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Bronchial branch tracing navigation in ultrathin bronchoscopy-guided radial endobronchial ultrasound for peripheral pulmonary nodule

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Abstract

Background Most malignant peripheral pulmonary lesions (PPLs) are situated in the peripheral region of the lung. Although the ultrathin bronchoscope (UTB) can access these areas, a robust navigation system is essential for precise localisation of these small peripheral PPLs. Since many UTB procedures rely on automated virtual bronchoscopic navigation (VBN), this study aims to determine the accuracy and diagnostic yield of the manual bronchial branch tracing (BBT) navigation in UTB-guided radial endobronchial ultrasound (rEBUS) procedures.

Methods Single-centre retrospective study of UTB-rEBUS patients with PPLs smaller than 3 cm over a two year period.

Results Our cohort consisted of 47 patients with a mean age of 61.6 (SD 9.53) years and a mean target size of 1.91 (SD 0.53) cm. Among these lesions, 46.8% were located in the 6th airway generation, and 78.7% exhibited a direct bronchus sign. Navigation success using BBT was 91.5% based on positive rEBUS identification. The index diagnostic yield was 82.9%, increasing to 91.5% at 12 months of follow-up. Malignant lesions accounted for 65.1% of cases, while 34.9% were non-malignant. The presence of a direct bronchus sign was the sole factor associated with higher navigation success and diagnostic yield. Cryobiopsy outperformed forceps biopsy in non-concentric rEBUS lesions (90.9% vs. 50.0%, $p < 0.05$), but not in concentric orientated lesions. One pneumothorax occurred in our cohort.

Conclusions BBT as an exclusive navigation method for small PPLs in UTB-rEBUS procedures has proved to be safe and feasible. Combination of UTB with cryobiopsy remains efficient for eccentric and adjacently oriented rEBUS lesions.

Keywords Bronchial branch tracing, Navigation, Bronchoscopy, Ultrathin bronchoscopy, Cryobiopsy

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Background

Early lung cancer poses a significant challenge for bronchoscopy, particularly because the majority of lesions are located in the peripheral region of the lung [1]. To effectively biopsy these peripheral pulmonary lesions (PPLs), thin instruments and a reliable navigation system are necessary to ensure accurate targeting and acquisition of tissue samples.

Ultrathin bronchoscope (UTB) is a slim instrument that allows access to peripheral areas of the lung during bronchoscopy. However, this advantage is frequently hindered by the small size of its working channel, which prevents the insertion of radial endobronchial ultrasound (rEBUS) probe for navigation verification. Recently, the introduction of a novel ultrathin bronchoscope with a 1.7 mm working channel has enabled rEBUS verification and shows promise for accessing PPLs in the lung periphery [2]. However, rEBUS is not a navigational tool, and an accurate roadmap to the target PPLs remains necessary. To date, the most commonly used navigation tool for UTB-rEBUS is virtual bronchoscopic navigation (VBN) [3–5]. However, VBN may not be readily available in all centres, particularly in resource-limited areas.

Bronchial branch tracing (BBT) is a manual navigation method that involves identifying the airways leading to the target lesion and translating them into a schematic map that correlates with actual bronchoscopic vision [6]. This provides a roadmap for the bronchoscopist to navigate the rEBUS procedure when approaching PPLs. While BBT has demonstrated effectiveness with therapeutic and thin bronchoscopes for PPL biopsy, its utilization with UTB remains limited in the literature [7, 8].

Herein, we aim to describe the performance of BBT as the sole navigation method in navigating UTB-rEBUS procedures for patients with small PPLs by assessing both the navigation success and the diagnostic yield.

Methods

Study design & setting

This is a single-centre, retrospective study that included patients with PPLs measuring three centimetres or less, who underwent UTB-rEBUS procedures at Sarawak General Hospital, Kuching, Sarawak, Malaysia, from January 1, 2022, to December 8, 2023. Patients with past history of lobectomy or segmentectomy for bronchial and pulmonary lesions ipsilateral to the target lesions were excluded. The study protocol was approved by the Medical Research & Ethics Committee, Ministry of Health Malaysia (*NMRR ID-23-03628-QAG (IIR) dated January 26, 2024*) which waived the need for additional informed consent.

All procedure planning and execution were performed by one of the three consultant pulmonologists (SSK, CSC, STT), each experienced in advanced diagnostic and therapeutic respiratory bronchoscopy, including rigid bronchoscopy. Data of interest were retrospectively extracted from respiratory endoscopy reports and medical records. In our institution, all PPLs were considered for a bronchoscopic approach unless deemed inaccessible by guided bronchoscopy. This approach is due to the high incidence of tuberculosis in our region, where a paired diagnostic bronchoalveolar lavage for mycobacterial analysis is essential [9, 10]. Additionally, it aims to limit the complications of pneumothorax and potential ipsilateral pleural contamination from a transthoracic biopsy in early lung cancer [11].

Bronchial branch tracing navigation

First, a volumetric computed tomography (CT) of the thorax with maximum slice thickness of 2 mm was performed before all procedures. Subsequently, the images were reconstructed and rotated in specific planes (*axial*, *coronal*, *or sagittal*) to align with the actual bronchoscopic vision depending on the lobar location of the PPL. Adjustments were made from the original description of this technique to enhance the view of each airway bifurcation, allowing the airway to be viewed in a cross-sectional plane that is perpendicular to the long axis of the airway of interest [6, 7]. The suggested algorithm can be found in the *Supplementary Material*.

We would then identify the bronchus sign leading into the target PPL and trace it back to the origin of the segmental airway. Subsequently, we would scroll through the CT images slice by slice from the ostium of the segmental airway into the target lesion, identifying each bifurcation and drawing them onto a schematic map. When recording the roadmap, the branching angle and the size of the bronchus would be taken into consideration. Additionally, in certain cases, the length of the airway after each bifurcation were measured and documented. The lesion size and airway generation were then recorded. The planning steps were illustrated in Fig. 1 and a representative case is shown in Fig. 2 and Video 1. Upon completion of mapping, the schematic map is clipped onto a rotational panel and placed on the bronchoscopy tower for reference during the actual rEBUS procedure (Fig. 3).

Radial endobronchial ultrasound (rEBUS) procedure with ultrathin bronchoscope

In this study, the usage of an artificial airway, total intravenous an aesthesia (TIVA), and fluoroscopy was at the discretion of the bronchoscopist during the procedure. We utilized the ultrathin bronchoscope (*BF-MP190F*, *Olympus Medical*, *Japan*) along with the 20 Hz mini rEBUS probe (*UM-S20-17 S*, *Olympus Medical*, *Japan*) for our procedure. The bronchoscope was steered and advanced according to the pre-planned roadmap. Each bifurcation was visualized and confirmed before

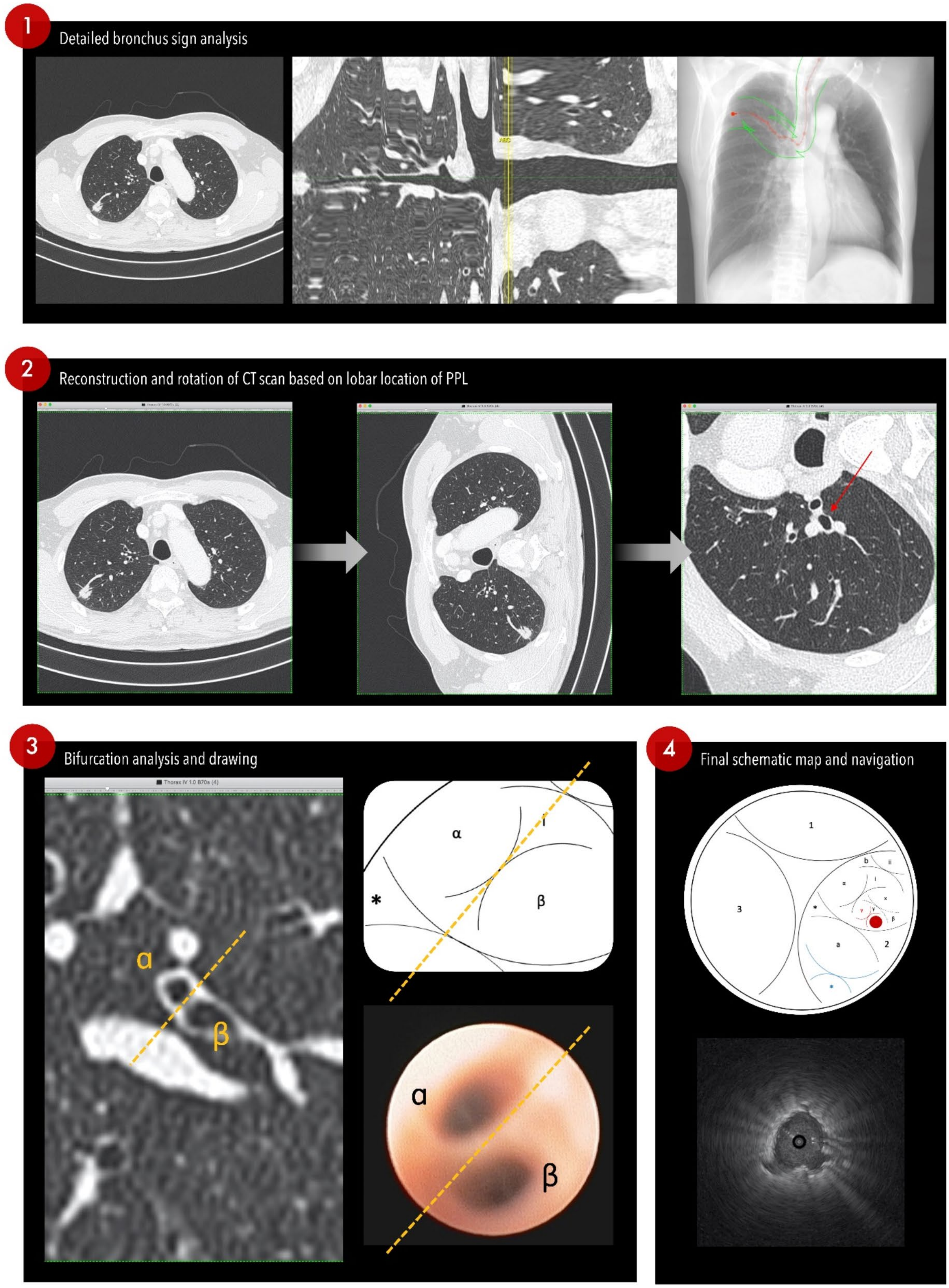

Fig. 1 (See legend on next page.)

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Fig. 1 *Step 1*: First, the bronchus sign leading into the 1.4 cm target nodule in RB2 was analysed meticulously from the segmental airway into the target. A path was then marked and overlaid on a digitally reconstructed radiograph. *Step 2*: The axial CT was then rotated 90 degrees counter-clockwise in this case (*right upper lobe target*) to align with the actual bronchoscopic vision. The planning then started from the most proximal segmental airway, in this case, the RB2 ostium (*red arrow*). *Step 3*: When recording the roadmap, the branching angle and the size of the bronchus were taken into consideration. The alpha-beta bifurcation in this case bifurcated in a vertical-to-vertical manner, and hence the branching angle (yellow dotted line) and size of the airway were drawn corresponding to the CT image. The actual bronchoscopic view of the alpha-beta bifurcation was shown. *Step 4*: The final schematic map of the target (*RB2-b-i-beta-y-x*) with the final segment marked. Radial EBUS confirmed a concentrically oriented lesion, and cryobiopsy confirmed adenocarcinoma of the lung with positive EGFR mutation

progressing to the successive generation. Upon reaching the final bifurcation, the mini rEBUS probe was inserted into the target segment for verification of navigation.

The site of interest, verified by rEBUS, was marked on single planar fluoroscopy. Subsequently, the biopsy tools, such as forceps (*FB-231D*, *Olympus Medical*, *Japan*) or the ultrathin 1.1 mm cryoprobe (*ERBE Medizintechnik*, *Tübingen*, *Germany*), were inserted into the same target segment and guided to the final position using fluoroscopy. In cases where fluoroscopy was not employed, biopsy tool insertion was guided by the *distance-measurement technique* [12]. Notably, the *en-bloc* method was used for cryobiopsy in this cohort, as the UTB and cryoprobe were withdrawn as a single unit after activation. We usually start with a 4 s freeze time with serial increment to 6 s if feasible (*under 50–65 bar pressure of carbon dioxide*) with a total of 2–3 passes based on our institutional experience [13]. A prophylactic balloon blocker was always available. Although cryoprobe retrieval through working channel of the bronchoscope had been described in literature, we did not employed this technique due to concern on instrument safety [14]. Rapid onsite examination was not routinely available in our institution. Upon completion of the procedure, a chest radiograph would be performed to check for pneumothorax.

Definition

Navigation success was determined by positive rEBUS signal upon verification of navigation. Concentric, eccentric, and adjacent signals were considered successful navigation, while an invisible signal was classified as failed navigation [15]. The classification of the bronchus sign, the nature of the target lesion, the nomenclature of the airway generation and the grading of bleeding are detailed in the *Supplementary Material*.

The procedure was considered conclusive if histological or microbiological studies provided a definite malignant or benign diagnosis. Granulomas, whether caseating or non-caseating, were categorized as tuberculosis in the appropriate clinical context, especially in our region with a high incidence of tuberculosis [9]. Lesions showing inflammatory findings on biopsy were initially classified as inconclusive (*index diagnostic yield*) and would be considered conclusive if the lesion remained radiologically stable for at least 12 months (*follow-up diagnostic yield*). Procedures were deemed inconclusive if the results did not provide a definitive answer to the presenting clinical problem, necessitating further biopsy or intervention.

Statistical analysis

SPSS (*version 20; Chicago*, *IL. USA*) was used for data analysis. Normality was assessed with the Shapiro-Wilk test. Results were presented as mean ± standard deviation (SD) for normally distributed variables, and as median and interquartile range (IQR) for non-normally distributed variables. Categorical data were expressed as absolute numbers and percentages, and compared using Pearson's Chi-squared test or Fisher's exact test. Independent sample *t*-tests and Mann-Whitney tests were used to compare normally and non-normally distributed variables between groups, respectively. A p-value of < 0.05 was considered significant.

Results

A total of 165 rEBUS cases were performed during the study period, with 51 cases (30.9%) requiring UTB. Four cases were excluded due to target size exceeding 3 cm. Therefore, 47 patients were included for analysis. Detailed cohort information can be found in Table 1.

Baseline demographic, target and procedural characteristic

The mean age of our cohort was 61.6 (SD 9.53) years, with two-thirds of the cohort being male. The mean size of the target lesions was 1.91 (SD 0.53) cm. The majority of the target lesions were situated in the 6th airway generation (46.8%), with a mean *target-to-pleural* distance of 1.56 (SD 0.81) cm. 68% of the lesions were located in the upper lobes, and 78.7% demonstrated a direct bronchus sign, with most lesions (83.0%) being solid in nature.

The median procedure time from the initiation of anaesthesia to the conclusion of the procedure was 40.0 (IQR 30.0–45.0) minutes. Total intravenous anaesthesia (TIVA) was used in 66% of cases, and fluoroscopy guidance was employed in 93.6% of cases.

Forceps biopsy was performed in 13 cases (27.7%) with a median of 6.0 (IQR 5.0–9.0) passes. Cryobiopsy was performed in 34 cases (72.3%) with a median of 2 (IQR 1–3) passes and a median average freezing time of 5.0 (IQR 5.0-7.5) seconds.

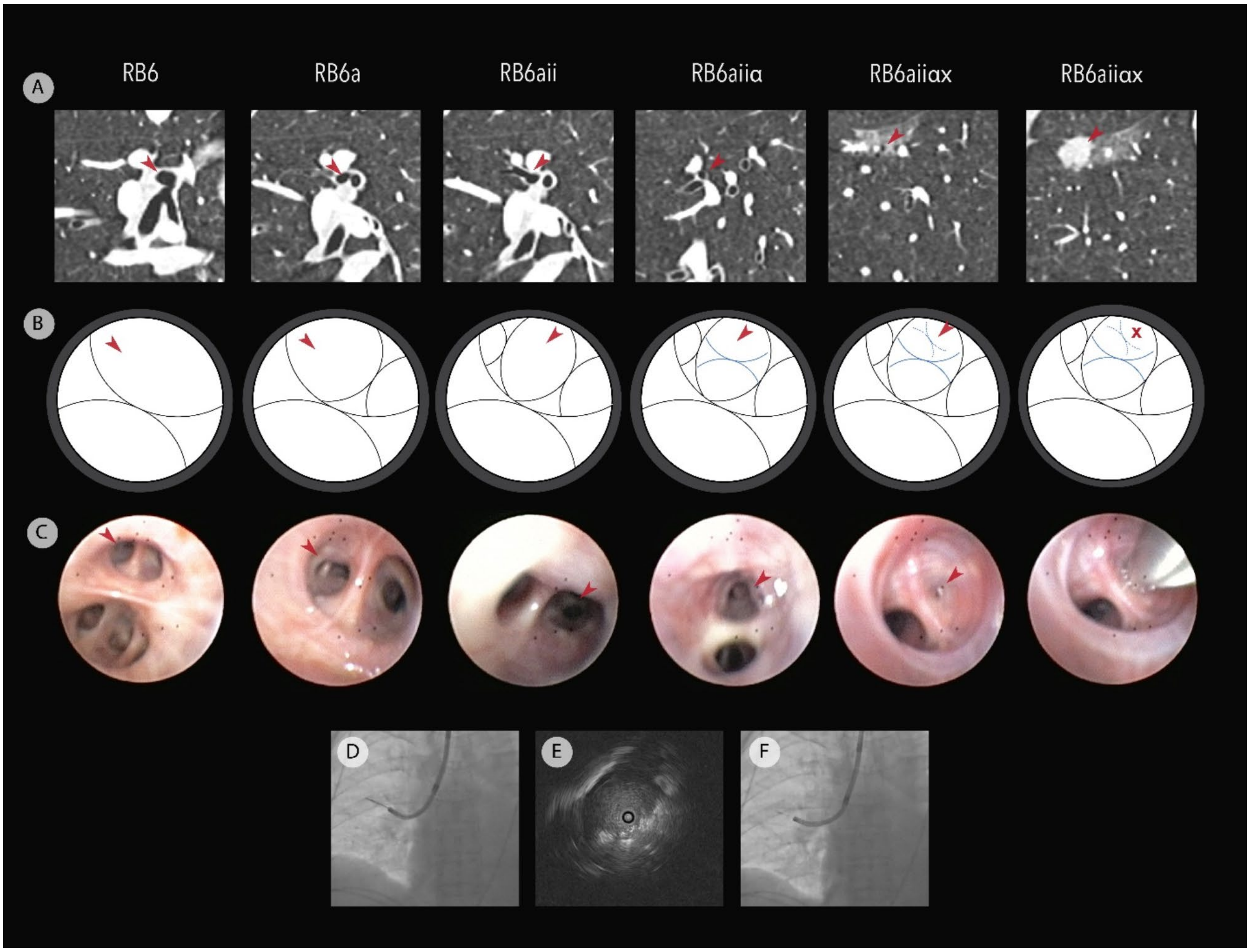

Fig. 2 Representative Case: A 1.2 cm nodule adjacent to visceral pleura, located in the 6th airway generation of the apical segment of the right lower lobe (RB6-a-ii-α-x). In *Panel A*, the thin slice CT scan in coronal reconstruction was traced from the ostium of RB6 to the target lesion. *Panel B* shows the corresponding bronchial map, and *Panel C* displays the actual bronchoscopic appearance from the ultrathin bronchoscope, with all corresponding target segments marked with *red arrows*. Radial EBUS confirmed a concentric lesion at the target segment under fluoroscopic guidance (*Panel D*, *E*), and cryobiopsy (*Panel F*) confirmed adenocarcinoma of the lung with EGFR mutation. The planning steps were illustrated in Video 1

Navigation success and diagnostic yield

The navigation success using BBT navigation was 91.5%. The localized lesions demonstrated concentric (44.7%), eccentric (34.0%), and adjacent (12.8%) orientation. Notably, the eight non-solid lesions were all part-solid in nature. Six of these lesions were successfully localized, while two were invisible on rEBUS and failed to provide a conclusive diagnosis.

At the time of initial follow up, the index diagnostic yield was 82.9% (39/47), and at 12 months of follow-up, the final diagnostic yield increased to 91.5% (43/47). The majority of target lesions, based on final diagnosis, were malignant in nature (65.1%), while 34.9% were non-malignant, including tuberculosis ($n=11$) and infection or inflammatory causes ($n=4$) (Supplementary Tables 1–2). The reasons for cases with failed navigation and inconclusive biopsy were presented in Supplementary Table 3.

There was one case of pneumothorax in our cohort. Overall, bleeding complications occurred in 38.4% of cases, with the majority (27.7%) being Grade 1. No severe bleeding or deaths were observed in our cohort.

Role of cryobiopsy in combination with UTB-rEBUS

The overall diagnostic yield for forceps biopsy was 84.6% (11/13) and 94.1% (32/34) for cryobiopsy, $p>0.05$.

In concentric-oriented rEBUS lesions, both forceps and cryobiopsy achieved a 100% diagnostic yield. However, in non-concentric lesions, cryobiopsy demonstrated a significantly better diagnostic yield than forceps [90.9% (20/22) vs. 50.0% (2/4), $p<0.05$] (Supplementary Table 4). No bleeding episodes were reported in the forceps biopsy group, but cryobiopsy had an overall bleeding rate (*any grade*) of 52.9%, $p<0.05$ (Supplementary Table 5).

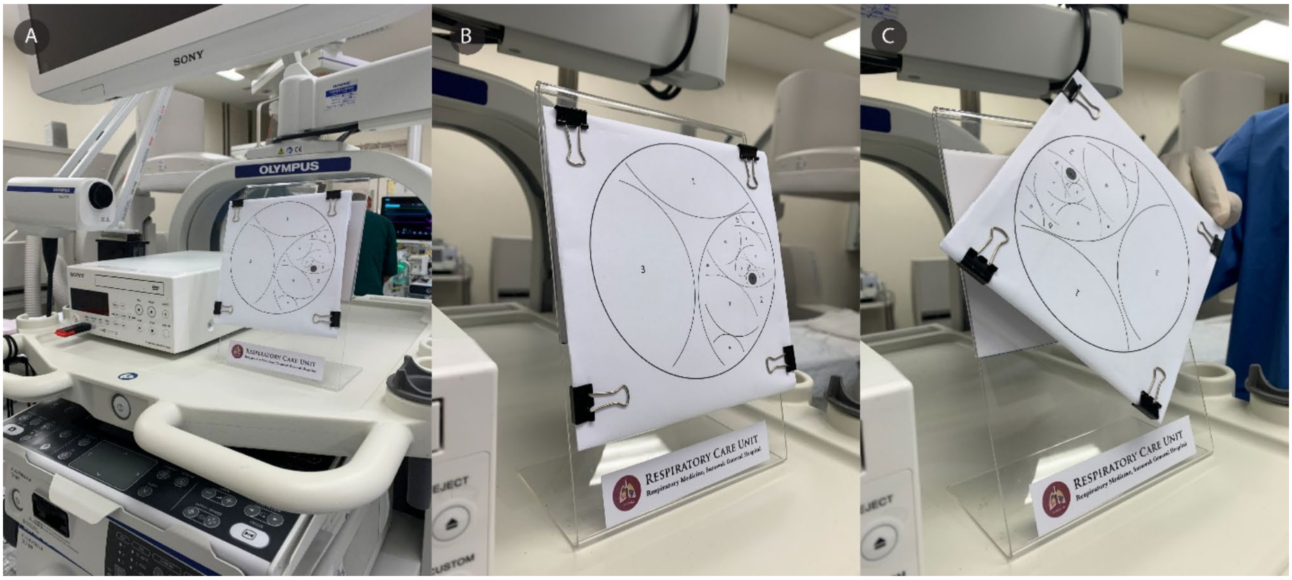

Fig. 3 The sketched bronchial map, attached to a rotatable panel and positioned on the bronchoscopy tower during the actual procedure (*Panel A*). The bronchial map can be rotated to align with the bronchoscope's rotation during the actual procedure (*Panel B*, *C*)

Factors associated with better navigation success and conclusive procedure

In navigation, the presence of a direct bronchus sign was associated with successful localization (97.3% vs. 70.0%, $p<0.01$). There were no differences in other parameters such as the size of the lesion, airway generation, lesion nature, lower lobe location, types of sedation, and usage of fluoroscopy.

Similarly, the direct bronchus sign was the only factor associated with a better final diagnostic yield (97.3% vs. 70.0%, $p<0.01$). Additional variables such as rEBUS orientation, biopsy methods, and the final diagnosis showed no differences in diagnostic yield as well (Table 2).

Discussion

In this study, we demonstrated that BBT as a method to navigate UTB-rEBUS procedures in small PPLs is feasible and safe. BBT is a technique first described by *Prof. Noriaki Kurimoto*, in which CT scans are rotated and flipped in a predetermined manner to simulate actual bronchoscopic vision and orientation [6]. Previous studies have demonstrated its feasibility in improving sensitivity of bronchial washing for cytology in malignancy as well as in the diagnosis of PPLs [7, 16]. Various enhancements of this method have also been described in the literature, such as hand-drawn hierarchical clock-scale mapping, and more specifically, enhanced CT reconstruction to allow better visualization of airway bifurcation [7, 8]. The beauty of this technique lies in its cost-effectiveness and allows the bronchoscopist to better understand the anatomy of the airway.

The use of BBT as a navigation method for UTB-rEBUS procedures is scarcely reported in the literature as most cohorts use VBN for UTB-rEBUS navigation [2–4, 17, 18]. However, VBN may not be available to all centres, and moreover, the resolution of airway segmentation at the extreme periphery of the lung is frequently limited, potentially leading to inaccurate navigation in the final few bifurcations where it matters most [19]. This is important because literature has shown that accurately placing the bronchoscope as near as possible to the target PPL was associated with a better diagnostic yield [20]. We have also reaffirmed this finding that the bronchus sign is the only factor associated with higher navigation success and diagnostic yield in BBT-guided UTB-rEBUS procedures, rather than the lesion size or airway generation in our cohort. This is likely due to the UTB's ability to be negotiated into very distal airway generation; thus, the actual location of the lesion and its size may not be as limiting, as long as the bronchoscope can reach the final bronchus leading into the lesion with guidance of BBT.

The nemesis of UTB is the limited size of biopsy tools that can pass through the narrow working channel, often resulting in suboptimal biopsy specimens. Miniaturization of the cryoprobe to 1.1 mm provides a valuable companion to UTB by addressing this challenge. Studies have demonstrated the superiority of ultrathin cryobiopsy when combined with UTB compared to forceps biopsy by providing larger and high quality specimen [5, 17, 21]. Cryobiopsy is known to be an effective tool for sampling eccentrically and adjacently oriented lesions in PPL due to its capability of 360-degree biopsy [15]. We further reaffirmed this finding that the ultrathin cryoprobe retains this capability despite its small diameter, significantly increasing the diagnostic yield of non-concentrically oriented PPLs. However, as bleeding was

Table 1 Baseline demographic, target lesion, procedure characteristic and outcome

Baseline demographic and target lesion characteristic		
Age, *mean (SD), years*		61.6 (9.53)
Gender, *n (%)*	*Male*	30 (63.8)
	Female	17 (36.2)
Target size, *mean (SD), cm*		1.91 (0.53)
Airway generation, *n (%)*	*3rd generation*	3 (6.4)
	4th generation	6 (12.8)
	5th generation	8 (17.0)
	6th generation	22 (46.8)
	7th generation	4 (8.5)
	8th generation	3 (6.4)
	9th generation	1 (2.1)
Target to pleural distance, *mean (SD). cm*		1.56 (0.81)
Lobe, *n (%)*	*Right upper lobe*	15 (31.9)
	Right middle lobe	3 (6.4)
	Right apical lower lobe	5 (10.6)
	Right lower lobe	3 (6.4)
	Left upper divisional	17 (36.1)
	Left lingula	2 (4.2)
	Left apical lower lobe	0 (0.0)
	Left lower lobe	2 (2.4)
Bronchus sign, *n (%)*	*Direct (Type A)*	31 (78.7)
	Indirect (Type B and C)	10 (21.3)
Target nature, *n (%)*	*Solid*	39 (83.0)
	Non-solid	8 (17.0)
Procedural characteristic		
Procedure Time, *median (IQR), minutes*		40.0 (30.0–45.0)
Sedation, *n (%)*	*Conscious sedation*	16 (34.0)
	TIVA	31 (66.0)
Fluoroscopy, *n (%)*	*Fluoroscopy*	44 (93.6)
	No fluoroscopy	3 (6.4)
Biopsy method, *n (%)*	*Forceps*	13 (27.7)
	Cryobiopsy	34 (72.3)
Forceps pass, *median (IQR)*		6.0 (5.0–9.0)
Cryobiopsy pass, *median (IQR)*		2.0 (1.0–3.0)
Cryobiopsy freezing time per pass, *median (IQR), seconds*		5.0 (5.0-7.5)
Procedural outcome		
Navigation success, *n (%)*	*Success*	43 (91.5)
	Failed	4 (8.5)
rEBUS orientation, *n (%)*	*Concentric*	21 (44.7)
	Eccentric	16 (34.0)
	Adjacent	6 (12.8)
	Invisible	4 (8.5)
Diagnostic yield, *n (%)*	*Index*	39 (82.9)
	12 months	43 (91.5)
Pneumothorax, *n (%)*		1 (2.1)
Bleeding, *n (%)*	*Grade 0*	29 (61.7)
	Grade 1	13 (27.7)
	Grade 2	2 (4.3)
	Grade 3	3 (6.4)

Table 2 Factors associated with navigation success and conclusive procedure

Variables		**Navigation success**	***p*-value**	**Conclusive**	***p*-value**
Target size	*< 2 cm*	91.3 (21/23)	0.965	95.7 (22/23)	0.317
	≥ 2 cm	91.7 (22/24)		87.5 (21/24)	
Airway generation	*< 6*	88.2 (15/17)	0.547	82.4 (14/17)	0.091
	≥ 6	93.3 (28/30)		96.7 (29/30)	
Bronchus sign	*Direct*	97.3 (36/37)	0.006	97.3 (36/37)	0.006
	Indirect	70.0 (7/10)		70.0 (7/10)	
Lesion nature	*Solid*	94.9 (37/39)	0.067	94.9 (37/39)	0.067
	Non-solid	75.0 (6/8)		75.0 (6/8)	
Lower Lobe	*Yes*	90.0 (9/10)	0.849	90.0 (9/10)	0.849
	No	91.9 (34/37)		91.9 (34/37)	
Sedation	*Conscious*	93.8 (15/16)	0.690	100.0 (16/16)	0.133
	TIVA	90.3 (28/31)		87.1 (27/31)	
Fluoroscopy	*Yes*	90.9 (40/44)	0.585	90.0 (40/44)	0.585
	No	100.0 (3/3)		100.0 (3/3)	
Only applicable for diagnostic yield					
Orientation	*Concentric*	-	-	100.0 (21/21)	0.060
	Non-concentric	-		84.6 (22/26)	
Biopsy methods	*Forceps*	-	-	84.6 (11/13)	0.296
	Cryobiopsy	-		94.1 (32/24)	
Final diagnosis	*Malignant*	-	-	90.3 (28/31)	0.690
	Non-malignant	-		93.8 (15/16)	

more common with cryobiopsy albeit of mild nature, careful patient selection remains crucial. Although wedging the UTB in place and retrieving the cryoprobe through the working channel is a potential option to effectively control bleeding, the theoretical risk of instrument damage resulting in high repair costs has hindered us from employing this technique; the potential use of a single-use bronchoscope with this method warrants further investigation [14]. Peripheral transbronchial needle aspiration (pTBNA) may also be useful for adjacently orientated PPLs; importantly, the novel peripheral TBNA needle (*PeriView FLEX*, *Olympus*, *Japan*) can now be inserted into the working channel of UTB to allow peripheral transbronchial access [18]. However, pTBNA only provides cytology specimen which may not always be adequate for molecular studies. Scattered case reports demonstrated that performing a highly targeted cryobiopsy through the mucosal defect created by pTBNA may mitigate the risk of bleeding associated with cryobiopsy in adjacently orientated PPLs, where normal bronchial epithelium is torn, while providing a high-quality histological specimen [22].

There are also some challenges with this technique. Firstly, the essence of BBT lies in visually confirming each bifurcation that leads to the target before the biopsy procedure. Consequently, the primary challenge of this technique is maintaining vision at the very distal airway generations, which can be challenging due to airway collapse, mucus, etc. Various techniques have been described to address this challenges, including air insufflation through the working channel, ventilation strategies, and importantly, limiting unnecessary suction during the navigation process [23]. This phenomenon was more apparent in cryobiopsy, where after the first cryo-pass, the target airways were often clotted with blood and secretions, posing challenges for subsequent visualization and navigation. Therefore, the first cryo-pass played a crucial role in cryobiopsy procedures. Literature has consistently shown that the first cryo-pass generally yielded the highest absolute diagnostic yield compared to subsequent attempts, primarily due to difficulties in localization caused by factors such as bleeding and coughing after the initial biopsy [24, 25]. Although other ancillary navigation tools such as virtual fluoroscopy via a digitally reconstructed radiograph with overlaid path may be able to guide the trajectory and alignment of the UTB fluoroscopically in the event of bronchoscopic vision loss in the final few airway generations, this may not always be optimal [26].

Additionally, steady control of the UTB during airway advancement is crucial, as the slightest motions could result in inadvertent withdrawal or overshooting of the bronchoscope to the previous or next bifurcation. This is of particular note in lower lobes PPLs, where excessive respiratory movement may confound, and lead to intra-procedural confusion. Additionally, engaging the lower lobe often necessitates almost a 180-degree rotation of the bronchoscope for ergonomic access, which may conflict with the static schematic map. To address this issue, our centre employs a rotatable panel for the schematic map, enabling us to rotate the map during the procedure and align it with the rotation of the bronchoscope (Fig. 2).

Our study also highlighted the common challenges associated with rEBUS and UTB (Supplementary Table 3). For rEBUS, a high-confidence signal depends on the solidity of the PPLs, the quality of contact between the rEBUS probe and PPLs, as well as the absence of artificial ventilation-related atelectasis in the segment of interest (Case 1–4). Interestingly, in Case 1 and 2, confidence in BBT navigation allowed us to perform cryobiopsy at the planned segment, which successfully yielded a diagnosis even without an optimal rEBUS signal. We believe that advanced intra-procedural imaging, such as augmented fluoroscopy or cone beam CT (CBCT), would be useful in such situations to complement the inadequacy of rEBUS. Studies have shown that combining CBCT with UTB-rEBUS can significantly increase diagnostic yield [27]. Moreover, improving ventilation strategies to reduce atelectasis will also be key to enhancing intra-procedural imaging [23]. For UTB, being overly flexible also posed some issues in peripheral navigation. In Case 5 and 6, when the UTB entered the acutely angled upper lobe bronchus, a downward force often failed to advance the bronchoscope distally once the scope was flexed maximally; instead, the force was transmitted to the point where the scope was most curved, causing it to buckle and paradoxically move further away. This phenomenon was referred to as the '*Watanabe phenomenon*' in Japanese literature [28]. Therefore, a more rigid steering tool with good column strength and structural integrity, such as a robotic bronchoscopic sheath, might potentially been a better option.

The main limitation of our study was the absence of a comparison arm, such as VBN, which prevented us from determining the true superiority of BBT as a navigation method for UTB-rEBUS. However, we demonstrated the feasibility and safety of using BBT as a sole navigation tool for UTB-rEBUS procedures, especially for centers without the luxury of VBN. Secondly, the high diagnostic yield of our cohort was likely compounded by selection bias, as only PPLs deemed possible to reach by guided bronchoscopy by the managing physicians were included in this study. Moreover, a significant number of PPLs in real life, especially those without a convincing bronchus sign, may still not be approachable by this technique. Adaptation of BBT as a navigation technique to drive more stable steering tools with transbronchial access capability, such as robotic-assisted bronchoscopy, may be worthwhile to be explored in the future. Our cohort also reported more male patients and a lower median age, hence a selection bias cannot be completely excluded. However, since the majority of our cohort consisted of malignant cases, this aligns with our national data which indicate that the mean age at lung cancer diagnosis is around 60 years old [29]. Additionally, our national cancer registry report shows that 68% of lung cancer cases were male and 32% were female [30]. Thus, we believe our data remain representative.

Thirdly, we did not report comprehensive physiological data for our patients, such as spirometry tests, as it is known that flexible bronchoscopy may have a detrimental effect on patients' lung function indices [31]. Lastly, while BBT was feasible and theoretically straightforward, actual mastery required extensive practice with a steep learning curve. Since this technique had been practiced in our institution for an extended period, well beyond the learning curve, the favourable results of this study may not be generalizable to all centers [7, 9]. Introducing a dedicated training program and a formal competency assessment tool could be beneficial for the wider adoption of this technique within the pulmonology community. Moving forward, employing artificial intelligence for segmentation and tracing of airways from CT may aid bronchoscopists in determining the feasibility of using BBT as a navigation tool [32]. Further studies to compare different navigational methods, such as electromagnetic navigational bronchoscopy, virtual bronchoscopic navigation, and a general comparison to the transthoracic approach or even robotic-assisted bronchoscopy, could be interesting in the future.

Conclusions

In conclusion, BBT as the sole navigation system for small PPLs in UTB-rEBUS procedures is safe and feasible. The presence of a direct bronchus sign is associated with higher navigation success and diagnostic yield. Furthermore, ultrathin cryobiopsy in combination with UTB remains useful and effective in eccentric and adjacently oriented lesions.

Abbreviations

BBT	Bronchial branch tracing
CT	Computed tomography
CBCT	Cone beam computed tomography
IQR	Interquartile range
pTBNA	Peripheral transbronchial needle aspiration
PPL	Peripheral pulmonary lesion
rEBUS	Radial endobronchial ultrasound
SD	Standard deviation
TIVA	Total intravenous anaesthesia
UTB	Ultrathin bronchoscopy
VBN	Virtual bronchoscopic navigation

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12890-024-03279-0.

Supplementary Material 1

Supplementary Material 2: ***Video 1*** - The planning steps of the representative case.

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Author contributions

Conceptualization: SSK, CSC, STT. Data Curation: SSK, CSC. Formal Analysis: SSK, SHT. Investigation: SSK, CSC, STT. Methodology: SSK, SHT, STT. Supervision: STT. Writing Original Draft: SSK, SKC. Writing Review & Editing: SHT, CSC, STT. All authors had read and approved the final version of this manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author, SSK, upon reasonable request.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Medical Research & Ethics Committee, Ministry of Health Malaysia (*NMRR ID-23-03628-QAG (IIR) dated January 26, 2024*) which waived the need for informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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