

The Use of Automated Pupillometry in Critical Care



DaiWai M. Olson, RN, PhD, CCRN*, Megan Fishel, RN, BSN, CCRN

KEYWORDS

- Multimodal monitoring • Neurologic assessment • Pupillometer
- Cranial nerve assessment

KEY POINTS

- The pupillary light reflex assessment evaluates the functional ability of the optic and oculomotor cranial nerves.
- Subjective (observational) scoring of the size, shape, and reactivity of the pupil in response to light is associated with limited interrater reliability.
- Thermometer technology replaced hand-to-skin temperature assessment. Objective scoring with automated pupillometry is a natural progression in technology.
- Although there is no consensus for which parameters are of most importance, the maximum size and neuropupillary index (NPI) are most frequently documented.
- The ability to evaluate the pupillary reflex from only 1 eye at a time is a recognized limitation.



Video content accompanies this article at <http://www.ccnursing.theclinics.com/>

INTRODUCTION

In romance literature, the eyes are said to be the windows to the soul. However, in the critical care setting, romance is not the issue. When performing a neurologic examination (neuroexamination) the eyes (more specifically the pupils) are closely examined, and the pupillary assessment becomes a window through which staff evaluate neurologic status. To be more specific, staff evaluate the functional status of the second cranial nerve (CN II) and third cranial nerve (CN III). This evaluation is important because

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The University of Texas Southwestern, Dallas, TX, USA

* Corresponding author. The University of Texas Southwestern, 5323 Harry Hines Boulevard, Dallas, TX 75390-8897.

E-mail address: DaiWai.Olson@UTSouthwestern.edu

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loss of CN reflexes may signal increased intracranial pressure (ICP) and an increased risk of central brain herniation.

NEUROLOGIC EXAMINATION

Assessment is at the core of the nursing process. Performing a comprehensive neurologic examination (neuroexamination) is a cornerstone of high-quality nursing care for patients with a wide variety of neurologic and neurosurgical injuries.^{1,2} The essential elements of the neuroexamination include an evaluation of level of consciousness (LOC), cognitive ability, CN function, motor function, and sensory function. By tradition, the neuroexamination is performed serially depending on the condition of the patient (eg, hourly following acute stroke). Results from each examination are compared with previous examination findings.^{1,3} The results of the neuroexamination provide data that practitioners can use to formulate new treatment plans and to evaluate the impact of prior treatments.³

The ability of a practitioner to link the results from one element of the neuroexamination with the functional ability of a corresponding region in the central nervous system (CNS) gives rise to the concept of functional neuroanatomy. Different elements of the neuroexamination provide insight into how well specific anatomic regions of the CNS are performing. For example, changes in the LOC may provide the examiner with clues about the general function of the reticular activating system and cerebral cortex, or paresthesia of the right arm may provide clues to a left middle cerebral artery stroke.^{4,5}

Nursing theory helps to define the importance of the neuroexamination to provide cues. The Coma-Cue Framework describes a paradigm whereby nurses are able to obtain cues from numerous sources of assessment and observation of patients with brain injury.⁶ These cues are vital for directing nurses, and ultimately the entire health care team, toward optimally timing care interventions. The cues from a neuroexamination help guide practitioners to decide when to intervene, or allow rest, or alter a course of therapy.

During the past 50 years, a variety of assessment tools have been developed to improve the consistency with which the neuroexamination is performed, documented, and discussed. During the same half-century, numerous practice patterns have become engrained. Consciousness is most often evaluated as the patient's level of wakefulness or responsiveness to stimuli. Tools such as the Glasgow Coma Scale (GCS) and the Full Outline of Unresponsiveness (FOUR) score have been developed and refined to help guide examiners.⁷⁻⁹ Portions of the GCS and FOUR score evaluate the LOC, portions evaluate the motor and sensory functions (frontal lobe, parietal lobe, thalamus), and portions evaluate some aspect of the brainstem (primarily FOUR score). A primary difference between the GCS and FOUR score is the inclusion of corneal reflexes as well as breathing pattern. Pupillary and corneal reflexes are assessed routinely as part of the CN examination. Elements of the motor and sensory examination are performed sequentially with a reflex hammer. The use of a penlight or flashlight has particularly aided CN assessment.

CRANIAL NERVES

The full assessment of CN function is an established norm that is well within the practice domain of both nurses and physicians.^{1,10} The concept of functional neuroanatomy introduced earlier helps to establish the importance of linking the results of the CN examination with a specific anatomic location within the brainstem. In brief, the 12 pairs of CN roots are located throughout the brainstem. Note that although

CN I and CN II emerge from the forebrain, whereas CN III and CN IV emerge from the midbrain, CN function and anatomy are generally discussed as brainstem function.^{1,11} Hence, it is convenient to discuss CN anatomy as 3 sets of 4 CNs. The first set, CN I to CN IV, emerge from the midbrain. The second set of 4, CN V to CN VII, emerges from the pons. The third set of 4, CN IX to CN XII, emerges from the medulla.¹¹

Examining the pupil (pupillary light reflex) provides nurses and physicians with information about the functional status of the optic (CN II) and the oculomotor (CN III) CNs. CN II is a tract of secondary sensory pathways. The CN II pathway begins when light enters the pupil and is converted into an electrical signal by rods and cones in the retina. This signal is passed to the primary neuron (bipolar cells). The signal is then passed to ganglion cells (the secondary neurons), which converge near the optic disc. The ganglion cell axons then exit the eyeball and become what is traditionally known as the optic nerve. Most of the tracts that make up the optic nerve then run through the optic chiasm and terminate in the lateral geniculate nucleus. Visual signals are then sent along the tertiary neuron to the visual cortex in the occipital lobe. However, a portion of the tracts separate before the lateral geniculate nucleus and terminate in the pretectal area of the midbrain.¹² These tracts are vital for the pupillary light reflex.

The oculomotor CN (CN III), as implied by the name, is crucial for the motor function of the eye. The somatic nucleus of CN III is in the midbrain and gives rise to somatic motor fibers. The parasympathetic fibers of CN III originate in the Edinger-Westphal nucleus. The somatic and parasympathetic fibers combine to form the CN III. Electrical signals carried along CN III cause the muscles of the eye to contract. These contractions result in movement of the eyeball and eyelid, and also are responsible for constriction of the pupil.¹²

A brief review of the pupillary light reflex helps to highlight the importance of these complex pathways. In short, bright light stimulates a signal that is carried along the afferent pathway of CN II to the tectal plate in the midbrain and then to the Edinger-Westphal nucleus (EWN). Then, efferent pathways of CN III carry the signal from the EWN to the eye; this causes the motor fibers of the eye to contract. This contraction is seen clinically as a constriction of the pupil. Because fibers from the EWN project to both eyes, light stimulus of either eye should result in constriction of both pupils.

By tradition, pupillary examinations were performed and evaluated subjectively using either a flashlight or penlight. The examiner was asked to first score the initial size (diameter) and shape (round or irregular) of the pupil. Then, after stimulating the pupil with light, the examiner was asked to score the reactivity of the pupil. Reactivity was scored either as present versus absent, or as briskly reactive versus sluggishly reactive versus nonreactive (fixed). Despite being an ingrained element of practice, the traditional method of subjective pupillary assessment has only fair to moderate interrater reliability.¹³ The interrater reliability is further decreased when skill mix, training, and a large variation in light source and examination conditions are factored into the equation.^{14–17} Automated pupillometry was introduced to the intensive care unit (ICU) as an alternative to the subjectivity required by human assessors.

PUPILLOMETER

The act of measuring the pupil and evaluating the pupillary light reflex has been a standard of practice for hundreds of years.¹⁸ Before electricity the pupil was examined by candlelight. Electric light technology allowed this practice to evolve. The hand-held flashlight and pupil gauge soon found acceptance in health care. During this evolution, evaluating the size, shape, and reactivity of the pupil was a subjective task that was

part of the art of medicine and nursing care. In recent decades, objective measures of pupil size and reactivity have also evolved. In 1960, the first automated pupillometry (measuring the pupil) was first described by using 16-mm film to examine pupil dilatation in response to emotional stimuli.¹⁹ The invention of high-speed miniaturized computer processors enabled the most recent technological evolution in pupil assessment.

At its core, automated pupillometry is a series of photographic images of the pupil digitally captured and scored for change in size over time. Hand-held portable pupillometers are now widely available and represent a logical step in nursing assessment. Historically, nurses subjectively evaluated temperature by touching the forehead, blood pressure by feeling the threadiness of the pulse, and oxygenation by observing for a bluish tinge in the lips or skin. Modern technology and human ingenuity gave rise to thermometers, manometers, and oximeters. Historically, nurses subjectively evaluated pupillary response using a variety of light sources manipulated in a variety of conditions. Modern technology and human ingenuity have again provided a technological advance to objectively measure (meter) another element of the physical examination.

The use of an automated pupillary assessment device, or pupillometer, has become increasingly common for patients with neurologic injuries.²⁰ The NeurOptics NPi-100 and NPi-200 are perhaps the most common commercial pupillometer devices used in critical care. These are hand-held portable devices that can be used with a disposable patient shield. This device provides a variety of measures of pupil size and reactivity, including maximum size, minimum size, constriction velocity (CV), latency, and the neuropupillary index (NPi). To obtain a reading, the practitioner (registered nurse [RN] or doctor of medicine [MD]) targets the pupil by pressing a button corresponding with either the left or right eye (Video 1). When the pupil is clearly seen on the pupillometer display screen, the practitioner releases the button; this activates the device to emit a short (0.8 second) burst of light (1000 lux). The device then stores repeated images taken at more than 30 frames per second for 3.2 seconds. From these images, the pupil is digitally scored and tracked. Results from each examination are provided on an LCD (liquid crystal display) screen within a few seconds of the examination.

The maximum pupil size and minimum pupil size are measured in millimeters to the nearest 100th (eg, 3.45 mm) decimal. The CV is measured in millimeters per second and calculated as the amount of constriction (size change) divided by the duration (time in seconds) during which the pupil remains constricted. Latency is defined as the time from light stimulus until the start of constriction. The NPi is a unique new variable, derived from a set of measurements obtained in healthy volunteers.²¹ The NPi ranges from 0 to 5 and is a comparison of the response of the patient to normal responses. The NPi is therefore derived by comparing output from a mathematical algorithm obtained from normal healthy volunteers. An NPi value greater than 3.0 is considered normal, whereas NPi values less than 3 are considered abnormal and associated with intracranial hypertension.²² An NPi of zero (no pupil constriction) equates with a fixed pupil (absent pupillary reflex).

DISCUSSION

The underlying concept of the pupillometer is simply an automation of the traditional pupillary assessment. Moreover, automating measurements is not new. Pulse oximetry automates the assessment of nail bed color and is a natural extension to measure tissue perfusion. Thermometers automate the assessment of how hot or cold the forehead feels, and are the natural extension to measure temperature. Blood pressure measurement, whether invasive or noninvasive, is a natural replacement for the

evaluation of how thready or robust a pulse feels to the assessor. Automating pupil assessment is therefore simply the next step in providing more consistent and reliable data from which to evaluate the patients' status.

Although it seems clear that pupillometry is an emerging technology that will become a mainstay in critical care, there are a variety of unanswered questions that require study. Can the device be used to compare the size of the left pupil with that of the right pupil (anisocoria), or is the device only useful to compare pupil reactivity? What are the normal ranges for pupillometry output data (NPi, CV, latency, pupil size), and which of these data should be documented? What are the assessment parameters that should prompt nursing action? Should readings be interpreted as absolutes, or are serial readings required? Is there a continued role for performance of the subjective examination (penlight)? The answers to these questions are likely to help to standardize practice, but will also generate new questions.

A recognized limitation of hand-held pupillometry is that the current version of the device is used to examine only 1 eye (pupil) at a time, and therefore may not provide adequate information to rule out the presence or absence of anisocoria (unequal sized pupils). Although there is no agreed-on cut point at which the pupils are deemed to be unequal in size, it is generally accepted that greater than 1.0-mm difference in pupil diameter (left eye vs right eye) is considered anisocoria.^{2,23,24} Although anisocoria can be a normal finding in approximately 20% of the population, there is some evidence that the presence of anisocoria is associated with worse clinical outcomes. To be specific, the presence of anisocoria in the setting of traumatic brain injury is a sign of secondary brain injury and may herald neurologic deterioration.^{25,26}

Although objective assessments provide more precise and reliable data, there is only an assumption that better data will result in better outcomes. Recent literature has examined automated pupillometry compared with subjective examination. There is inadequate interrater reliability between humans in evaluating pupil size, shape, and reactivity. In a recent study of more than 2300 paired assessments, the interrater reliability between 2 RNs, 2 MDs, or an RN and an MD was inadequate to support the assumption that any one practitioner would score pupil function the same as any other practitioner. This finding was especially noted for fixed pupils (<50% agreement that a pupil was not reactive).¹³ Meeker and colleagues²⁷ found only limited interrater reliability for subjective scoring of size, shape, and reactivity between practitioners.

Pupillometers provide several new values that are not available with subjective assessment. Of these, NPi is the most widely reported. Several studies suggest that NPi, as a measure of pupil function, is associated with early detection of intracranial disorder.^{28,29} However, there are no studies that have been designed to prospectively evaluate outcomes linked specifically to treatments that are determined by NPi data. Moreover, although an NPi of less than 3.0 is established as a general criterion for abnormal pupillary reaction, there are inadequate normative data to determine whether this relationship is linear (ie, whether an NPi of 1.0 is half as good as an NPi of 2.0). Variables such as CV, minimum size, and maximum size are intuitive to most practitioners. However, because these variables are only recently available, intuition mandates testing.

Nursing assessment is steeped in practical pearls. New ICU nurses are quickly educated that teeth brushing can mimic tachycardia, or that pulse oximetry is unreliable in the setting of carbon monoxide toxicity. Likely, there are medical and pharmaceutical conditions that will be revealed as conditions in which pupillometry should be interpreted cautiously.

SUMMARY

Hospitals across the globe are quickly adopting a practice that includes automated pupillometer assessment.^{30,31} Assessment of pupillary function is a noninvasive method of providing vital information about patients' current neurologic function.^{2,32} Pupil size, shape, and reactivity provides an indication of CN function for CN II and CN III, as well as providing insight into the sympathetic nervous system functional status. When optimally functional, light stimulus to 1 or both pupils causes constriction of both pupils. Given that the bilateral pathways (afferent and efferent) are intact, the normal finding is that the pupils are equal in size, round, and reactive to light. Abnormal findings are associated with specific injury such as CN III damage, and brainstem or transtentorial herniation.^{33–35}

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at <http://dx.doi.org/10.1016/j.cnc.2015.09.003>.

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