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DESIGN OF AN AUTOMATED MEASUREMENT SYSTEM FOR EPISCLERAL VENOUS PRESSURE

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BACKGROUND

Episcleral venous pressure (EVP) refers to the pressure in the episcleral veins. It is used by scientists in glaucoma physiology and pharmacology research to study the parameters of aqueous humor dynamics as part of the Goldmann equation [1]. The episcleral veins drain into the superior ophthalmic vein which drains into the cavernous sinus. Our previous work in a pig model [2] shows for the first time that EVP is an excellent non-invasive quantitative marker for intracranial pressure (ICP) estimation (high ICP leads to high intracranial venous pressure and high EVP). Intracranial pressure (ICP) is an important marker of outcomes in traumatic brain injury. There is an unfulfilled civilian and military need for a non-invasive ICP measurement modality. EVP could serve as a quantitative ICP biomarker, measurable by personnel with different skill levels for remote acute triage in battlefields and other urgent situations.

EVP measurement using current techniques needs a slit lamp for illumination, magnification and stabilization in human subjects and an operating microscope in animals or supine human subjects. Under the operating microscope, the instrument is not stabilized, and the slightest movement of the instrument makes the measurement challenging. This would preclude the use of EVP measurement in any emergent situation. [3]. A typical device for measuring EVP is shown in Fig. 1.

Accuracy of EVP measurement within 2 mmHg is critical. In our animal study [2], a 3-mmHg ICP change caused a 1-mmHg EVP change. Thus, an error of 2 mmHg in EVP would cause a 6-mmHg error in ICP estimation. Uncertainty above this level may cause life-threatening triage decision errors.

In this paper we present the design of an attachment for a standard episcleral venomanometer which allows the measurement to be automatically recorded, reducing the potential for uncertainty in the measurements and opening up possibilities for computerized post-processing using image analysis.

Figure 1. Photo of episcleral venomanometer.

METHODS

An existing episcleral venomanometer (EyeTech EV-310) was used in this study. The operating principle of this venomanometer is that a transparent silicone bulb is placed into contact with the eye over the episcleral vein. The operator raises the pressure in the bulb, using a knob coupled to a piston inside the device, while simultaneously looking through the bulb to observe the pressure at which venal occlusion occurs. Two main factors lead to uncertainty in this measurement. First, venous occlusion is determined subjectively at the vein's half blanched point by the operator looking at the eye through a slit-lamp (Fig. 2). Second, the pressure reading is taken from the knob which is marked with an analog scale, and the scale can be read differently according to the viewing angle.

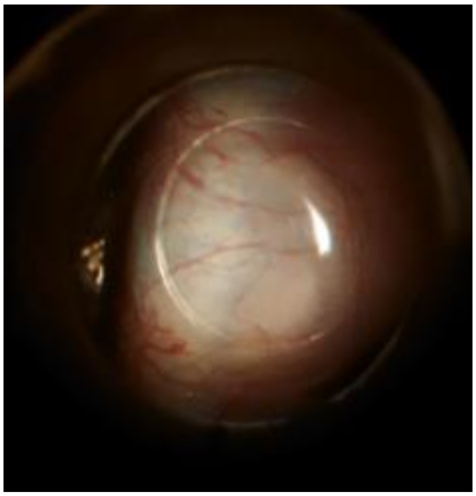

Figure 2. Episcleral veins viewed through venomanometer.

The venomanometer was retrofitted with a camera, light source, lens, potentiometer, and microcomputer in order to decrease measurement uncertainty and make the device portable (decouple it from the slit lamp). A 3D-printed case was designed to house the added components, attach to the venomanometer, and enforce appropriate focal distance for the camera with respect to the contact area of the venomanometer (see Fig. 3). Lenses with fixed 10x and 25x magnification, as well as mini-microscope devices with adjustable magnification from 20x to 40x, were fitted on the device to find the right amount of zoom as judged by ophthalmologists' evaluation. A floor-mounted stand was fabricated by adapting a microphone stand and adding weight at its base to improve stability, and topping it with a flexible gooseneck end for fine positioning. A Raspberry Pi Zero microcomputer, running a version of the Linux operating system (Raspbian Jessie) and fitted with a Raspberry Pi Camera Board v2 (8 megapixels) and Adafruit PiTFT 2.8" touchscreen display (Fig. 3), was used to serve as the user interface and for recording data from the visual measurements. A clip-on LED reading lamp was used to provide oblique, diffuse lighting. The potentiometer was attached in series with the pressure adjustment knob, configured to feed pressure data to the microcomputer via an Arduino microcontroller. A program was written in Python, version 2.7, to capture the image at 30 frames per second, overlay the pressure reading as text, and compress the resulting data stream to a video file.

Initial benchtop testing consisted of positioning the device against stiff wooden eye phantoms painted with representations of the venous structure (Fig. 4). Different levels of reflectiveness were used on these phantoms in order to test not only focus and general functionality, but also the effects of light positioning to achieve robustness against glare.

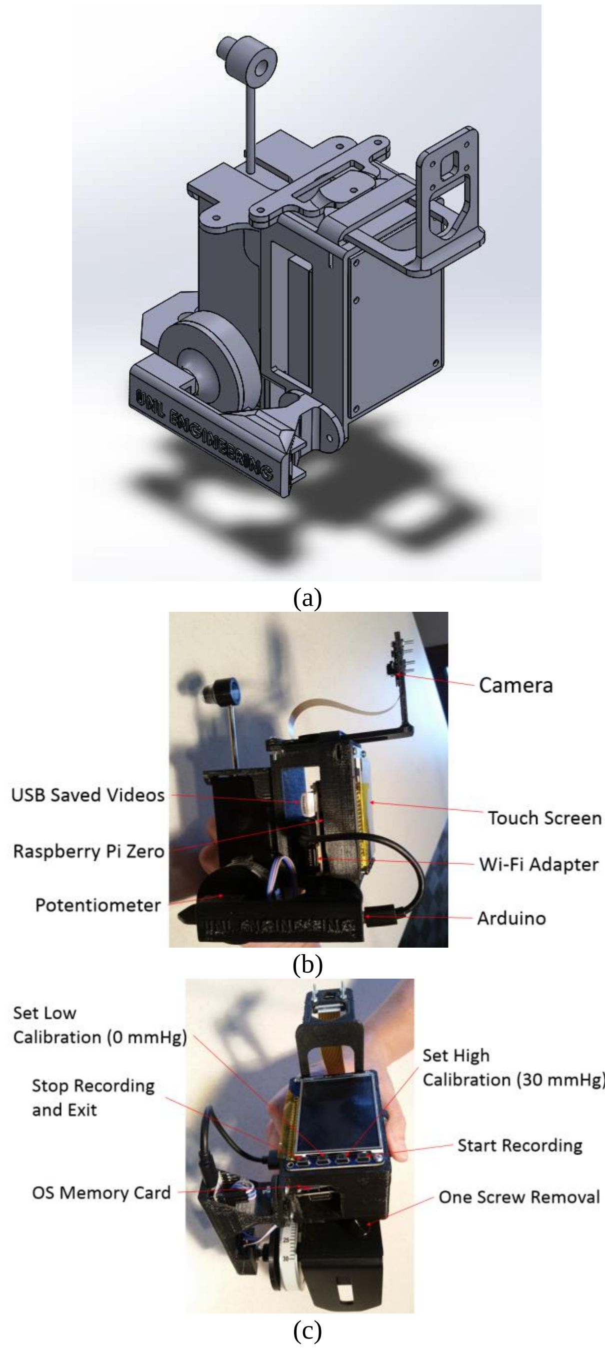

Figure 1. Computer model (a) and critical components of prototype (b-c).

Figure 2. Early example of wooden (phantom) eye test.

RESULTS

Evaluation of the design was done through benchtop tests and the validation of design requirements. The requirements were: low cost, portability, ability to capture footage or pictures of the eye, ability to capture correlated pressures, ease of use, and small footprint.

The entire cost of the prototype device with added electronics is $1213.54, with $950.00 of that price being the cost of the episcleral venomanometer. This means the cost of the electronics and construction total at just $263.54, making this an affordable option. Extra savings can be appreciated by the removal of need for a slit lamp and associated dedicated floor space. The portability of such a device means that measurements can be taken in less specialized rooms, along with unconventional locations such as battlefields or sports arenas. The ability to capture footage and pictures was achieved by using a 4-button interface for setting calibrations and recording options. Pressure values can be seen in real-time on the display, eliminating the need for the test administrator to avert their gaze from the subject's episcleral vein to check the correlated pressure. With improvements, the device still functions the same (i.e., the wheel adjusts the pressure to the silicone bulb), meaning minimal training is needed to acquire proficiency. Lastly, the footprint of the device is still small enough that it allows not only easy portability but storage as well, as seen in Fig. 3. The entire addition to the episcleral venomanometer can be removed with one existing screw, adding to the potential compactness and adaptability of the device.

INTERPRETATION

The modified venomanometer was designed to overcome current limitations in measurement of episcleral venous pressure in the eye, namely uncertainty inherent in pressure readings and lack of portable devices for venomanometry. By integrating a camera and microcomputer along with indirect pressure sensing (pressure adjustment knob position sensing), the uncertainty in reading the scale on the knob is removed, and the visual data are captured such that the pressure at which venous occlusion occurs can be more objectively measured. Notably, this opens up the possibility for computerized post-processing of the video data in an algorithmic and unbiased manner. Furthermore, because the device integrates magnification and lighting, measurement of episcleral venous pressure can now be done without a slit-lamp, meaning that field measurements are possible. This may lead to broad improvements in the use of EVP measurement for diagnosis of intracranial conditions bedside in intensive care units or on the battlefield for high intracranial pressure.

Further advancements in the device would allow an even more robust use of the episcleral venomanometer. Advancements such as the inclusion of an on-board power source, such as a LiPo battery, would eliminate the need for wall power. This elimination of wall power would also make the device relatively power-grid-agnostic for international use. A future version could include automation of the dial to increase and decrease pressure such that EVP could be determined using image processing alone. All of these improvements would help reduce the need for trained professionals, specialized rooms, and expensive machinery, allowing wider use in the medical field. Notably, this use could include novel studies of the potential correlations between EVP and various diseases and conditions.

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