



ARTIS Pheno[®] – the future of thoracic hybrid theatre for lung nodule resection?

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With the increasing availability of computer tomography (CT) scans and proven efficacy of low dose CT for lung cancer screening in high risk groups (1), more and more small lung nodules are being picked up. Up to 20% of lung nodules between 8 to 20 mm size are malignant (2), and early detection and treatment provides an opportunity for curative resection. Recently, sublobar resection has regained popularity as increasing evidence have shown that sublobar resection of stage Ia non-small cell lung carcinomas (NSCLC) provides similar overall survival compared to lobectomy (3-5). Uniportal video thoracoscopic thoracic surgery (VATS) has also been shown to improve post-operative pain, shorten hospital stay, and has non-inferior 1 year survival (6,7). The prerequisite of these successes, however, is accurate localization of small pulmonary nodules, so that adequate margin can be attained during sublobar resections, and the difficulty of nodule palpation through a single intercostal space during uniportal VATS can be circumvented. As the future of thoracic surgery becomes increasingly minimally-invasive, there is a surging need for hybrid operating room (HOR) to accurately and efficiently localize small pulmonary nodules for subsequent resection (8).

Since the late 1990s, clinicians have attempted to localize small lung nodules pre-operatively using CT-guided hookwire/microcoil insertion or dye injection, which are typically done in a CT suite by radiologists, followed by patient transferal to the operating room for

resection. However, this tedious process has a high chance of complications, including pneumothorax requiring chest drain insertion (up to 2–4%), hookwire dislodgement during transfer (up to 3.7%) (9), and dye diffusion during the long interval time between localization and surgery. Therefore, early pioneers attempted to combine radiological suites and operating theatre to streamline the process, giving birth to the idea of HORs. Several models have been reported, for instance multi-detector CT (MDCT) (definition FLASH CT; Siemens, Washington, DC, USA) (10) and mobile O-arm CBCT (Medtronic Japan Co., Ltd., Tokyo, Japan) (11). The former still carries the risk of wire dislodgement during patient transfer despite the MDCT and operating table being in the same room, while the latter has a much higher radiation exposure and time-consuming manual adjustment of O-arm centre. On the contrary, C-arm CBCT (e.g., ARTIS zeego[®]; Siemens Healthcare GmbH, Erlangen, Germany) is superior to the above two systems in several aspects. It has an open gantry design that allows flexibility during lesion targeting, and is capable of performing circumferential scanning around the surgical table, thus no patient transfer between localization and surgery is required (12). Additional navigation software are also integrated to the system, for example the iGuide and PURE[®] which offers a user-friendly interface for localization procedure, such that even surgeons can competently perform the procedure after receiving appropriate training (12).

The advantages of HOR intra-operative localization method over conventional CT suite pre-operative localization have been demonstrated by numerous studies. Chen's group compared preoperative CT suite and intraoperative HOR dye localization, and found shorter global time and similar peri-operative and post-operative outcomes (13). Hsieh's group reported that the use of HOR significantly reduced the patient time at risk (interval between completion of localization and skin incision) from 215 to 13 minutes (14), and the HOR method allowed multiple nodules to be almost simultaneously localized leading to a shorter procedural time (mean difference of 15.83 minutes) and lower radiation exposure (mean difference of 15.59 mSv) (15). A cumulative sum analysis by the same group revealed that proficiency was achieved after 38 procedures, with mean localization time improving from 32.13 to 13.34 minutes and success rate rising from 86.8% to 98.1% (16). Our institute have also compared hookwire localization between pre-operative CT suite insertion versus intraoperative HOR insertion, showing that the former has a significantly longer 'at-risk' period (109 *vs.* 41.1 minutes) and higher risk of hookwire dislodgement (up to 25% in the pre-operative CT group and 0% in the hybrid group) (17). All the above studies were conducted using the ARTIS Zeego[®] C-arm CBCT representing an example of state-of-art hybrid theatre systems of the past few years.

Results published by Cheng *et al.*'s recent article "*Image-guided video-assisted thoracoscopic surgery with ARTIS Pheno[®] for pulmonary nodule resection*" (18) are in line with the above mentioned studies. It is a retrospective analysis conducted in 2018 where 126 patients were divided equally and non-randomly into two groups. The first group received localization in a CT room and the second group received image-guided VATS (iVATS) in a HOR. As expected, the time from localization to skin incision was significantly shorter in the iVATS group (23.57 *vs.* 372.11 minutes), and the CT room group has a significantly higher complication rate (77.8% *vs.* 3.2%). The results further support the favorable outcomes and experience by other groups using the ARTIS Zeego[®] system. Nevertheless, the most exciting aspect of Cheng's paper is that it is one of the first ever published article regarding Siemens's updated system ARTIS Pheno[®] (Siemens Healthcare GmbH, Erlangen, Germany) for thoracic surgery.

Cheng *et al.*'s experience with ARTIS Pheno[®] has been satisfactory, citing little difficulty with patient and equipment positioning which has troubled some users

of ARTIS Zeego[®]. Compared with its predecessor, ARTIS Pheno[®] has a wider C-arm with 130 cm focal-spot-to-detector distance that gives a usable clearance up to 95.5 cm. All patients in the study were set at true lateral decubitus position during both localization and surgery, without ensuing collision due to the longer radius of gyration provided by ARTIS Pheno[®] (18). After localization, surgery can immediately start without the need for repositioning the patient. Therefore, the group is able to achieve a mean of only 23.57 minutes between end of localization and skin incision, which is much shorter than Hsieh *et al.*'s initial 32 minutes, although the same group has been able to reduce that time to a mere 13 minutes (16) after extensive experience with ARTIS Zeego[®]. In fact, the initial learning curve of ARTIS Zeego[®] for Hsieh's group was steep and required numerous attention to details, such that they have even published an interesting paper to specifically discuss about it (12). Depending on where the target lesion is located, the hemithorax is divided into 4 zones, and the optimal C-arm entry position for each zone is different. For a peripheral lung nodule located laterally, in order to include both the target lesion and the needle entry site into the CT image while patient lies lateral decubitus, the table may be placed too low leading to a collision with the rotating C-arm. The solution is to move the table towards the C-arm side, a 6 cm lateral move would gain a 3 cm height, which avoids C-arm collision. Patients may even need to be rotated to semi-prone position in order to include both target lesion and skin entry site into the CT field of visualization. Our initial experience with ARTIS Zeego[®] has seen similar challenges. Decubitus position with arm board was too bulky and frequently leads to collision, so that we have resorted to mostly supine or prone positioning during lesion localization, and repositioning to lateral decubitus for surgery. Many details have to be attended to, including the height of mattress, positioning of endotracheal tubes and monitoring lines. Precious time was wasted during test rotations of C-arm, repositioning and table movements in order to avoid collision. Nevertheless, our centre has gained experience and the localization-to-incision time was only 41 minutes (17), which includes intubation with double-lumen endotracheal tube (unlike Hsieh's and Cheng's group where patients were already intubated before localization), then to lateral decubitus for surgery. However, with ARTIS Pheno[®]'s wider C-arm space, it is possible to perform intubation first, then lie the patient true lateral decubitus with arm boards, followed by needle insertion during maximal inspiratory hold by

ventilator. This can potentially achieve a more precise localization than the awake patient holding a deep breath which can be unreliable. In addition, patients' satisfaction will likely improve as they can be spared the apprehension and pain of localization procedure. Needless to say, the wider C-arm space also allows easier image acquisition and needle placement for obese patients.

ARTIS Pheno® also boasts a more powerful surgical table, allowing patient weight up to 280 kg, which is a 30 kg increase from its predecessor. Unfortunately, our system's Maquet Magnus surgical table coupled with ARTIS Zeego® in our centre is unable to flex, so that we need to put a wedge-shaped cushion beneath the chest in order to facilitate thoracic rib separation during surgery (19). ARTIS Pheno®'s multi-tile table likely allows adequate flexion required for standard VATS surgery. The fluoroscopy image quality has also been upgraded to live 2k images, enabling the operator a better appreciation of faint small lesions, which would be crucial for various localization procedures, for instance needle placement during percutaneous route or during electromagnetic navigation bronchoscopy (20). Other upgrades include a 15% faster scan time to reduce contrast injection and motion artifacts, but are probably less relevant to thoracic surgical practice.

Cheng *et al.* should be congratulated on their article, sharing with us their latest experience with ARTIS Pheno® in thoracic surgery. The upgrade to ARTIS Pheno® seem enticing as the larger working space provides hassle-free positioning and shortens procedural time, such that the hybrid procedure can be more intuitive and user-friendly. However, the benefits of an upgrade have to be balanced against the financial cost, thus future studies comparing the two ARTIS models shall be informative, for instance the number of CT scans and radiation exposure required for localization procedure, the localization time, localization-to-incision time, etc. It would also be interesting for the groups with access to ARTIS Pheno® to report their experience with other thoracic procedures, for example electromagnetic navigation bronchoscopy or virtual bronchoscopy. We look forward to an innovative era where early stage lung cancers are treated with precise localization followed by minimally invasive resection in a streamlined hybrid protocol.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <http://dx.doi.org/10.21037/jtd-2020-50>). CSHN reports other from Siemens Healthineer, Germany; other from Johnson and Johnson, USA; other from Medtronic, USA, during the conduct of the study. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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