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Vessel suppressed chest Computed Tomography for semi-automated volumetric measurements of solid pulmonary nodules

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ABSTRACT

Objective: To evaluate whether vessel-suppressed computed tomography (VSCT) can be reliably used for semi-automated volumetric measurements of solid pulmonary nodules, as compared to standard CT (SCT)

Material and methods: Ninety-three SCT were elaborated by dedicated software (ClearRead CT, Riverain Technologies, Miamisburg, OH, USA), that allows subtracting vessels from lung parenchyma. Semi-automated volumetric measurements of 65 solid nodules were compared between SCT and VSCT. The measurements were repeated by two readers. For each solid nodule, volume measured on SCT by Reader 1 and Reader 2 was averaged and the average volume between readers acted as standard of reference value. Concordance between measurements was assessed using Lin's Concordance Correlation Coefficient (CCC). Limits of agreement (LoA) between readers and CT datasets were evaluated.

Results: Standard of reference nodule volume ranged from 13 to 366 mm^3. The mean overestimation between readers was 3 mm^3 and 2.9 mm^3 on SCT and VSCT, respectively. Semi-automated volumetric measurements on VSCT showed substantial agreement with the standard of reference (Lin's CCC = 0.990 for Reader 1; 0.985 for Reader 2). The upper and lower LoA between readers' measurements were (16.3, -22.4 mm^3) and (15.5, -21.4 mm^3) for SCT and VSCT, respectively.

Conclusions: VSCT datasets are feasible for the measurements of solid nodules, showing an almost perfect concordance between readers and with measurements on SCT.

1. Introduction

The number of solid pulmonary nodules detected at computed tomography (CT) examinations increased since the introduction of multidetector scanners [1]. In the lung cancer screening setting only a small percent of nodules represented lung cancers [2,3] and most nodules are of uncertain significance (i.e. "indeterminate") at the time of detection, requiring further evaluation [4]. Among morphologic features, the management mainly relies on diameter and growth rate, as size is the main predictor of malignancy [5,6]. Manual measurement of diameter is currently the most widespread technique to assess dimensions, although it shows inferior reproducibility than volumetric measurement [7–10]. Furthermore, nodules may grow asymmetrically, a pattern that can be difficult to detect with manual measurements alone [11]. Precision and accuracy are mandatory for the evaluation of pulmonary nodules to produce consistent management recommendations [12] and semi-automated volumetric measurements were shown to be accurate and repeatable [13]. Nevertheless, visual perception and semi-automated volumetric measurements depend on both scanning parameters [14,15] and nodule features (i.e. nodules that are ill-defined or adjacent to vessel walls are prone to overestimation) [16]. Without vessels altering the actual outline of solid nodules, overestimation of their volume might be less frequent, and measurements may be more reproducible among readers.

The aim of this study was to test if a dedicated software capable of removing vessels in chest CT, thus producing datasets hereinafter termed "vessel-suppressed CT" (VSCT)" can reliably be used for semi-automated volumetric measurements of solid nodules. Furthermore, we aimed to evaluate the consistency of volumes derived from VSCT compared with those of standard CT datasets (SCT).

Abbreviations: CAD, computer-aided detection; CCC, concordance correlation coefficient; CI, confidence interval; CT, computed tomography; SCT, standard CT; VSCT, vessel-suppressed CT

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2. Material and methods

2.1. Study population

In this retrospective study 93 consecutive patients referred to our department for clinical non-enhanced chest CT between August 2014 and February 2015 were included. The study population comprises patients that underwent single-energy helical chest CT scans with low-dose scanning protocol. The study was approved by institutional review board and local ethics committee. Written informed consent was waived due to retrospective setting.

2.2. Chest CT scan protocol

Low-dose CT scans were acquired with a third generation 192-slice Dual-Source scanner (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) equipped with an integrated high-resolution circuit detector (Stellar Technology; Siemens Healthcare) using a tin filter. Scan parameters were as follows: 100 kVp with a quality reference tube current-time product of 45 mAs, pitch of 1.2, collimation of 96 × 0.6 mm and a gantry rotation time of 0.5 s. The image matrix was 512 × 512 pixels. Images were reconstructed using a slice thickness of 2 mm, an increment of 1.6 mm with a sharp tissue convolution kernel (Bl64) and advanced modelled iterative reconstruction (ADMIRE) using strength level 3, as used in the clinical setting of our department.

2.3. CT post-processing

CT post-processing was performed using the commercially available software ClearRead CT (Riverain Technologies, Miamisburg, Ohio). Briefly, ClearRead CT is an advanced image analysis and machine learning software capable of normalizing various scanning parameters and able to isolate lungs and airways. Subsequently, it segments and removes vascular, bronchial and fissural structures. Finally, the software produces a new CT dataset (Fig. 1) used to highlight solid nodules (Fig. 2).

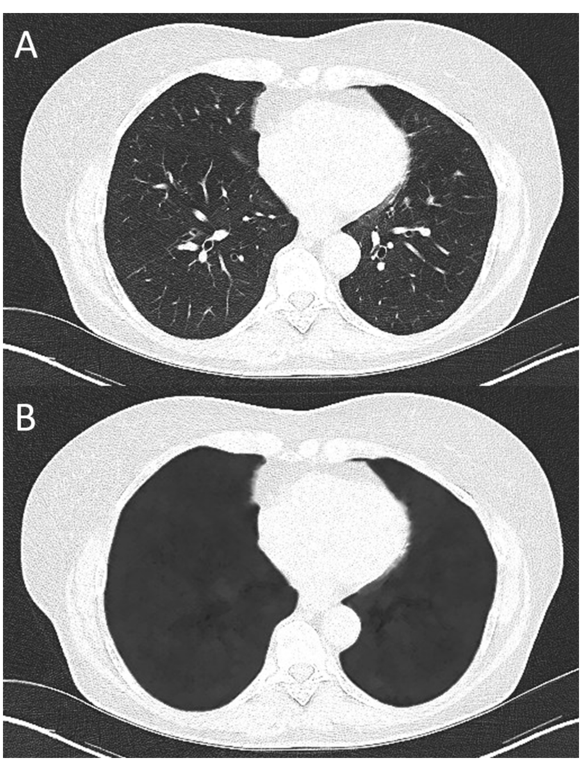

Fig. 1. Axial CT image and corresponding vessel suppressed image.

2.4. Image analysis

SCT and VSCT were transferred to a workstation (Syngo.via TM, Siemens Healthcare) and reviewed using dedicated computer aided detection (CAD) software (MM Oncology, Siemens Healthcare) on axial and multiplanar reconstruction (MPR) images. Images were analysed with standard lung window (window level, WL: 700 HU; window width, WW: 2000 HU).

Solid nodules – defined as homogeneous soft-tissue attenuation nodules – were detected on SCT by Reader 1 (GM, board certified radiologist with 3 years of experience in chest CT) and dedicated software (MM Oncology) [17]. The software acted as second reader [18] and was used for semi-automated volumetric measurements. Reader 1 evaluated all findings assigning a 5-point Likert score as follows: (1, no nodule; 2, no confident nodule; 3, probable nodule; 4, more definite nodule; 5, definite nodule). Only findings with a score of 3 or higher were included. The location of each nodule was evaluated, namely subpleural/perifissural, peripheral (nodules located in the pulmonary parenchyma within 2 cm from the pleura) and central nodules. Furthermore, the contact with an adjacent vessel was recorded when present. Spatial coordinates and table position were recorded to allow for future nodule matching.

Reader 1 and Reader 2 (IVDM, radiology resident with a cumulative 1 year of experience in chest CT) independently performed semi-automated segmentations for solid nodules, on both SCT and VSCT. The measurements were first performed on SCT. By clicking in the centre of the nodule the software automatically assessed nodule size. Results of semi-automated measurements (i.e. longest diameter, maximum orthogonal diameter, volume) were independently reviewed by two readers to detect potential overestimations. If needed, each reader manually corrected the margins of the solid nodules to include only actual margins (Fig. 3). Subsequently, the same measurement procedures were repeated on VSCT by each reader, independently and blinded to the SCT measurements. After the independent reading performed by the two readers, volumes and longest diameters measured on SCT by Reader 1 and Reader 2 for each nodule were averaged and the resulting values acted as standard of reference. For further analysis only solid nodules with a standard of reference volume $< 400\,mm^3$ (the latter being the volume of a sphere with a diameter of 9 mm) were included.

2.5. Nodule management

The suggested management for each solid nodule was derived from the Fleischner Society Guidelines, according to the cut-off proposed for volumetric measurements (i.e. $< 100\,mm^3$, $100–250\,mm^3$ and $> 250\,mm^3$) [7].

2.6. Statistical analysis

Normality of data distribution was assessed by Shapiro-Wilk test. Normally distributed variables were reported as mean and standard deviation (SD), non-normally distributed variables were reported as median and inter-quartile range (IQR). Categorical variables were reported as frequencies and percentages. To determine the reliability between the performed measurements, Lin's concordance correlation coefficient (CCC) was calculated between each pair of variables. Lin's CCC assesses how close measurements are about the line of best fit and how far that line is from the 45° line through the origin [19]. According to the thresholds proposed by McBride, values between 0.950 and 0.990 were interpreted as index of substantial agreement, whereas values above 0.990 were interpreted as index of an almost perfect agreement [20].

The method published by Bland and Altman was used to assess