非触知肺結節に対する移動式CT及びナビゲーションシステムを用いたマーキング法の開発

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内容の要約

触診でも判別不能な肺結節に対して術中にマーキングを行うことは胸腔鏡下手術のために必須である。CTガイド下フックワイヤ法は広く普及しているが、稀ながら致死的となり得る空気塞栓を起こしうるため安全性に懸念がある。我々はこの問題を解決するためにナビゲーションシステムと連動した移動式CTを導入した。撮影された3D-CTデータはナビゲーションシステムに送られてプローブを患者の体表で動かすことで仮想CT透視が可能となり、標的病変に最も近い皮膚位置を特定出来る。この皮膚位置直下の肺表面に色素で印をつけて同部に金属針を留置して、再度CTを撮影することで針の位置と実際の標的病変の位置を評価出来る。手技に起因する合併症は認めていない。

このアイデアを提供して下さったのは当院臨床工学室のスタッフで、手術中の機材準備においても彼らの本法確立への貢献度は非常に大きい。また麻酔管理も重要となるが、当院麻酔科スタッフにも手技の理解と協力を得て運用可能となった。単に目新しい手技の導入だけでなく、その背景にあるのは聖隷浜松病院の高い臨床能力の結集があることを強調しておきたい。

研究・活動内容

CT 検診の普及により早期肺がんの発見数が増えている。これらは触診で病変を確認できないこともあるため、術前に何らかのマーキングが必要である。当科では従来はCT 室で局所麻酔下にマーカーを打ち込む手法を採用していた（CT ガイド下フックワイヤ法)。この手技は比較的簡便で広く普及している一方で、時に致死的ともなり得る空気塞栓を発症するなど安全面で問題があった。また従来法では穿刺後に気胸がほぼ必発のため、不適切な位置にマーカーが留置された場合でも再穿刺による修正は事実上不可能であった。これらはいずれも経皮的に肺穿刺することに起因するもので、従来法では不可避な事象であった。そこで我々は安全性と確実性を同時に向上させるためにナビゲーションシステムと連動した移動式 CT によるマーキング法を導入した。

本法では全身麻酔導入後に移動式CT で撮影した3D 画像をナビゲーションシステムに連動させて患者の体表上でプローブを動かすことで仮想 CT が可能となり、病変からの最短位置を皮膚上で特定できる。更にこの直下に色素綿球を固定した後に肺を拡張させて肺表面に着色させる。この部分に金属針を留置して再度 CT を撮影することで病変とマーキングの位置関係を検証する。良好な場合は引き続き該当部位を切除するが、不適切な場合は再度針を適切な位置に留置し直して CT 再検で確認のうえ切除に移行する。論文執筆の時点で 12 例にこの手技を行い、全例で目標病変を特定の上切除できた。1 例でマーキング位置がやや不適切であることが再スキャンで判明したが、再度マーキング位置を修正することで適切に病変の特定が可能であった。また手技にともなう有害事象は認めなかった。

本法では従来法に比較して経皮的な肺穿刺を行わないため安全性が高い。またマーキング失敗例でも再試行が可能な点で精度も向上した。また、従来法では CT 室で意識下に穿刺を行った後に手術室へ移動して麻酔導入後手術としていたが、本法では麻酔導入後に全ての手技を行うため患者負担の軽減という意味でも有益と考

えている。

移動式 CT とナビゲーションシステムを連動させた本法は末梢非触知肺結節のマーキング法として有力な選択肢である。今後更に需要が増すと思われる早期肺癌症例に対して本法を積極的に施行していく予定で、症例集積によりさらに精度と安全性を改善していく所存である。

移動式CTとナビゲーションシステムの併用は整形外科領域で広く行われているが、呼吸器外科での実績は少ない。このアイデアを提供して下さったのは当院臨床工学室のスタッフで、手術中の機材準備においても彼らの本法確立への貢献度は非常に大きい。また呼吸に同調させた撮影が必要となるため麻酔管理も重要となるが、当院麻酔科スタッフにも手技の理解と協力を得て運用可能となった。単に目新しい手技を導入したというだけでなく、その背景にあるのは聖隷浜松病院の高い臨床能力の結集があることを強調しておきたい。

資料

R. Fujikawa, Y. Otsuki, H. Nakamura, K. Funai and T. Nakamura. Marking method for peripheral non-palpable pulmonary nodules using a mobile computed tomography scanner with a navigation system. General thoracic and cardiovascular surgery 2020, doi 10.1007/s11748-020-01332-3.（紙冊子を別に送付します）

General Thoracic and Cardiovascular Surgery
https://doi.org/10.1007/s11748-020-01332-3

HOW TO DO IT

Marking method for peripheral non-palpable pulmonary nodules using a mobile computed tomography scanner with a navigation system

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Received: 10 December 2019 / Accepted: 28 February 2020

Abstract
Intraoperative localization is essential for video-assisted thoracoscopic surgery of non-palpable pulmonary nodules. Although a computed tomography (CT) guided hook-wire localization is widely used, it might be accompanied by a rare but fatal complication such as an air embolism. We applied a mobile CT scanner with a navigation system to resolve this problem. The three-dimensional images obtained by the mobile CT scanner were transferred to the navigation system, which allowed for virtual fluoroscopy to scan the nearest skin site from the target lesion using a navigation probe. The lung surface was stamped by a dyed gauze ball anchored just beneath the skin marking and a needle was placed at this point as a landmark. With this method, we could verify the positional relationship between the needle and target lesion by the additional CT scan without any procedure-related morbidity.

Keywords Ground glass nodule · Mobile computed tomography · Navigation system · Image-guided video-assisted thoracoscopic surgery

Introduction

Widespread use of low dose computed tomography (CT) in lung cancer screening has led to the increased detection of small pulmonary nodules such as ground glass nodules. Because those lesions are difficult to detect either by visual inspection or digital palpation, an accurate intraoperative localization technique is essential. Although a CT-guided hook-wire localization method for peripheral non-palpable nodules has been widely accepted because of its simplicity and effectiveness [1–3], the hook-wire insertion might cause air embolisms by permitting the passage of air between the bronchiole and adjacent pulmonary vasculature [4]. It rarely occurs [2, 4], but could be fatal [5] and is inevitable as long as a percutaneous pleural puncture is required. We introduced a mobile CT scanner with a navigation system as a substitute for the CT guided hook-wire marking.

Technique

A mobile CT scanner (O-arm™, Medtronic Japan Co. Ltd., Tokyo, Japan) and navigation system (Stealth Station™ S7, Medtronic Japan Co. Ltd., Tokyo, Japan) were used for the localization of peripheral pulmonary nodules. Under general anesthesia with a double-lumen tube, each patient was placed in the lateral decubitus position on a radiolucent operating table (MAGNUS carbon fiber table top, Getinge Group Japan K.K., Tokyo, Japan). We placed a navigation camera at the foot of the patient and a navigation reference on the anterior superior iliac spine to calibrate the navigation software (Fig. 1). We obtained three-dimensional (3D)

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11748-020-01332-3) contains supplementary material, which is available to authorized users.

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Published online: 13 March 2020

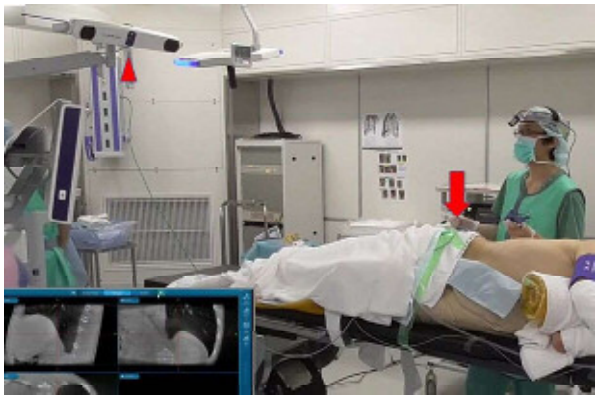

Fig. 1 Navigation system camera (arrowhead) was placed at the foot of the patient and a navigation reference (arrow) was placed on the anterior superior iliac spine

images using a mobile CT scanner during a breath-hold at the maximum inspiratory level under positive-pressure ventilation. During the scanning, a navigation system recognized the navigation reference of the patient through the camera and received the CT images. The mobile CT scanner was removed from the operative field once the desired images were obtained. The navigation system synchronized the hand probe on the reference and CT images through the camera and enabled grasping the location of the lesion and also simulating the trajectory for the instruments by virtual fluoroscopy. We placed the skin marking at the shortest distance over the target lesion using the probe (Fig. 2). After standard skin sterilization and draping, we inserted a Lapa-Her-Closure needle (Hakko Co. Ltd., Nagano, Japan) at the skin marking under thoracoscopic guidance. We inserted a nylon thread from the other port and withdrew it from the thoracic cavity by a Lapa-Her-Closure, and anchored a gauze ball containing gentian violet dye at the end of the thread on the parietal pleura (Fig. 3a) [6]. We expanded the collapsed lung fully enough to stamp dye on the lung surface and placed a needle at that point (4-0 PDS, PS-4) (Fig. 3b). We verified the proper needle placement by a second CT scan (Fig. 4) and performed a VATS wedge resection of the lung shortly thereafter. In the case of an apparent discrepancy, we translocated the needle to a more appropriate site confirmed by an additional scan. The supplemental movie file shows an overview of this method (see Online Resource 1).

Comment

In comparison to a CT-guided hook-wire localization, this method using a mobile CT scanner with a navigation system could avoid air embolisms because of no need for a percutaneous pleural puncture. We applied this method in 12 patients (12 nodules) over 16 months without any procedure-related morbidities. One lesion located on the posterior segment of the right upper lobe required a redo marking because of a 32 mm discrepancy between the initial marking and target nodule (Fig. 5a, b). We considered that a small

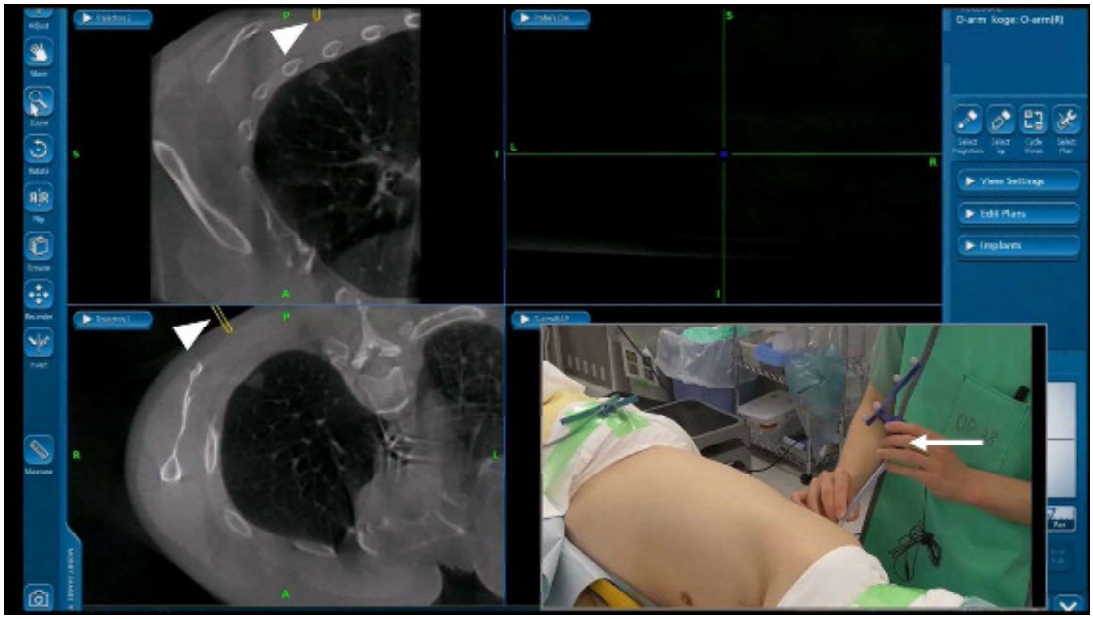

Fig. 2 Proper skin marking was determined with the navigation hand probe (arrow) registered on the navigation system, which showed the three-dimensional anatomy both in the sagittal and axial views verifying the virtual index of the probe (arrow heads)

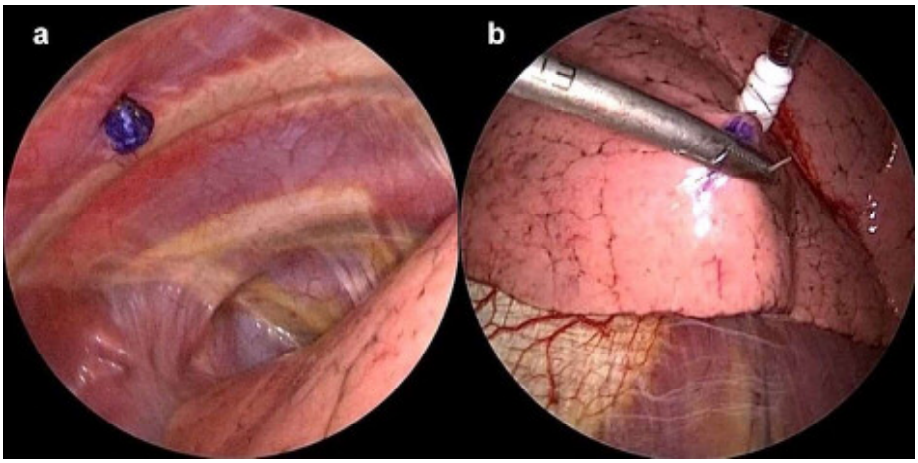

Fig. 3 a Gauze ball containing gentian violet dye was anchored on the parietal pleura. b After full expansion of the lung, a needle was placed at the dye marking site stamped on the lung surface

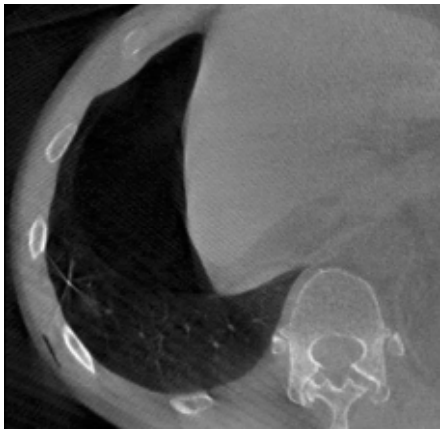

Fig. 4 Second scan with the mobile computed tomography scanner confirmed the appropriate needle placement just above the target lesion

difference in the angle of the Lapa-Her-Closure needle insertion made a large gap between the skin marking and target lesion because of the thick dorsal chest wall with a narrow intercostal space. This kind of error might be avoided using the navigation probe in an aseptic fashion to ascertain the correct trajectory of the needle insertion during surgery [7]. The remaining 11 patients were successfully targeted during the initial attempt. Consequently, all lesions were localized and removed successfully. Redo marking in case with an apparent discrepancy or dislodgement is hardly available in the hook-wire method due to a pneumothorax, which is the most common complication. These results suggest that our method is preferable to improve not only the safety but marking accuracy. Our method also would be more beneficial to reduce the patients' stress than the hook-wire marking, because both the marking and lung resection could be done in a single stage procedure under general anesthesia.

To avoid air embolisms, several noninvasive methods have been developed. CT guided marking without a pleural puncture is one of the most promising techniques and would be safer and more useful than a hook-wire method [6, 8]. However, they require digital palpation to confirm the location of the nodule relying upon the dye pigmentation on the surface of the visceral pleura. Meanwhile, we considered that an objective evaluation of the positional relationship between the marking site and target lesion by visual confirmation as shown in our method would be more accurate

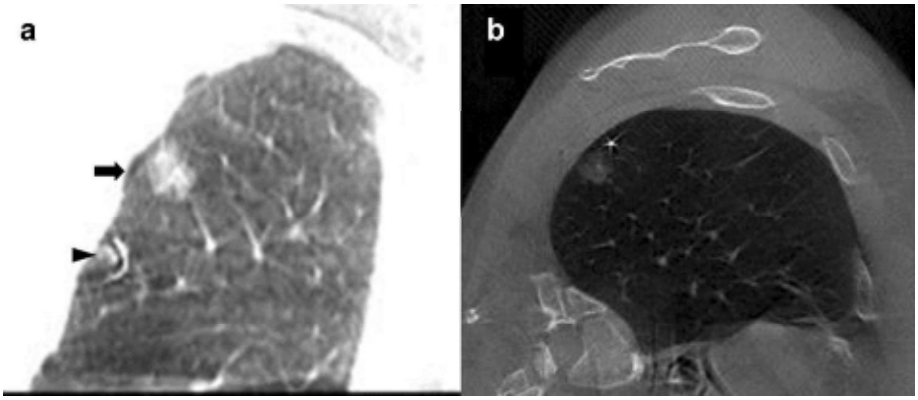

Fig. 5 a Case with a marking failure had a gap distance of 32 mm between the initial marking (arrowhead) and target lesion (arrow). b After the redo marking, the needle was successfully placed adjacent to the nodule

than a subjective digital palpation alone. Moreover, we also considered that the same respiratory condition both at the time of the skin marking and stamping on the lung under positive-pressure ventilation would lead targeting accuracy. In the intrathoracic stamping method, because they marked the skin based on the preoperative CT images scanned at a maximal inspiration during spontaneous breathing and stamped the lung inflated by positive-pressure ventilation, the positional relationship between those two markers might have been discrepant. In addition, because the navigation system allows surgeons to view 3D anatomy and to simulate the optimal needle trajectory through the chest wall using the navigation probe under the same patient's position, we could insert the needle with accurate trajectory by this preoperative simulation. Different patient's positions and respiratory conditions between the preoperative CT and the surgery might lead a targeting discrepancy in the intrathoracic stamping method. Therefore, the advantage of the mobile CT with the navigation system would be accuracy compared with methods using conventional CT.

Although we could identify the nearest point from the target lesion with this method, deeper lesions might be missed by a wedge resection depending on the depth from the pleura. Our method may be applicable only to peripheral lesions which are amenable to a wedge resection with an enough vertical margin reserved.

Radiation exposure of the high definition 3D protocol of the O-arm™ was reported to be lower than that of the conventional CT in the O-arm™ Imaging System Dosimetry Report by Medtronic Navigation Inc. Because the frequency of CT scans is equivalent with both methods, which require at least two scans, we considered that the radiation exposure would be equal or lower with our method than the hook-wire method. The radiation exposure to the medical staff was deemed to be a minor concern, because the mean radiation dose to the scan operator during the mobile CT scan has been reported to be only 0.63 μSv [9].

In conclusion, the marking method using a mobile CT scanner with a navigation system seemed to be a feasible option for the localization of peripheral non-palpable pulmonary nodules. Further accumulation of cases might prove its accuracy and safety.

Acknowledgements The authors thank the department of Clinical Engineering of our hospital for their contribution to establish this method.

Compliance with ethical standards

Conflict of interest The authors have declared that no conflict of interest exists.

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