Title: Spontaneous venous pulsations detected with infrared videography

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Abstract

Background

Assessment of spontaneous venous pulsation (SVP) is commonly undertaken to help determine whether intracranial pressure (ICP) is elevated. Previous studies using direct ophthalmoscopy or slit lamp assessments have found that SVP is not observed in up to a third of subjects with normal ICP, and that SVP grading has relatively poor inter-observer agreement.

Methods

Patients (n=105) undergoing clinically indicated retinal ocular coherence tomography (OCT), who were all thought to have normal intracranial pressure, had 10-second infrared video recordings performed with the Heidelberg Spectralis OCT system (Heidelberg Engineering GmbH, Germany). The presence and amplitude of SVP in each video was independently graded by two neuro-ophthalmologists.

Results

The two observers found SVP present in 97% and 98% of right eyes, and in one or both eyes in 99% and 100% of subjects. There was a high rate of inter-observer agreement in SVP amplitude grading (Cohen's Kappa 0.82 for right eyes). Optic discs with a smaller cup had a significantly lower SVP amplitude (Spearman's rho = 0.22, p=0.02).

Conclusion

Infrared video is widely available in eye clinics via the use of OCT imaging systems, and is substantially more sensitive in detecting SVP than traditional assessments using ophthalmoscopy. SVP are absent in as few as 1% of people with presumed normal ICP.

Introduction

Elevated intracranial pressure (ICP) is a feature of various neurological conditions including idiopathic intracranial hypertension, hydrocephalus, intracranial mass lesions, trauma, stroke, and prolonged reduction of gravity in astronauts (1).

The gold standard for ICP assessment is lumbar puncture opening pressure; however, many clinical centers now use continuous ICP monitoring with intraparenchymal pressure transducers. Both techniques are invasive and risk bleeding and infection (2,3).

Due to the risks of invasive ICP measurement, many attempts have been made to develop reliable non-invasive tests for raised ICP. Computer tomography and magnetic resonance imaging can be used to study the diameter of the optic nerve sheath and other anatomical indicators of high ICP (4,5). Ultrasound can be used to measure the retrobulbar optic nerve sheath diameter (6), and transcranial doppler can measure blood flow in the basal cerebral arteries (7). Cochlear fluid pressure can be used as a surrogate measure of cerebrospinal fluid (CSF) pressure, and can be estimated by tympanic membrane displacement or reemitted sound in response to acoustic stimuli (8,9). Pupillometry gives prognostic information in traumatic brain injury, possibly mediated via elevated ICP (10). Abnormalities of electronically recorded eye tracking are associated with high ICP (11). Ophthalmoscopy is widely used to assess for papilledema, which usually develops within hours or days of developing high ICP. However, patients with pre-existing optic atrophy, and some with apparently healthy optic nerves, may not develop papilledema even with very high ICP (12).

Each of these non-invasive techniques of ICP assessment has its limitations, variously including suboptimal sensitivity, inter-rater variability, significant variation between healthy individuals, expense, time required, radiation exposure, or a need for baseline invasive ICP measurements. For these reasons, none has been universally accepted as a screening tool, and lumbar puncture or invasive ICP measurements remain essential in patients in whom intracranial hypertension is suspected.

Spontaneous retinal venous pulsation (SVP) assessment offers an alternative non-invasive approach to assessing intracranial pressure. By the early 20th century, evidence from animal studies had clearly established that SVP disappeared when intracranial pressure was high, and could be re-established by elevation of the intraocular pressure until it exceeded intracranial pressure by around 5 to 10mmHg (13).

The mechanism of SVP has been studied in detail, and a variety of mathematical models proposed (14,15). Venous pulsation synchronised with the cardiac cycle occurs in highly compliant (expansible) veins near the site of high venous pressure gradients. The main site at which this occurs in humans is the optic disc. On entering the disc, the central retinal vein's pressure is determined by intraocular pressure; as the vein passes through the sclera, its pressure decreases reflecting the lower pressure of the CSF around the retrobulbar optic nerve. Cessation of SVP in the presence of high ICP reflects the diminution or reversal of this physiological venous pressure gradient. The resulting engorgement of the retinal veins due to decreased outflow inhibits their ability to change diameter during the ocular pressure cycle (14,15).

In humans, SVP are not observable in up to a third of healthy individuals when examined with either an ophthalmoscope or slit lamp (16,17, 20). We have found that spontaneous venous pulsation is more easily visible using the *en-face* infrared image of the fundus seen during image acquisition with the Spectralis ocular coherence tomography (OCT) system (Heidelberg Engineering GmbH, Germany). Some Spectralis models allow short fundus infrared video segments of up to 30 seconds to be recorded using scanning laser ophthalmoscopy. Image stabilisation can be applied to video segments using the Spectralis's inbuilt software prior to video playback, eliminating motion artefacts that could be mistaken for SVP, and making small-amplitude SVP readily visible.

Use of the Spectralis system to identify SVP has previously been described by Kim *et al*, who assessed SVP in glaucoma subjects, with SVP graded in a binary fashion as present or absent. SVP was found to occur less commonly in patients with glaucomatous disc cupping (18,19). There are no previous descriptions of this assessment method in the neuro-ophthalmic literature.

This paper describes a study designed to establish the sensitivity of motion-stabilised infrared fundus video in detecting and grading SVP in patients without ICP-affecting disease, and to establish the inter-rater reliability of a 4-point SVP grading scale using this technique.

Methods

Participants were recruited from patients undergoing routine OCT scanning in the eye clinic of the National Hospital for Neurology and Neurosurgery. Potential participants were excluded if they had optic disc swelling or pseudopapilledema, symptoms suggestive of high intracranial pressure, pathological disc cupping due to glaucoma, or a past medical history of abnormal intracranial pressure. The most common indication for OCT was routine screening for hydroxychloroquine retinopathy (31.4%). Other participants had a variety of neuro-ophthalmic problems not associated with abnormal ICP, including optic neuropathies, optic neuritis (without disc swelling), and hereditary ataxias. The mean age of participants was 47.8 ± 15.9 years. Most of the participants (69.5%) were female. All participants gave consent to participation in the study, which was approved by a Research Ethics Committee.

The Spectralis OCT system was used to record a ten-second infrared video of each fundus, centred on the optic disc. Each recording was viewed by two independent assessors (JM, FB). All videos were motion-stabilised using the Spectralis' inbuilt software. The presence and amplitude of venous pulsation were graded using the system described by Hedges *et al* and later used by Wong and White (17,20): grade 0 = no SVP, grade 1 = <33% change in venous diameter, grade 2= between 33% and 67% change in venous diameter, grade 3 = >67% change in venous diameter.

Each eye also had a structural OCT of the disc, including a measurement of the vertical cup:disc ratio at the level of Bruch's membrane.

Results

Gradable infrared video recordings of the ocular fundus were possible in all 210 eyes examined. Observer 1 found SVP in 103/105 right eyes (98%), and SVP in at least one eye of 104/105 subjects (99%). Observer 2 found SVP in 102/105 right eyes (97%), and SVP in at least one eye of all 105 subjects (100%). The frequency of observing different grades of SVP using video recordings is shown in Fig. 1.

Cohen's kappa for SVP grades of subjects' right eyes between the two independent assessors was 0.82. When comparing the highest grade of SVP seen in either eye, Cohen's kappa between the two assessors was 0.89, indicating high levels of inter-rater agreement.

Table 1 shows the SVP gradings assigned by each assessor to right eyes, demonstrating the relatively low number of discrepancies between the two observers. Figure 2 summarizes the relationship between SVP and cup:disc ratio (CDR). Discs with a larger cup had higher-amplitude SVP (Spearman's rho 0.22, p=0.02). However, even in the group of eyes with no cup (CDR zero) at the level of Bruch's membrane, 85% of eyes had detectable SVP using infrared video assessment.

Conclusions

This study demonstrates that in a group of outpatients attending a neuro-ophthalmology clinic, it was possible in every case to record infrared fundus videos of sufficient quality to allow grading of SVP.

Comparison of our results with earlier studies shows that SVP is visible in the vast majority (99%) of eyes of patients with normal ICP using infrared video, compared with 67%-81% of eyes in patients with normal ICP using a direct ophthalmoscope (16,17,20).

Hedges *et al* (20) reported that discs with large cups, and those where veins could be viewed end-on, had higher rates of visible SVP (69%). Crowded discs without cups, and those in which disc veins were obscured by arterioles or glial tissue had much lower rates of visible SVP (6%). The inclusion of arteriovenous relationships in their disc grading system prevents the relationship between cup size and SVP from being understood in isolation. Our study used the SVP grading system described by Hedges *et al* to analyse SVP amplitude, but discs were analysed according to the cup:disc ratio. Our study showed a clear relationship between a smaller cup:disc ratio and higher proportion of eyes with low-amplitude or absent SVP. There was a much higher rate of SVP in all disc categories in our videographic study than in any of the disc categories reported by Hedges *et al* using conventional ophthalmoscopy (20).

It can be inferred from our results that SVP are in fact present in the great majority of healthy subjects, and the significant minority in which they could not previously be detected is largely due to the inherent limitations of examination with an ophthalmoscope or slit lamp rather than a true absence of retinal venous pulsations in those patients. We suggest that the difference is primarily due to the ability of the Spectralis system to motion-stabilise recorded images, revealing subtle pulsations which would otherwise be extremely difficult to observe. A further advantage of the Spectralis OCT in particular is that it uses a near infrared light source which generates less reflections from vessel walls than visible light and is displayed as a black-and-white image, compared to the red-on-tan of vessels seen against the retina and disc with visible light. Fundus video recordings can be magnified and each recording played as a loop to allow a considered decision on whether pulsations are present.

These technical advantages are also reflected in the much higher rate of agreement between the two assessors in this study: Cohen's kappa 0.82 in right eyes, and 0.89 when comparing the higher value of the two eyes graded by each observer; compared to 0.42 between the two observers using a direct ophthalmoscope reported by Wong and White (17). It should be noted that direct ophthalmoscopic SVP grading by two assessors was not recorded for the patients in our study, so direct comparison between the interrater reliability of Spectralis video assessments and of direct ophthalmoscopy is not possible.

The Spectralis and equivalent OCT systems are found in most neuro-ophthalmology clinics; thus the technology for IR video SVP assessment is already widely available. Infrared video assessment of SVP in both eyes takes under a minute, and can be used in both ambulatory and wheelchair-bound patients. Our group is undertaking further validation work using the infrared video assessment technique and SVP grading system described in this paper to examine patients with suspected elevated intracranial pressure while undergoing continuous transcranial pressure measurements.

The main limitation of the technique described is that the Spectralis OCT can only be used on subjects in a sitting position, and therefore cannot be used to screen acutely ill bedbound patients such as those with traumatic brain injury. Further work is needed to develop this technique for use in patients who cannot be examined in a sitting position.

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		Observer 1			
		grade 0	grade 1	grade 2	grade 3
Observer 2	grade 0	1	2	0	0
	grade 1	1	15	12	1
	grade 2	0	1	39	7
	grade 3	0	0	3	23

Table 1: right eye SVP grading by two independent observers, using the grading system described by Hedges et al (20).

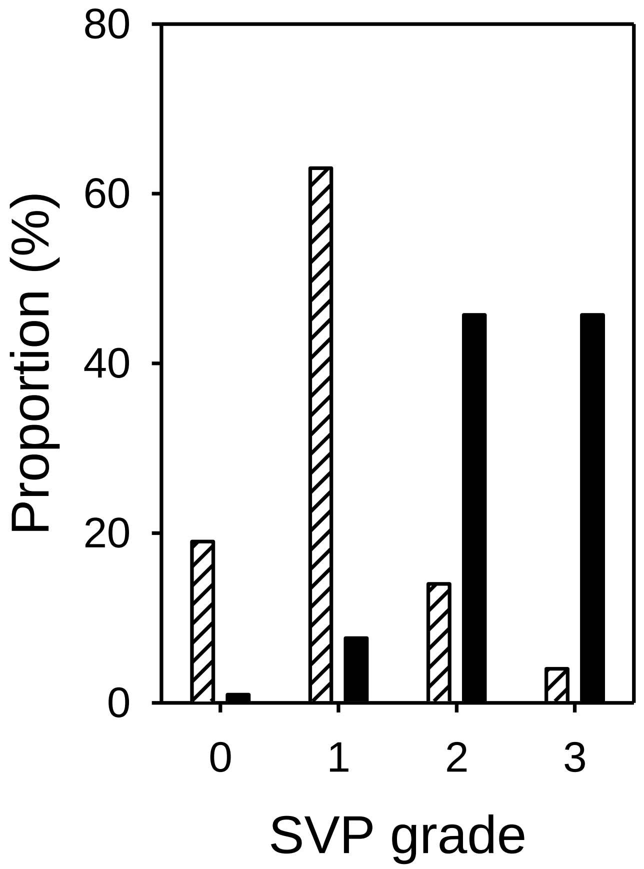

Figure 1: Frequency of different grades of spontaneous venous pulsation (SVP) in normal subjects. Hashed columns show data in patients with normal ICP from Wong & White (17) using direct ophthalmoscopy; black columns show data from the present study using infra-red videography.

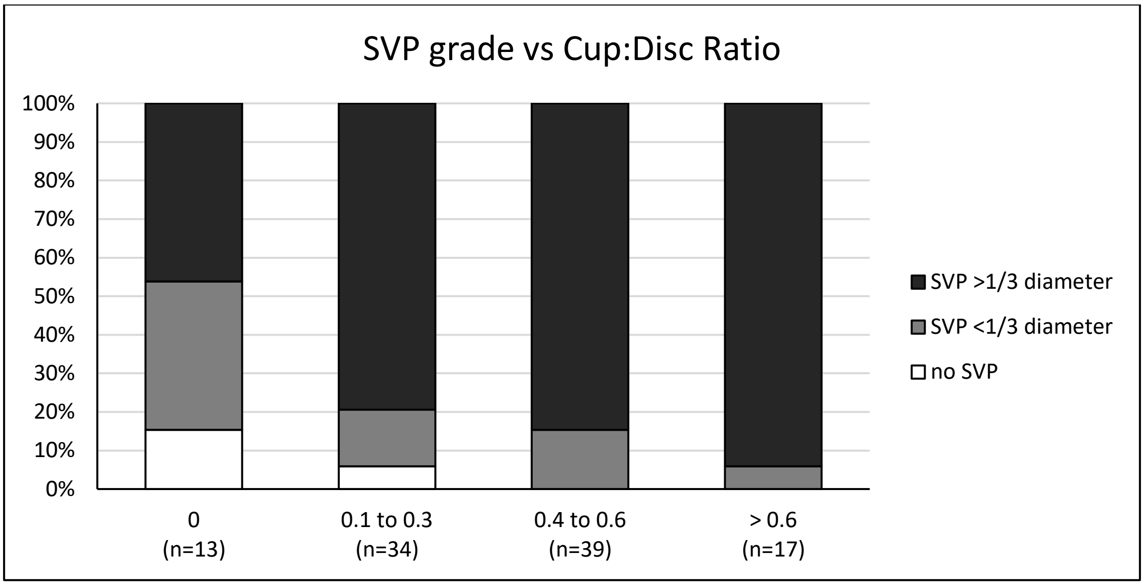

Figure 2: SVP grades of right eyes with different cup:disc ratios.