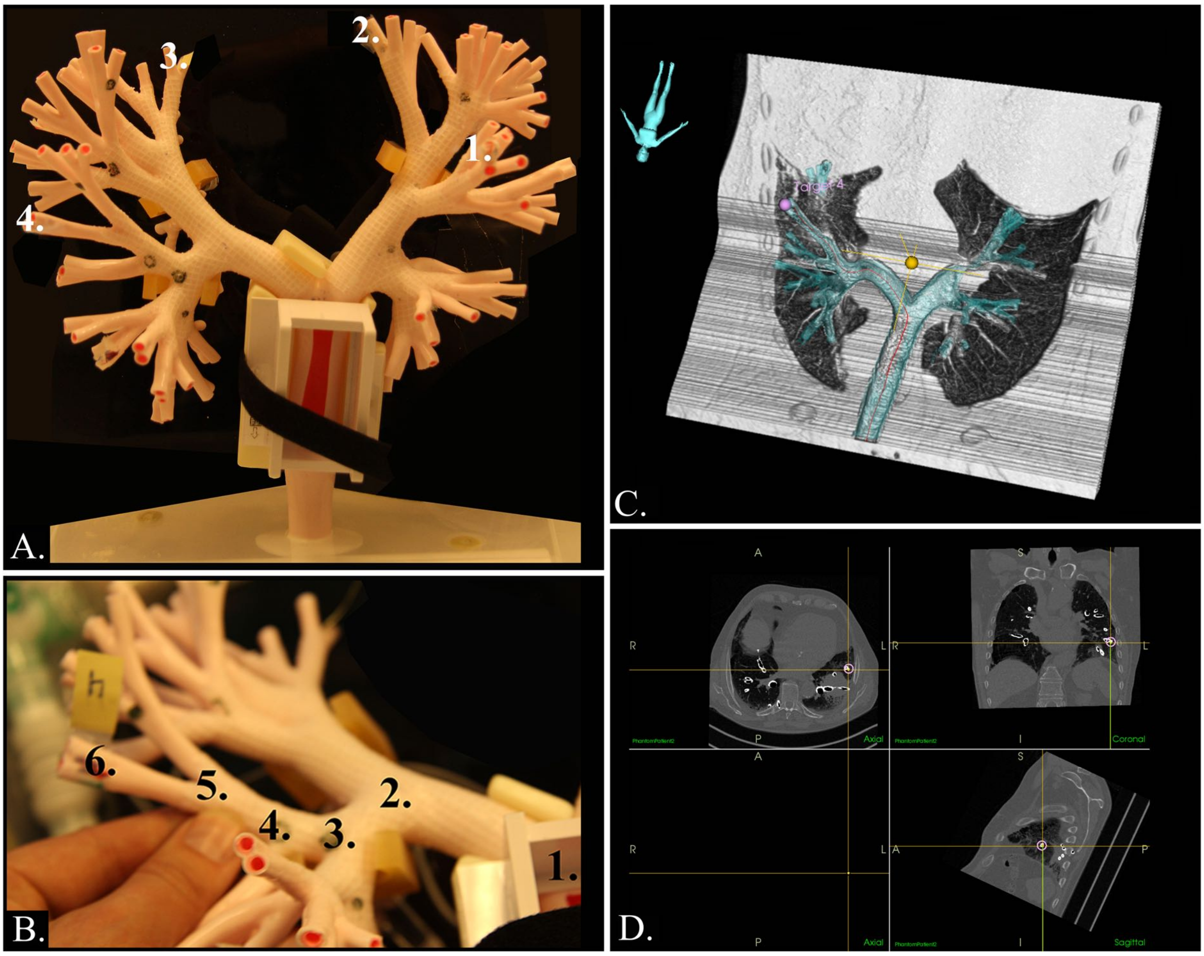

Figure 3. *A. Physical phantom with four different targets. B. Bifurcation numbers from carina. C. Fraxinus view virtual phantom; ACCuSurf of lung phantom and patient data fused. D. Fraxinus view virtual phantom; ACS lung phantom and patient data fused.*

The visualisation method tested was shown on a computer monitor next to a box containing the physical phantom covered with blanket (Fig 4A). The pulmonologists could not see the physical phantom during their procedure time. After the pulmonologist had used the Fraxinus navigation system to plan the physical route to target for oneself, the bronchoscopy procedure was performed using a video bronchoscope with a working channel (Olympus BF-1T240 and Olympus CV-240 video processor, Olympus, Tokyo, Japan).

Measured Parameters

The time was measured during the planning from when the pulmonologist first saw either the ACS or the ACCuSurf until informing the surveyor that he or she was ready to perform the bronchoscopy. The procedure time was measured from the moment the pulmonologist saw the carina on the video bronchoscope until he or she had pushed the forceps from the bronchoscope tool channel through the end of the route to target (Fig 4B). The procedure was then given a grade between 0-100% depending on how many bifurcations along the route-to- target he or she could navigate through correctly. Full grade score of 100% was given if the forceps made the right exit out of the phantom i.e. reaching the right target, no score for turning into the wrong side of the lungs. The score of 100% was given for reaching through eight bifurcations to target 1 and 3, seven bifurcations to target 2, and six bifurcations to target 4. The data was processed with SPSS v23 (UNICOM, California, USA).

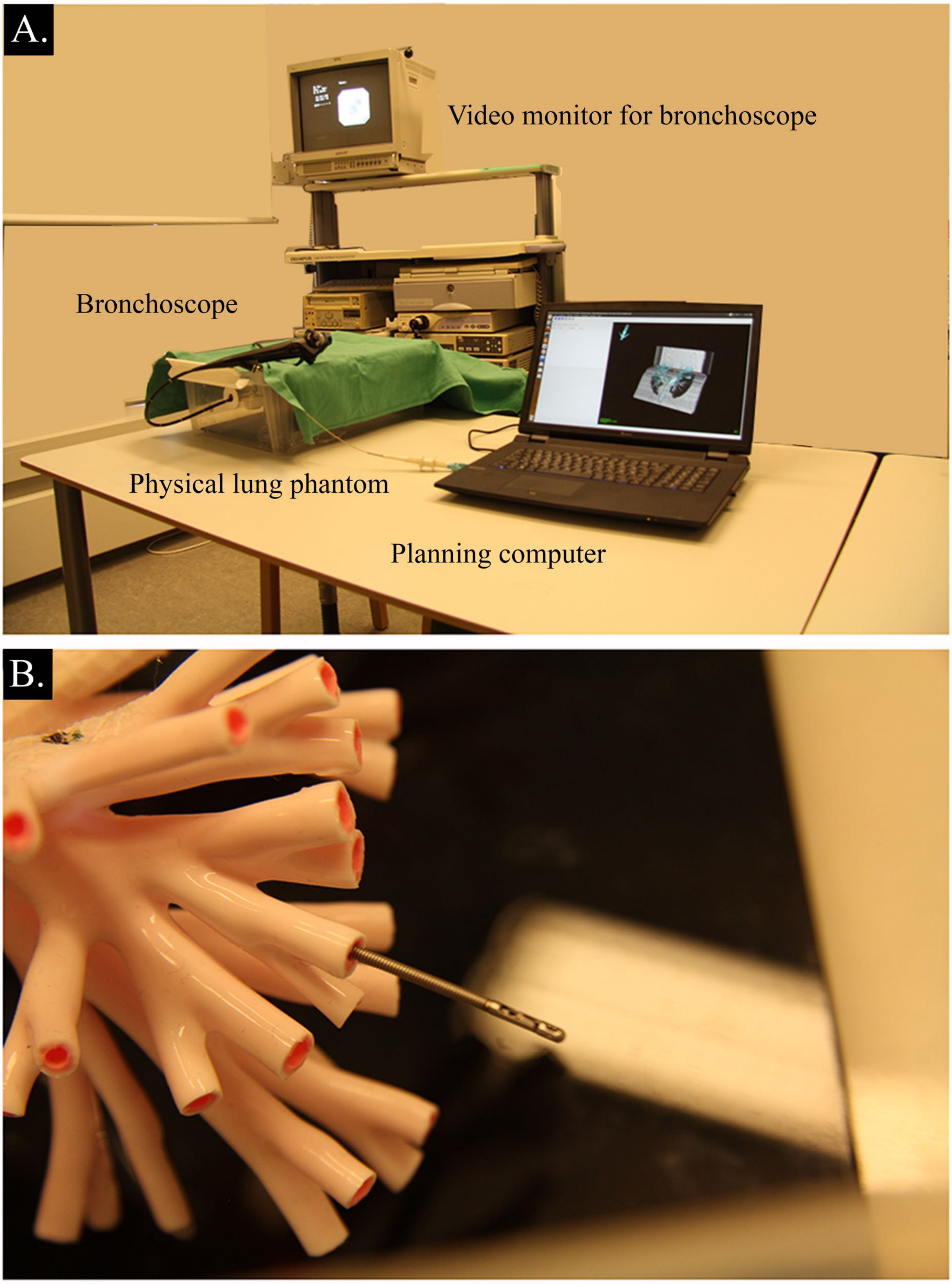

Figure 4. *A): The experiment setup B): Forceps reaching the target and exiting the phantom airway at the correct branch.*

Due to small sample size, we used Mann-Whitney U test with two sided 95% ($p<0.05$) confidence interval and using Shapiro Wilk test to compute the p-values on averages for grades, planning time and bronchoscope time between ACS and ACCuSurf. Mann Whitney test is a non-parametric test and it is not necessary that the data are distributed normally. The targets might not all have the same level of difficulty, but due to the number of tested doctors, we presume this is not affecting the results significantly. Furthermore, all targets were located at bifurcations 6-8. The difference in distance are minor for these, approximately 5 mm from trachea. The most experienced pulmonologists qualitatively rated reaching the targets as equally difficult. The sample size is too small for each single target (six ACS and six ACCuSurf each) to establish any further statistical analyses other than the whole sample ACS vs. ACCuSurf.

Finally, the lung doctors were also free to give their subjective opinions comments regarding the methods after completing the procedure.

Results

Bronchoscopy Phantom trial

The averages of grade, planning time, and procedure time with Mann-Whitney U test on the averages is presented in table 1. Box plots for these averages are in Figure 5.

	ACS	ACCuSurf
Grades [%]	55 (± 21)	82(± 12)
Planning time [s]	141 (± 82)	57 (± 31)
Procedure time [s]	106 (± 83)	76 (± 44)

Table 1. *Average (± Standard deviation.) grade, planning time and procedure time for ACS and ACCuSurf. Total number of samples are 24 for both categories and confidence interval is 95% ($p < 0.05$). The significance level for both grade and planning time average are sign.level $p \approx 0.05 > 0.005$ indicating difference between ACS and ACCuSurf. There is no difference however in procedure time averages (sign.level $p \approx 0.49 > 0.05$) between ACS and ACCuSurf.*

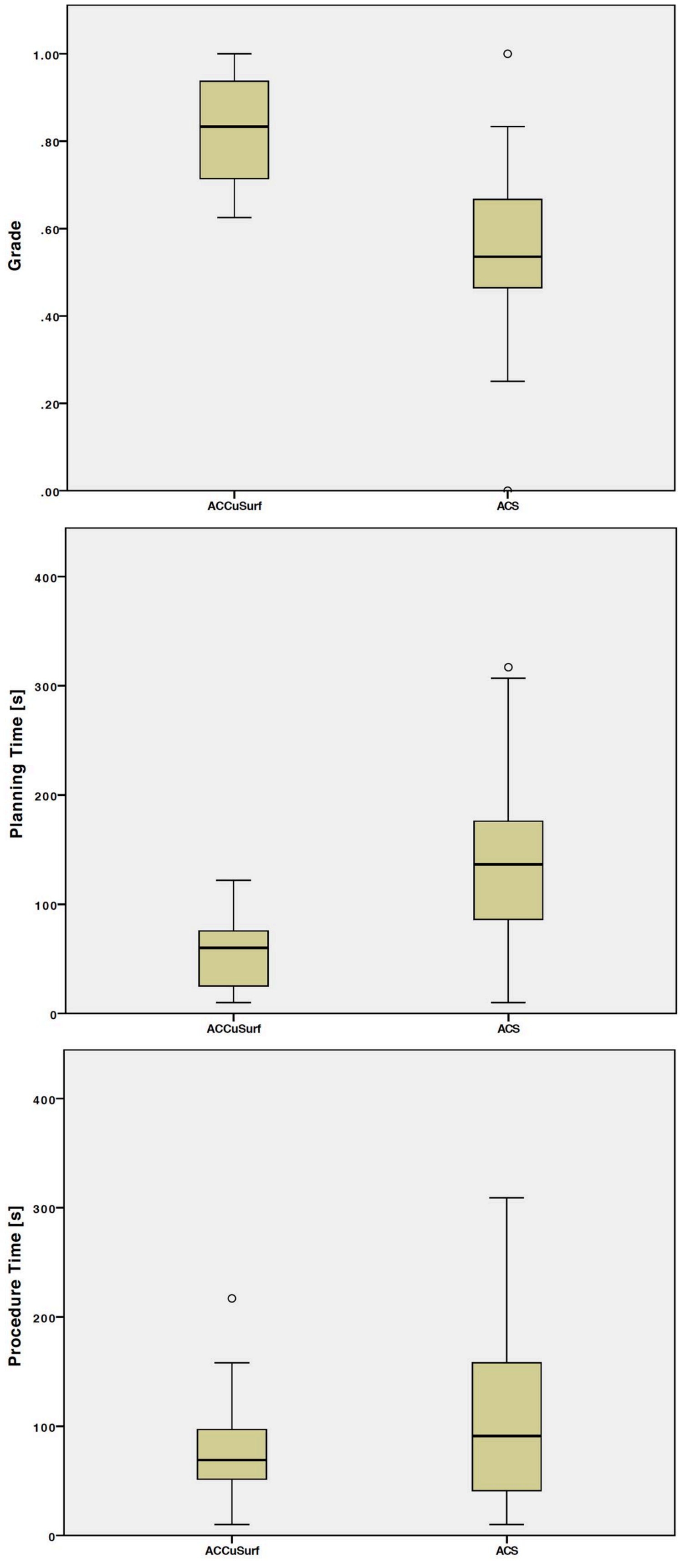

Figure 5. *Box plots of averages, grade, planning time and procedure time from top to bottom.*

Discussion

Patient Phantom

The image fused phantom and patient CT data is a novel approach, and was done to make both the regular ACS and the new ACCuSurf visualisations look more realistic and recognizable to the lung doctors (Fig 3 on the right).

All pulmonologists were able to transfer the knowledge gained from the planning phase to the following bronchoscopy procedure, and overall, we believe that this approach was valuable. The main problem encountered during the process was the mapping of the phantom anatomy to the corresponding anatomy in the patient CT, as they had different size. The physical phantom is a good replica of the airway anatomy, but it is of course not a perfect match to any patient. Though, the trachea on patient and phantom image fusion matched via carina, some of the phantom end branches ended outside the patient lungs. These flaws were caused by a difference in the image volume size between the two datasets. On the other hand, it was only some of the 1-2 most peripheral bifurcations of the physical phantom that went outside the patient chest, giving the route to target almost the same representation as a real patient data. There was not an option to scale the patient data because then the trachea to carina on both the phantom and patient data would not match. All participating pulmonologist commented that the data resembled an actual patient and only the distal part of the phantom airways slightly degraded the impression.

Another obvious flaw was the lack of respiratory motion apparently making it easier for the operating pulmonologist to manoeuvre the endoscope through a still phantom airway. The pulmonologists also commented that real lungs are easier to manoeuvre through because the physical phantom was dry and stiff despite the use of silicone lubricant. Furthermore, the pulmonologists added that the bronchoscope we used was an older model and perhaps using a newer one could lead to improved results. Finally, some commented that the fused phantom and patient data set (virtual phantom i.e. patient and physical phantom) could provide an interesting solution as a training tool.

Bronchoscopy phantom trial

From the Mann-Whitney U test we found that the pulmonologists performed significantly better (both sign.level $p \approx 0.05 > 0.005$) regarding grades with the ACCuSurf method (82±12) % vs. (55±21) % for ACS. The Mann-Whitney U test also demonstrates difference in planning time between ACCuSurf and ACS with (57±31) s and (141±82) s respectively. There is a difference in planning time and grades between methods that indicates improvement between method in performance and being faster finding the route but not faster performing the procedure. The Mann-Whitney U test failed undoubtedly to demonstrate difference in procedure time between ACCuSurf and ACS, that can indicate that quick planning time doesn't necessary mean faster procedure time.

Only one pulmonologist out of the 12, wanted only ACS as a planning tool, all other pulmonologists preferred ACCuSurf as an addition to ACS. It should be noted again that the sample size was small and it would be necessary to perform the evaluation with a larger number of pulmonologists in future studies.

Overall

The sample size is small (12 pulmonologists, four targets, six ACS and six ACCuSurf samples for each target) and all the statistical results have to be interpreted with caution. As mentioned, the use of navigation systems is rare among lung doctors despite the improved diagnostic success rates achieved [5]. Our sample size does not allow conclusion regarding experience versus performance with the ACCuSurf technique, but we believe that such navigation technology could benefit novices in bronchoscopy. In our study group the variation, as mentioned, was form 2-20 years, with eight pulmonologists having performed bronchoscopy for more than 10 years (at most 20) and 4 less than 4 years. The different experience is a limitation, but at our hospital this is our personnel. Beside the cost, we believe that the lack of using navigated bronchoscopy is also partly due to the lack of optimal visualization modes for lung doctors. Comparing navigated bronchoscopy display to Global Positioning System (GPS) monitors, the GPS user display has been optimized to make it easy to use. The ACCuSurf method is a way towards creation of an overall user-friendly view, and a more appropriate display in navigated bronchoscopy for attracting lung doctors to use navigated bronchoscopy. This can consequently increase the diagnostic success rate in lung medicine.

Conclusion

Phantom Assessment

The phantom was sufficient to perform a comparison experiment between ACS and ACCuSurf. Both physical phantom and image data proved realistic according to the pulmonologists. The virtual image data can be improved by using patient image data with matching dimensions compared to the phantom.

Bronchoscopy Phantom trial

Our results indicate that ACCuSurf is a more accurate planning tool in success-rates than ACS if one looks on the grade alone (82±12) % vs. (55±21) with sign.level $p \approx 0.05 > 0.005$. Our results imply that the planning time for ACCuSurf is faster than ACS. We conclude that ACCuSurf in combination with ACS would be more efficient in planning for bronchoscopy than ACS alone. This was the first time that all the participating pulmonologist in the study experienced the ACCuSurf view. The experience between the pulmonologists varied from 2-20 years. In such a small sample there is not a possibility to conclude that ACCuSurf was better for either the experienced or the less experienced pulmonologists. If evaluation with bigger sample of pulmonologists would be performed, one could perhaps measure a difference between experienced and the less experienced pulmonologists. We evaluated that using both methods on all four targets for each pulmonologist would give the pulmonologist a chance to know the path in the first try.

Overall

Improvements and optimization in visualisation or display techniques can increase the use of navigated bronchoscopy. We believe that increased use of navigated bronchoscopy would consequently lead to increased successful diagnostic success rates, implying that more patients will get a correct diagnosis earlier, and hence receive the right and necessary treatment earlier.

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Conflict of interest

The authors declare that they have no conflict of interest related to the work in this study.

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