Original article

Multipurpose computed tomography window for fusion display with functional imaging

ABSTRACT

Current positron emission tomography/computed tomography (PET/CT) and single photon emission CT (SPECT)/CT displays have major drawbacks, in that the CT only shows one tissue type at a time, which leads to a suboptimal fusion display. We developed a multipurpose CT level/window aiming at enhancing fusion display. A total of thirty CT examinations as part of fluorodeoxyglucose PET/CT examinations (15 were open source from the OsiriX website and 15 from our PET facility) and the open-source software MIPAV were used. During the development phase, a nuclear medicine physician manually modified the lookup table in a way that preserved the soft tissue contrast as well as enhanced the lung and bone tissue as much as possible. The developed multipurpose CT window was used in the subsequent validation phase and scored by two nuclear medicine physicians, who scored the image quality based on a 3-point score. Descriptive statistics was used to summarize the visual scores. The multipurpose CT window is a composite of several segments of linear CT levels/windows and contains an inverted linear level/window in the low range of Hounsfield unit designed to enhance lung/soft tissue contrast. In doing so, the multipurpose CT window preserves the high soft tissue contrast; the visualization of the lung parenchyma is satisfactory; the contrast for the bone tissue is improved but remains suboptimal when compared with conventional bone window. The multipurpose CT window was found to be "very useful" (median score 3; 95% confidence interval [CI] 2.0–3.0) for the purpose of fusion with functional imaging, with a prevalence asymmetry index 0.97 (95% CI 0.83–1.0). The multipurpose CT window was developed for image fusion and is not intended for diagnostic purposes. It shows favorable similarities to conventional CT windows with only minor artifacts and allows for enhanced visualization of fused PET/CT and SPECT/CT images. The multipurpose CT window is particularly valuable for case review/demonstrations on standard personal computers and handheld devices (smartphones, tablets).

Keywords: Computed tomography level/window, fusion display, Hounsfield units, positron emission tomography/computed tomography, single photon emission computed tomography/computed tomography

INTRODUCTION

Multimodality imaging, such as positron emission tomography/computed tomography (PET/CT), combines functional imaging (PET) with anatomical imaging (CT). Multimodal imaging is commonly used to diagnose cancer and other disorders and plays a major role in diagnostic radiology. The advantage of multimodality display is the ability to overlay (fuse) functional and anatomical images in a visually compelling fashion that allows for the proper visualization and characterization of findings. Functional imaging such as F-18 fluorodeoxyglucose (FDG) PET imaging is indiscriminate of the type of tissue structures being shown while CT image display usually requires a selective lookup table (LUT) because of the limited 256 grayscale levels that cover the wide dynamic range of Hounsfield unit (HU) from −1032 to +3074.[1] A clinically useful LUT has a suitable range of HU depending on the tissue being evaluated. As a result, the current display of multimodality imaging (PET/CT and single

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Access this article online	
	Quick Response Code
Website: www.wjnm.org	
DOI: 10.4103/wjnm.WJNM_34_17	

How to cite this article: Nguyen NC, Vejdani K. Multipurpose computed tomography window for fusion display with functional imaging. World J Nucl Med 2018;17:145-50.

photon emission CT [SPECT]/CT) has major drawbacks, in that the CT only shows one tissue type at a time (e.g., soft tissue, lung, or bone), which leads to a suboptimal fusion display.[2] It is desirable to have a CT window capable of displaying all tissue types, including lung, soft tissue, and bone simultaneously. We seek to develop a "multipurpose CT window capable of displaying as many tissue types as possible, which is intended for fusion with functional imaging and to improve the visualization of fused datasets."

MATERIALS AND METHODS

Subjects

Open-source FDG PET/CT data from nine subjects with 15 associated contrast-enhanced and unenhanced CT examinations were downloaded from the OsiriX viewer website (http://www.osirix-viewer.com/datasets/).[3] Additional 15 FDG PET/CT cases were retrieved from our PET facility with the approval from the Institutional Review Board, which waived the requirement for consent. Of the total 30 CT examinations, 16 were diagnostic quality with intravenous contrast media, and 14 were low-dose without contrast media, which was intended to keep a balance between enhanced and unenhanced CT cases [Table 1]. The open-source software MIPAV version 5.4.4 – Medical Image Processing, Analysis and Visualization; Center for Information Technology, National Institutes of Health (http://www.mipav.cit.nih.gov) – was used for the development and validation of the multipurpose CT window.[4]

Development phase

Five CT datasets (two diagnostic CT and three nondiagnostic CT) from six different subjects were used for the development phase. The DICOM files were loaded into the MIPAV software. Using the LUT tool embedded in MIPAV, the standard 256 grayscale levels were used to display the dynamic range of the CT data.[1] A board-certified nuclear medicine physician with more than 10 years of experience in PET/CT scanning and interpretation opened the same CT dataset twice and displayed them side-by-side. One dataset was used as a reference to display the conventional settings (lung, mediastinum, and bone) while the other

Table 1: Scan parameters of the 30 computed tomography examinations

ID number	IV contrast	Body section	Manufacturer	Scanner name	Slice thickness (mm)	kVp	Exposure (mAs)
1	Yes	Skull base to upper thigh	Siemens	Emotion Duo	5	130	110
2	No	Brain	Siemens	Sensation 16	1	120	320
3	No	Skull base to mid chest	Siemens	Emotion Duo	5	130	130
4	No	Skull base to upper thigh	Siemens	Sensation 16	2	120	135
5	Yes	Abdomen, pelvis (arterial phase)	Siemens	Sensation 16	2	120	167
6	Yes	abdomen, pelvis (venous phase)	Siemens	Sensation 16	2	120	168
7	Yes	Heart (arterial phase)	Siemens	Sensation 64	3	120	881
8	Yes	Heart (arterial phase)	Siemens	Sensation 64	0.6	120	881
9	No	Top of head to upper thigh	Siemens	Biograph 64	2	120	118
10	No	Top of head to toes	Siemens	Sensation 16	2	120	57
11	No	Head, neck plus upper extremities	Siemens	Sensation 16	2	120	64
12	Yes	Chest, abdomen (arterial phase)	Siemens	Sensation 16	3	120	110
13	Yes	Abdomen, pelvis (venous phase)	Siemens	Sensation 16	3	120	77
14	No	Skull base to upper thigh	Siemens	Sensation 16	3	120	149
15	No	Top of head to upper thigh	Siemens	Sensation 16	2	120	276
16	Yes	Skull base to upper thigh	GE medical systems	Discovery 710	3.75	120	398
17	Yes	Skull base to upper thigh	GE	Discovery 710	3.75	120	325
18	No	Skull base to upper thigh	GE	Discovery 710	3.75	120	79
19	No	Skull base to upper thigh	GE	Discovery 710	3.75	120	104
20	No	Skull base to upper thigh	GE	Discovery 710	3.75	120	79
21	No	Skull base to upper thigh	GE	Discovery IQ	3.75	120	90
22	Yes	Top of head to pelvis	GE	Discovery 710	3.75	120	99
23	No	Skull base to upper thigh	GE	Discovery IQ	3.75	120	90
24	No	Skull base to upper thigh	GE	Discovery IQ	3.75	120	90
25	Yes	Top of head to pelvis	GE	Discovery 710	3.75	120	99
26	Yes	Skull base to upper thigh	GE	Discovery 710	3.75	120	160
27	Yes	Skull base to upper thigh	GE	Discovery 710	3.75	120	390
28	Yes	Skull base to upper thigh	GE	Discovery 710	3.75	120	398
29	Yes	Skull base to abdomen	GE	Discovery 710	3.75	120	143
30	Yes	Skull base to upper thigh	GE	Discovery 710	3.75	120	398

IV: Intravenous

dataset was used to develop the multipurpose CT window. An operator studied the impact of level/window changes on the CT images empirically. Using the cursor, the operator had the freedom to add or delete the display curves as well as to modify the window settings by moving the X (dynamic range of HU) and Y (grayscale) coordinates within the LUT. Given the greatest abundance of soft tissue and organ tissue in the human body, the goal was to maintain the high contrast of soft tissue compared with the conventional mediastinal setting while enhancing the lung tissue/air and bone tissue as much as possible. The MIPAV software has the advantage that it allows a free manipulation of CT levels/windows with a real-time display of image results, allowing for a quick and easy exploration of image manipulations. Multiple trials and errors were undertaken by modifying the levels/windows as well as assembling different patterns of levels/windows until the operator was satisfied with the CT results, which was called "multipurpose CT window." The parameters of the multipurpose CT window were documented and then used in the subsequent evaluation phase.

Evaluation phase

Two physicians (rater #1 and #2) with clinical PET/CT experience, one of which was instrumental for the development phase, loaded each of the 30 CT examinations in MIPAV, including the one previously used during the development phase. The multipurpose CT window was displayed side-by-side to the conventional mediastinal setting, lung setting, and bone setting, which served as a reference. The physicians scored the image quality of multipurpose CT as compared to the conventional mediastinal setting, lung setting, and bone setting each using the following 3-point system (1 = not satisfied; 2 = satisfied; 3 = very satisfied). Finally, they scored the usefulness of multipurpose CT for fusion with functional data (1 = not useful; 2 = useful; 3 = very useful).

Statistical analysis

Descriptive statistics (median, minimum–maximum; 95% confidence interval [CI]) were used to summarize the visual scores. The inter-rater agreement was assessed using weighted kappa or the Byrt's Prevalence Asymmetry Index when the use of weighted kappa was inappropriate. The statistical software MedCalc 12.7.1 (MedCalc Software) and DAG_Stat spreadsheet were used.[5]

RESULTS

CT scan parameters including slice thickness, kVP, and mAs are shown in Table 1. A distinct composite of CT levels/windows was found to be appropriate for the multipurpose window [Figure 1]. It is characterized by a composite of nonlinear levels/window settings that covers the full spectrum of dynamic HU as well as grayscale levels, as opposed to the selective, linear level/window setting in a conventional display. Furthermore, the composite setting contains an inverse level/window at −400–−130 HU designed to enhance the lungs as well as provide better a better separation of lungs and soft tissue.

Representative images of the chest with and without intravenous (IV) contrast media at CT as well as the abdomen without IV contrast media are shown in Figures 2-4. With both raters combined, the multipurpose window scored "very satisfied" (median 3, range 3–3; 95% CI 3.0–3.0) compared with the soft tissue setting; "satisfied" (median 2, range 2–3; 95% CI 2.0–2.0) compared with the lung setting; and "not satisfied" (median 1, range 1–3; 95% CI 1.0–1.0) compared with the bone setting. The

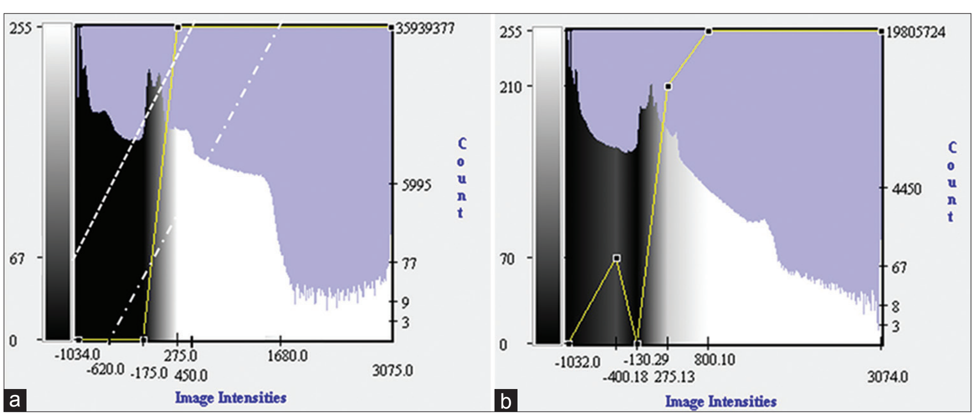

Figure 1: (a) Three predefined lookup tables in MIPAV are shown for lung setting (dash line), mediastinum setting (solid line), and bone setting (dash-dot line). (b) Multipurpose lookup table is composed of three linear window settings and one inverted window setting between Hounsfield unit −130 and −400, which is necessary to separate soft tissue from air structures. The description of the traditional level/window is not appropriate for the multipurpose lookup table because it is composed of multiple lookup tables. Therefore, the X and Y coordinates (Hounsfield unit/grayscale) are provided from the lowest to the highest Hounsfield unit: (−1034/0); (−400/70); (−130/0); (275/210); (800/256)

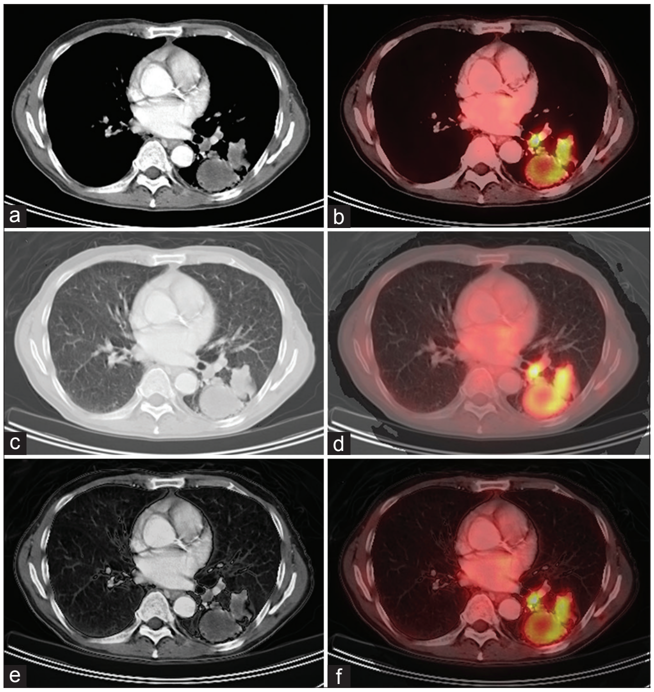

Figure 2: Fluorodeoxyglucose positron emission tomography/computed tomography examination with diagnostic computed tomography quality and intravenous contrast media (source: OsiriX website). (a) Mediastinal window; (b) fused mediastinal window/positron emission tomography; (c) lung window; (d) fused lung window/positron emission tomography; (e) multipurpose window; (f) fused multipurpose window/positron emission tomography. With multipurpose computed tomography (e and f), the anatomical details of the fluorodeoxyglucose avid left lower lobe pulmonary lesions and soft tissue structures (e.g., mediastinum, vessels, muscles) are preserved; the visualization of the pulmonary lesions against the surrounding parenchyma is enhanced compared with a and b; thin lines of artifacts at air and soft tissue interface (along the pleura and bronchi) are minimal and do not limit the visualization of findings

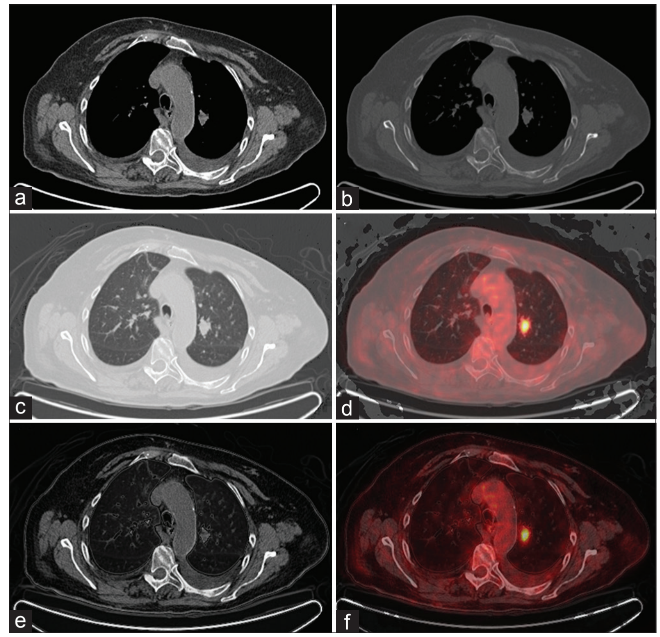

Figure 3: Fluorodeoxyglucose positron emission tomography/computed tomography examination with unenhanced computed tomography (source: OsiriX website). (a) Mediastinal window; (b) bone window; (c) lung window; (d) fused lung window/positron emission tomography; (e) multipurpose window; (f) fused multipurpose window/positron emission tomography. With multipurpose computed tomography (e and f), the anatomical delineation of the fluorodeoxyglucose avid left upper lobe pulmonary opacity is preserved; the visualization of the lung opacity against the surrounding parenchyma is enhanced compared with a and b; bilateral posterior pleural effusion is well delineated against the lung parenchyma and chest wall; thin lines of artifacts at air and soft tissue interface (along the pleura and bronchi) are minimal and do not limit the visualization of findings; anatomical details of bone tissue are improved compared with mediastinal window (a) but are suboptimal compared with bone window (b)

raters scored the multipurpose CT window "very useful" (median 3, range 2–3; 95% CI 2.0–3.0) for the purpose of fusion display. The score results of individual raters are summarized in Table 2. The agreement between the two raters was excellent regarding soft tissue comparison (prevalence asymmetry index 1.0, 95% CI 1.0–1.0); good regarding lung tissue comparison (weighted kappa 0.67, 95% CI 0.45–0.9); moderate regarding bone tissue comparison (weighted kappa 0.57, 95% CI 0.26–0.88); and very good regarding the usefulness of multipurpose CT window for fusion display (prevalence asymmetry index 0.97, 95% CI 0.83–1.0).

Table 2: Summary of visual scores of Rater #1 and Rater #2

	Soft tissue	Lung tissue	Bone tissue	Image fusion
Rater #1				
Median (lowest-highest)	3 (3-3)	2 (1-3)	1 (1-2)	3 (3-3)
95% CI	3.0-3.0	2.0-3.0	1.0-1.8	3.0-3.0
Rater #2				
Median (lowest-highest)	3 (3-3)	2 (1-3)	1 (1-2)	3 (2-3)
95% CI	3.0-3.0	2.0-2.8	1.0-1.0	3.0-3.0

CI: Confidence interval

DISCUSSION

We have developed a multipurpose CT level/window that allows the visualization of most tissue structures and is especially useful for image fusions such as PET/CT and SPECT/CT. The advantage of multipurpose CT window is the preservation of soft tissue details, in both unenhanced and enhanced CT images, while allowing satisfactory visualization of lung tissue, and to a lesser degree of the bone tissue, compared with the conventional level/window settings. The successful preservation of the soft tissue is supported by the excellent agreement between the two raters. The less favorable inter-rater agreements for the bone tissue and lung tissue (albeit moderate and good) may be explained by the imaging appearance in areas with highly variable dynamic range such as air/lung nodule and bone marrow/cortex. Finally, both raters highly agree on the potential value of multipurpose window for image fusion.

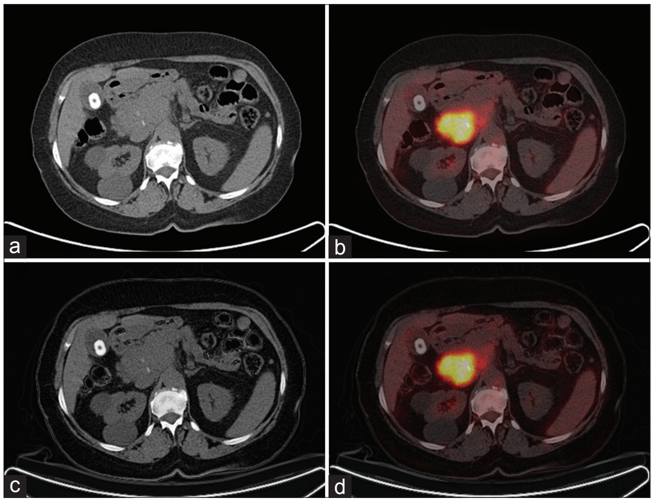

Figure 4: Fluorodeoxyglucose positron emission tomography/computed tomography examination with unenhanced computed tomography (source: OsiriX website). (a) Mediastinal window; (b) fused mediastinal window/positron emission tomography; (c) multipurpose window; (d) fused multipurpose window/positron emission tomography. With multipurpose window (c and d), the anatomical details of the physiologic soft tissue structures (e.g., liver, spleen, and renal cysts) as well as the precaval mass are preserved; thin lines of artifacts outlining the air space of the large bowel are minimal and do not limit the visualization of findings

The concept of multiple linear or nonlinear CT windowing is not new. John *et al*.[6] used a bilinear approach aiming at improving the display of the chest. In imitating that window setting with one of our subjects, we found a significant loss of soft tissue information although the lung display is satisfactory. Gomori and Steiner[7] devised a double window approach consisting of an "inverted" linear window for the lung/air and a bi‑sloped window for the soft tissue. Their approach is most consistent with our approach, but the significant difference lies in the lowest dynamic range before the inverted window. In their approach, they assigned the maximum display intensity (grayscale level 256) across the very low dynamic range, while our approach builds in a linear slope with a maximum grayscale level of 70 [Figure 1]. In simulating the window setting by Gomori and Steiner[7] with one of our cases, we found that the lung tissue and air appear bright compared with the soft tissue, which would cause a loss of contrast between the lung and soft tissue resulting in suboptimal detection of lung opacities. In the current multipurpose window, lung opacities can be easily distinguished from the lung parenchyma. Moreover, the soft tissue contrast is preserved while image artifacts are kept to a minimum, making the multipurpose more suitable for image fusion. The developed multipurpose CT window is the most complex LUT to date, yet it shows favorable similarities to conventional window settings with only minor artifacts. Other researchers have used a different method called "adaptive histogram equalization" in an attempt to enhance tissue visualization across the dynamic HU range, but this approach is associated with a loss of soft tissue contrast as well as an increase in image noise.[8,9]

The multipurpose CT window has been developed as a complementary window setting for fusion display and is not intended for diagnostic purposes. Its implementation is simple and does not require image processing. It may not have significant value during diagnostic read because a radiologist will have all the conventional CT window settings available for the interpretation, and the fused data may be adjusted to individual CT window settings. The multipurpose CT window, however, may have added value in certain situations because of its strengths in revealing the anatomical relationship in lesions or areas with high tissue contrast. For example, it may help distinguish a pulmonary tumor lesion from adjacent atelectasis or postobstructive pneumonia; a pleural‑based mass lesion from adjacent nonspecific pleural thickening; or enhance the visualization of a bone mass lesion with a soft tissue component. Most notably, the multipurpose window will be highly valuable for scenarios outside of radiology offices, such as case review on personal computers (PCs) during professional conferences and in medical offices as well as on handheld devices (smartphones, tablets). With the use of the multipurpose window, pertinent PET/CT or SPECT/CT findings can be shown in an easy way without the need for switching between CT window settings, which is convenient and does not disrupt the imaging review process. It helps avoid cumbersome human‑computer interactions and does not require a familiarity with display tools. Therefore, a fusion display with multipurpose CT window may be the most efficient way to demonstrate combined PET/CT findings without the need for large or multiple screens/monitors. It may also allow for an easy comparison of serial PET/CT data, which accounts for the majority of PET/CT examinations. As a result, multipurpose CT window has the potential to improve the quality of imaging service and may have a positive impact on patient care as well as patient satisfaction.

Another advantage of multipurpose CT is related to the potential saving of data storage in picture archiving and communication system. Currently, most fused data are being stored using the abdomen or mediastinum CT window because most findings related to oncologic and neurological PET/CT or SPECT/CT imaging are located within the soft tissue. However, an additionally fused dataset using lung CT window is frequently generated and archived to be able to demonstrate findings within the lungs. Therefore, image fusion using the multipurpose window may not only help reduce storage data but also have a positive impact on faster image retrieval because of the smaller data volume being retrieved. Potentially, multipurpose CT window may be relevant for zero footprint radiology where the image archive and review are entirely cloud based without the need for additional software installation at the local computer.[10]

The main limitation of multipurpose CT window is that it is not appropriate for diagnostic interpretation. The modification of the dynamic HU range results in minor artifacts at adjoining structures of high contrast which mainly affects border areas between lung tissue or air and soft tissue. However, they are not being perceived as disturbing. The composition of several segments of linear windows, as well as the insertion of an inverse linear window setting, does not affect the intrinsic noise or spatial resolution of the CT data, but the signal-to-noise ratio may be affected.[11] As the current work is the first step to any formal adoption of the proposed method, we did not assess for diagnostic accuracy in terms of sensitivity and specificity. Given the intended purpose for image fusion, the visual evaluation of image quality as provided in the current study appears sufficient.

CONCLUSIONS

The multipurpose CT window was developed for image fusion and is not intended for diagnostic purposes. It shows favorable similarities to conventional CT windows with only minor artifacts and allows for an enhanced visualization of fused PET/CT and SPECT/CT images. Although the multipurpose CT window plays no significant role in diagnostic interpretation, it is particularly valuable for case review/demonstrations on standard PCs and handheld devices (smartphones, tablets) and has the potential to improve patient–physician communication.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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