Computed tomography based assessment of programmable shunt valve settings

Thomas Decramer\textsuperscript{a,b,1,*}, Steven Smeijers\textsuperscript{a,1}, Michaël Vanhoyland\textsuperscript{a,b}, Walter Coudyzer\textsuperscript{c}, Frank Van Calenbergh\textsuperscript{a,b}, Johannes van Loon\textsuperscript{a,b}, Philippe De Vloo\textsuperscript{a,b}, Tom Theys\textsuperscript{a,b}

\textsuperscript{a} Department of Neurosurgery, University Hospitals Leuven, Leuven, Belgium
\textsuperscript{b} Research Group Experimental Neurosurgery and Neuroanatomy, KU Leuven and the Leuven Brain Institute, Leuven, Belgium
\textsuperscript{c} Department of Radiology, University Hospitals Leuven, Leuven, Belgium

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ABSTRACT

Introduction: Programmable shunt valve settings can sometimes be difficult to assess using classic read-out tools, warranting a skull X-ray.

Research question: Can we use available head computed tomography (CT) scans to determine the valve settings, in order to obviate the need for additional skull X-rays?

Material and methods: The valve setting of two different programmable shunts (Codman Certas Plus\textsuperscript{®} and Sophysa Polaris\textsuperscript{®}) were assessed by two blinded observers in 24 patients using 65 head CT scans (slice thickness ≤2 mm).

Using multi-planar reconstruction (MPR) tools, images were resliced according to the direction of the valve, allowing a direct readout of the valve settings. We validated our CT based method against 32 available skull X-rays.

Results: For all CT scans it was possible to assess the valve setting. No interobserver variability was found and there was a 100 % concordance between the CT based method and skull X-rays.

Discussion: CT based assessment of programmable shunt valve settings is feasible and reliable. It may obviate the need for additional skull x-rays when a head CT scan is available.

Conclusions: This technique can reduce radiation exposure and can be applied to historical CT imaging with unknown valve settings.

1. Introduction

Programmable neurosurgical shunt valves are increasingly used (Xu et al., 2013). The valve settings can be read out and adjusted bedside using magnet-based tools. For correct clinical decision making, exact knowledge of the current and sometimes also previous valve setting is indispensable. However, bedside read-outs and/or adjustments can be difficult, cumbersome, painful and user-dependent. Therefore, the gold standard to confirm the valve setting remains a skull x-ray perpendicular to the valve (Lollis et al., 2010). Obtaining a perfect X-ray image for reliable read-outs can be difficult due to patient-related factors (e.g. in children, developmentally delayed or hyperkinetic patients) or due to the setting (e.g. on ICU). Even in cooperative ambulatory patients, an additional x-ray represents an extra examination, cost and radiation dose. Furthermore, when only historical computed tomography (CT) or magnetic resonance imaging (MRI) scans are available, but valve X-rays have not been acquired systematically, one has to rely on the notes to know the valve settings at that time.

We recently came across the possibility to determine the settings of programmable shunt valves from standard clinical head CT images. Herein, we describe three CT post-processing techniques for this goal, one using surgical navigation software, one using the software in the CT scan suite itself and one using a standard DICOM viewer. Further, we validated this novel technique against the standard valve X-ray and discuss the potential advantages of implementing this method.

2. Methods

We performed a literature search through the Medline database using the terms: computed tomography, programmable valve and setting. We
did not find any previous studies demonstrating the use of CT to determine the valve setting of programmable valves.

We retrospectively studied 24 patients with a programmable shunt valve who had at least one follow-up head CT scan between 1 and 11–2018 and 10-08-2020 at University Hospitals Leuven. During this period, two different valves were used (Codman Certas Plus (Integra Lifesciences, Plainsboro, NJ; n = 11) and Sophysa Polaris (Sophysa, Orsay, France; n = 13)). Study protocol S64590 was approved by the local IRB (Ethische commissie onderzoek UZ / KU Leuven) and was conducted in compliance with the principles of the Declaration of Helsinki (2008), the principles of good clinical practice (GCP), and in accordance with all applicable regulatory requirements. Patients were informed of the study through their electronic medical file, formal informed consent was not deemed necessary by the local IRB.

2.1. CT-based shunt valve setting read-out

Initially, we transferred the thinnest available (range 0.5–2 mm, median 1 mm) native axial bone-window head CT images (Siemens, Forchheim, Germany) to the neuronavigation software (Brainlab iPlan

![Fig. 1. CT based assessment of valve settings. The blue trajectory along the valve-axis and the yellow trajectory along the valve mechanism are depicted in the right panels (see Methods). For the Codman Certas plus valve, it is essential to delineate the radio-opaque reference marker (red dot) and the T-shaped part of the valve mechanism (green rectangle). The CT image shows a valve in position 4, which was confirmed by skull X-ray. For the Sophysa Polaris valve, it is essential to recognize the different radio-opaque markers and the axis of the valve mechanism. The CT shows a valve in position 3, which was also confirmed by skull X-ray. An overview of the valve settings is shown for both valve types. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)](image)
3.0 Cranial, Munich, Germany).

By using the *trajectory* feature, we defined an entry at the proximal end of the valve, and a target at the distal end of the valve (Fig. 1, CT based assessment, blue line). A second trajectory was created along the valve mechanism (Fig. 1, CT based assessment, yellow line). Using the *probe view* option of the trajectory feature, perpendicular views to these trajectories were created, which can be used to determine the valve settings (Fig. 1, CT based assessment). For a complete step-by-step guide for both valve types using the Brainlab software, see supplementary information.

Later, we obtained similar reconstruction images directly from the scan suite software (Siemens) (Fig. 2A). Using a more generic approach, we demonstrate the multi-planar reconstructions (MPR) using a basic DICOM viewer program (RadiAnt; Medixant, Poznan, Poland) (Fig. 2B–C).

2.2. **Cross validation study**

For each CT scan (n = 65), we performed a CT-based valve setting read-out as described above. The CT based valve setting was independently assessed by two blinded observers (neurosurgical residents SS and MV). If a skull X-ray was available (n = 32), the valve settings was derived from the X-ray by both observers in a blinded fashion (for the other observer and for their own CT based assessment). We rated the interobserver variability and the concordance between the CT based method and skull X-ray.

2.3. **Statistical analysis**

We used Kappa (Fleiss’ kappa) statistics for both the comparison to the golden standard as the interobserver variability. Use of kappa statistics has been criticized, because the basic assumptions underlying the calculations rely on observer independence (Kraemer and Bloch, 1988). We therefore blinded both observers (the residents) from the results of each other and from the other modality, and presented the scans/x-rays in a random order which differed between both residents.

3. **Results**

For all CT scans (n = 65) it was possible to assess the valve setting

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Fig. 2. Direct reconstructions in the CT scan suite and multiplanar reconstructions using DICOM viewer. (A) Direct reconstructions in the CT scan suite of a Sophysa Polaris valve. The green lines indicate the 5 different markers which can be seen on the resliced CT scan images. As these markers are not in the same plane as the valve mechanism, we need to scroll through different slices to determine the valve setting, indicating the valve mechanism at position 2. (B–C) Reconstructions of a Codman Certas Plus valve, using DICOM viewer RadiAnt. On the classically oriented clinical head CT (B), we put the crosshair on the valve mechanism, see axial slice. We now can reorient the images by angling the purple-blue cross until it is perpendicular to the valve mechanism as in (C), see arrow on axial slice. By scrolling through the images perpendicular to the valve (perpendicular 2) we can recognize the radio-opaque marker and the valve mechanism which is at position 4 (see inset, *). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
4. Discussion

In this report, we describe a novel way to assess the settings of programmable valves using a CT based method. This method allowed to assess the valve settings in all patients, with no interobserver variability and with a perfect correlation to the current gold standard, a skull X-ray.

It is important to note that the method is based on performing specific multi-planar reconstructions (MPR) of a native head CT. These MPR can be performed using a variety of software packages, we choose to use a server based neuronavigation package, as this is accessible through every computer in our hospital. In some centers MPR functionality is embedded in the PACS viewer, which clearly facilitates the workflow and processing speed.

In addition to reconstructions performed by the surgeon, the workflow can be simplified by creating reconstructions directly in the CT scan suite. The advantage of the latter method is that (a) it can be immediately performed by the CT operator, and (b) that these images can be exported to the PACS as a separate series of the CT examination, facilitating later interpretations. One can think of a hospital-wide protocol in which every CT scan in a patient with an adjustable shunt valve is processed to obtain this extra series. Additionally, image processing scripts could be developed to recognize the valve type and valve settings automatically.

In some cases, one can determine the valve setting based on the scout-view of the CT scan or on a sagittal CT reconstruction. This is of course only the case when these acquisitions or reconstructions are made perpendicular to the valve.

A skull X-ray remains the first choice to determine valve setting if no head CT is available, however there are several advantages that come with the use of CT to determine the valve setting when these images are already available. First, this obviates the need for bedside read-outs, which can be cumbersome, painful, inconsistent and subjective. Second, this obviates the need for an additional skull X-ray, which decreases the burden, cost and radiation exposure for the patient. A third important advantage of this technique is that it can be applied to historical CT imaging to determine the shunt valve setting even when no skull X-ray was performed or no reliable note was made in the patient charts at that time. Finally, if the reconstructed images are added as a separate series to the CT examination in the PACS, one exam contains all necessary information.

The main limitations of the technique are that (1) it requires an extra processing step, although this could be performed by an experienced CT technician at the moment of acquisition in less than a minute or by using a PACS viewer with MPR functionality; (2) one needs to scroll through multiple slices to obtain a clear read-out as additional reference markers are not always in the same plane, depending on the shunt type; and (3) in order to obtain reconstructed images of sufficient quality, a native CT with a slice thickness ≤2 mm is necessary, which is nowadays standard in our center without increasing the radiation exposure to the patient thanks to refinement of multi-detector CT technology. Another limitation is the fact that more and more centers use rapid MRIs (Yue et al., 2015) instead of CTs for pediatric patients with shunt malfunctioning, limiting the use in this patient population. A limitation of the validation study is that we assessed only the two valve types which we implant frequently in our practice. However, we have obtained interpretable reconstructions using this method in other shunt types (Medtronic Strata II and Miethke ProGav 2.0) as well (see Supplementary Fig. 1).

5. Conclusions

Assessment of programmable shunt valve settings using standard head CT images is feasible and reliable. This method obviates the need for additional skull X-rays or bedside read-outs when a CT scan is performed in patients with programmable valves, and can be applied to historical CT images to determine the valve setting at that time.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2021.100003.

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