Journal of Clinical Neuroscience 100 (2022) 180–183

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.journals.elsevier.com/journal-of-clinical-neuroscience

Clinical study

Inter-device reliability of the NPi-200 and NPi-300 pupillometers

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ARTICLE INFO

Keywords:
Pupil
Cerebral edema
Neurological examination
Critical care
Nursing
Clinical research
Neurocritical care

ABSTRACT

The pupillary evaluation is an essential part of the neurological examination. Research suggests that the traditional examination of the pupil with a handheld flashlight has limited interrater reliability. Automated pupillometers were developed to provide an objective scoring of various pupillary parameters. The NPi-200 pupillometer is used for quantitative pupillary examinations, the NPi-300 was launched in July 2021 with enhanced features. The purpose of this study is to compare results from the NPi-200 to the NPi-300 to ensure that data are translatable across both platforms. This study examines the inter-device reliability of the NPi-200 compared to the NPi-300 in two cohorts: 20 patients at risk for cerebral edema and 50 healthy controls. Paired assessments of the devices were made from all participants. Each assessment included bilateral PLR readings within a 5-minute interval. Data showed high agreement between the two devices for the Neurological Pupil Index (NPi) reading (k = 0.94; CI: 0.91–0.99) and for pupil diameter assessment (k = 0.91; CI: 0.87–0.96). There is a very high level of agreement between the NPi-200 and NPi-300 among healthy controls and critically ill patients. Clinicians and researchers can interpret the results from either device equally.

1. Introduction

Accurate assessment of neurological functioning is vital in critically ill patients, particularly in those with neuronal injuries [1,2]. One of the crucial elements of the neurologic assessment is the pupillary light reflex (PLR®) [3]. Research has shown that a subjective estimate of PLR function using a flashlight or penlight is insufficient [4]. Automated infrared pupillometry (AIP) was developed to standardize the PLR assessment and it has influenced clinical care and served as a catalyst for multiple research studies [5,6]. The majority of this work was conducted with NPi®-100 or NPi®-200 pupillometers which were shown to have high inter-device reliability. Introduction of the NPi®-300 requires reliability assessment to understand and establish data translation across platforms. The purpose of this study is to compare results from the NPi-200 to the NPi-300 to ensure that data are translatable across both platforms.

2. Background

Pupil assessment has been studied in multiple specialties, and is of particular interest in acute neurological care because the pupillary light reflex (PLR) provides information about the functional status of several cranial nerves [7]. When bilateral afferent and efferent pathways are intact, both the left and right pupil should be equal in diameter and rapidly constrict in response to bright light. Abnormal reactivity in one or both eyes is associated with neurological conditions such as brainstem compression, injury to the optic or oculomotor nerve, or transtentorial herniation [8,9]. This change from normal intact pathways to injured pathways may occur quickly or slowly, thus prompting the need for serial PLR assessments to objectively track activity over time [3].

Several studies conclude that subjective examination of PLR has poor interrater reliability [4,10,11]. This is further complicated by medications and medical comorbidities [12]. Anecdotally, a variety of medications have been hypothesized to affect the PLR, yet there was an absence of widely available objective methods to quantify pupillary function. Automated hand-held pupillary assessment technology was

Abbreviations: AIP, Automated Infrared upillometryP; CV, Constriction Velocity; DV, Dilation Velocity; NPi, Neurological Pupil Index; NSICU, Neuroscience Intensive Care Unit; PD, Pupil Diameter (pupil size); PLR, Pupillary Light Reflex.

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https://doi.org/10.1016/j.jocn.2022.04.023
Received 18 February 2022; Accepted 20 April 2022
Available online 26 April 2022

developed in the early 2000 s and is now considered standard of care at many hospitals. Automated infrared pupillometry (AIP) is a reliable and objective measure of the PLR, in contrast to subjective pupillary examinations in which a PLR is scored present or absent, sluggish or brisk [4,13,14]. Pupillometry provides a novel objective measure of pupil diameter and reactivity to include a number of discrete variables and a summary variable known as the Neurological Pupil index™ (NPi) [15]. The NPi is a proprietary index where a number of pupil variables (e.g., initial size, constriction velocity, dilation velocity, and minimum size) are combined and compared against a mean of a reference distribution of healthy subjects. The set of all the standardized differences are then combined to fall within a scale set between 0 and 5. A score ≥ 3 indicates that the pupil measurement is within the boundaries of normal pupil behavior as defined by the NPi algorithm. Values < 3 suggest that abnormal PLR; absence of pupil constriction is reported as zero [15]. Additionally, a difference between the left and right NPi scores is a sign of pupil abnormalities indicating potential brainstem compression [16].

As the pupillometer becomes standard of care across hospitals and is used in multiple research studies, it is important to validate the inter-device reliability [17]. The most current version of the pupillometer, the NPi-300 has a few enhanced features including advanced wireless charging technology, an incorporated barcode scanner and an updated graphical user interface. Previous research showed high inter-device reliability of the NPi-100, an earlier model of the pupilometer [14]. As pupillometry becomes the standard for PLR assessment, it is reasonable to expect technological advances in the pupillometry devices. Advances in technology may provide different quality results (usually improved accuracy and precision). Knowing the relationship of results obtained with previous pupillometry devices, and results with devices from different vendors is vital to provide meaningful translation of data over time. The purpose of this study is to compare results from the NPi-200 to the NPi-300 to ensure that data are translatable across both platforms. We hypothesize that the pupillometers have high inter-device reliability.

3. Methods

This institutional review board approved study purposely replicates the methods from a 2016 [14] study that examined the inter-device reliability of the NPi-100 pupillometer. In the current study there were two cohorts, patients and healthy controls. Patients ($n = 20$) were consented if they were admitted to the neuroscience intensive care unit (NSICU) with a neurological or neurosurgical diagnosis that placed them at risk for cerebral edema and had orders for a neurological exam which included PLR assessment. Healthy controls ($n = 50$) were hospital staff or faculty. Patient demographic data were extracted from the electronic medical record. Due to confidentiality restrictions, demographic data were not collected on healthy controls.

For this study, we defined a complete sample as a collection of 4 pupillometer readings. Two from a paired (left and right eye) PLR reading obtained using the NPi-200, and two from a paired PLR reading obtained using the NPi-300. Only complete samples were obtained and patients in whom PLR could be obtained from only 1 eye (e.g., prosthetic eye) were excluded. The NSICU standard of care is to complete PLR assessments using a pupillometer. For data collection, the NPi-200 device was always used before the NPi-300 device. The right eye data was always collected before the left eye data. For study patients: within 5-minutes of a routine PLR assessment with an NPi-200, a second paired reading was obtained using the NPi-300. Patients were eligible to provide up to 8 samples per day, so long as the samples were obtained at least 1 h apart. Each healthy control provided only 1 sample. These samples were obtained at the convenience of the consented subject. Like patients, each sample consisted of a paired PLR reading using the NPi-200 and a paired PLR reading using the NPi-300.

The NPi-200 and NPi-300 both provide the following measures as routine data for all PLR assessments: latency, maximum pupil diameter (maxPD), minimum pupil diameter (minPD), constriction velocity (CV), maximum CV (maxCV), dilation velocity (DV), and summary score known as the neurologic pupil index (NPi). Latency is measured in hundredths of a second. The maxPD and minPD are measured in mm to the nearest 100th. The CV, maxCV, and DV are measured in mm/second. Unless noted, continuous data are reported as mean (standard deviation), and ordinal or nominal data are reported as frequency (percent). The primary analysis was conducted using Cohen's Kappa. Paired *t*-test and percent agreement models were constructed to fully explore the data.

4. Results

The 171 complete samples (left & right eye with NPi-200 and left & right eye with NPi-300) included 50 samples from healthy controls and 121 samples from patients. The 50 healthy controls each provided only 1 complete sample. The 20 patients provided a mean of 6.05 (1.98) samples (range 1–9 samples per patient). Because a complete sample includes 4 readings, there were 684 readings used in this analysis.

Patients had a mean age of 62.8 (16.5) years, 11 (55%) were Female, 12 (60%) were White, and 16 (80%) were non-Hispanic (Table 1). Cohen's Kappa (k) assessment showed high agreement in NPi between the NPi-200 and NPi-300 ($k = 0.95$; CI: 0.91–0.99); and for maxPD ($k = 0.91$; CI: 0.87–0.96). A Bland-Altman plot generated for NPi_200 and NPi_300 values shows no systematic bias (supplemental digital content 1). There were 3 observations from 2 patient subjects with a difference in NPi values ≥ 0.7. There were no statistically significant differences in paired mean NPi values for the entire cohort (Table 2a), nor for the subset of healthy controls (Table 2b), nor for the subset of patient subjects (Table 2c). As noted in Table 2a, 2b, 2c, when comparing each of the individual metrics that comprise the PLR, there are very few statistically different readings between the NPi-200 and NPi-300 and no clinically relevant differences. To further explore the data, we created models of percent agreement (Table 3). The NPi-200 and NPi-300 had high (>95%) agreement in readings for NPi, latency, minPD, percent change in pupil diameter, CV, and DV. The percent agreement was lower, but still > 80%, for maxPD and meanCV.

5. Discussion

Readings from the NPi-200 and NPi-300 are remarkably similar and provide several new insights that may inform clinical practice and future research. Not all physiologic measures have high instrument reliability. For example, blood pressure, intracranial pressure, and temperature vary by site and device. [18–21] The image resolution from early generation computerized tomography (CT) scans is significantly less precise than from current models [22]. The high inter-device reliability is reassuring in both clinical and research settings because this provides clinicians with knowledge that it is not necessary to know which device was used, when interpreting the data. Furthermore, no additional training is needed for the use of different devices.

The highest agreement was in the PLR summary score (NPi). While the Bland-Altman plot shows no systematic bias (supplemental digital content 1) [23], there were 3 observations clinical differences in NPi,

Table 1
Demographics for patients as subjects.

Demographic		Statistic*
Age (mean[sd])		62.8 (16.5)
Sex*	Female	11 (55%)9
	Male	(45%)
Race*	Black	4 (20%)12
	White	(60%)4
	Not Given	(20%)
Ethnicity*	Hispanic	4 (20%)16
	Non-Hispanic	(80%)

*reporting n(%).

Table 2
Paired T-Test Comparisons of NPi-200 and NPi-300.

(a) Paired T-Test Comparison for the Total Sample (patients and healthy controls)

Variables	Left Eye			Right Eye		
	NPi200	NPi300	P-Value	NPi200	NPi300	P-Value
NPi	4.24 (0.75)	4.29 (0.70)	0.171	4.26 (0.71)	4.31 (0.65)	0.228
Maximum pupil diameter	3.6 (0.94)	3.59 (0.90)	0.486	3.70 (0.87)	3.62 (0.84)	0.010
Minimum pupil diameter	2.58 (0.59)	2.56 (0.59)	0.197	2.62 (0.54)	2.55 (0.52)	<0.001
Percent change	28.41 (8.23)	28.92 (7.86)	0.146	29.58 (8.12)	29.07 (8.32)	0.167
Constriction velocity	2.03 (0.96)	2.08 (0.82)	0.258	2.10 (0.83)	2.09 (0.83)	0.773
Maximum constriction velocity	3.02 (1.21)	3.09 (1.18)	0.108	3.23 (1.17)	3.14 (1.24)	0.078
Latency	0.23 (0.05)	0.26 (0.15)	0.024	0.24 (0.07)	0.24 (0.08)	0.813
Dilation velocity	0.94 (0.40)	0.91 (0.38)	0.165	0.96 (0.40)	1.01 (0.40)	0.152

(b) Paired T-Test Comparison for pupil readings from the 50 healthy controls

Variables	Left Eye			Right Eye		
	NPi200	NPi300	P-Value	NPi200	NPi300	P-Value
NPi	4.31 (0.27)	4.32 (0.30)	0.598	4.28 (0.38)	4.35 (0.29)	0.117
Maximum pupil diameter	4.28 (0.93)	4.19 (0.81)	0.133	4.37 (0.83)	4.20 (0.77)	0.007
Minimum pupil diameter	2.83 (0.45)	2.71 (0.41)	0.362	2.88 (0.44)	2.77 (0.42)	0.005
Percent change	32.36 (7.90)	32.58 (6.31)	0.793	33.44 (6.98)	33.30 (6.34)	0.859
Constriction velocity	2.82 (1.11)	2.83 (0.74)	0.941	0.22 (0.04)	2.73 (0.72)	0.973
Maximum constriction velocity	3.99 (1.14)	4.03 (1.08)	0.704	4.08 (1.09)	4.00 (1.09)	0.491
Latency	0.22 (0.04)	0.28 (0.25)	0.094	0.22 (0.04)	0.22 (0.07)	0.605
Dilation velocity	1.21 (0.33)	1.06 (0.42)	0.014	1.15 (0.39)	1.22 (0.39)	0.277

(c) Paired T-Test Comparison for pupil readings from the 20 patients at risk for cerebral edema

Variables	Left Eye			Right Eye		
	NPi200	NPi300	P-Value	NPi200	NPi300	P-Value
NPi	4.22 (0.87)	4.28 (0.81)	0.203	4.26 (0.81)	4.30 (0.75)	0.803
Maximum pupil diameter	3.32 (0.79)	3.33 (0.81)	0.735	3.41 (0.71)	3.38 (0.75)	0.310
Minimum pupil diameter	2.47 (0.61)	2.45 (0.62)	0.345	2.51 (0.54)	2.45 (0.54)	0.027
Percent change	26.76 (7.82)	27.38 (7.96)	0.073	27.96 (8.04)	27.29 (8.84)	0.103
Constriction velocity	1.70 (0.66)	1.77 (0.63)	0.027	1.83 (0.69)	1.82 (0.72)	0.647
Maximum constriction velocity	2.61 (0.99)	2.70 (0.98)	0.075	2.87 (1.01)	2.78 (1.12)	0.080
Latency	0.24 (0.05)	0.25 (0.07)	0.075	0.24 (0.08)	0.24 (0.08)	0.999
Dilation velocity	0.84 (0.38)	0.84 (0.34)	0.666	0.88 (0.38)	0.92 (0.36)	0.356

Table 3
Percent agreement between NPi200 and NPi300 readings from left and right eyes.

Pupillometer Metric	% time same reading was obtained	
	Left Eye	Right Eye
NPi	97.66%	96.49%
Initial Diameter	85.38%	87.72%
Minimum Diameter	98.25%	95.91%
Percent Change	98.25%	95.32%
Constriction Velocity	93.57%	92.40%
Latency	98.25%	99.42%
Dilation Velocity	98.83%	97.66%
Mean Constriction Velocity	84.21%	84.21%

*Values were considered similar if the difference in NPi, pupil initial or minimum diameter, or latency was < 0.5; if the difference in percent change in pupil diameter was < 10%; or if the difference in constriction, mean constriction, or dilation velocity was < 0.8.

and statistically significant differences in maxPD and minPD by device. The observations with clinically relevant differences in NPi were all found in the patient cohort. The neurocritically ill patients in our sample were known to be at risk for cerebral edema and it is established that cerebral dynamics such as intracranial pressure (ICP) are dynamic and may change significantly over a short period of time. Several studies have found associations between NPI and intracranial pressure [24–27], or pressure related conditions such as midline shift [28]. It is also worth noting that our PLR assessments were timed to occur when the nurse would be completing a full neurological exam, and these exams are conducted after turning off any sedative infusions. Early work out of Canada has identified that sedation levels may impact NPi values [29]. Because ICP and sedative infusion data were not collected during this study, it is unknown if these 3 observations were associated with dynamic changes in intracranial or sedative status.

The differences in PD may be explained by accommodation or, as noted above, by changes in ICP or sedation status. The biggest differences were seen in healthy controls suggesting that they may have focused their vision at a further distance during one of the exams, resulting in a larger PD. It is also possible that patients may have had different alertness levels (e.g., been more awake during one exam versus the other) and thus they focused their vision closer or further during the two exams. Prior research has established that CV can be influenced by the baseline PD and is not a good indicator of pathology [30,31]. For example, a small pupil has a limited size change and will therefore have a slower CV. These potential explanations warrant further research because they could guide clinicians to individualize the PLR exam by increasing or decreasing the observation interval. Prior to the pupillometer CV was described only as sluggish, brisk, or fixed [28,32].

Readings were obtained by nurses, physicians and study personnel. Not having restrictions on who obtained the readings has benefits and drawbacks. The usage of pupillometers is standard of care and both clinical staff and research staff obtained readings during the study. A clear benefit is that the results represent real-world conditions. The drawback is that this reduces the internal validity of the measurement. Similar technology such as transcranial Doppler, and the application of electroencephalography leads are known to be operator dependent [33]. However, the finding of high reliability suggests that there is not an operator dependent confounder present in pupillometry.

6. Limitations

Although normal ambient light conditions do not impact the pupillometer summary score (NPi), light does affect pupil diameter [34]. It is possible that controlling for ambient light would have resulted in higher inter-device reliability, especially for pupil size. As noted earlier, this study used a real-world setting and not controlling for ambient light increases the external validity of the findings. Obtaining readings within

5 min of the prior reading was intended to increase internal validity associated with rapid changes in patient conditions (not uncommon for NSICU patients). However, this may have limited the ability of some patient's pupils to fully recover. The correct amount of time to wait between readings to avoid habituation or muscle fatigue in a diverse sample of NSICU patients is not known but may play a role in repeated PLR measurements [35,36]. This study was designed to be similar to prior research, therefore, the time between readings was decided based on previous research [14].

7. Conclusion

The results indicate that there is a very high level of agreement between the NPi-200 and NPi-300. This supports our hypothesis that data from the devices are translatable for clinical assessments and decision-making. The NPi-200 and NPi-300 show very high inter-device reliability when used to assess both patients at risk for cerebral edema, and healthy controls. Moreover, all healthy controls had NPi values $\geq$ 3.0. This supports that the current practice of describing NPi values $\geq$ 3.0 as *normal* is reasonable. The data also showed that inter-device reliability was not different for healthy controls versus acutely ill patients. For clinicians and researchers transitioning from the NPi-200 to the NPi-300 there is little need for retraining on interpretation of results.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest

DaiWai Olson is a chief editor of American Association of Neuroscience Nurses. All other authors have no conflicts to report.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jocn.2022.04.023.

References

[1] Giamarino K, Blessing R, Boelter C, Thompson JA, Reynolds SS. Exploring the Relationship Between Objective Pupillometry Metrics and Midline Shift. J Neurosci Nurs 2021;53(6):233–7. https://doi.org/10.1097/jnn.0000000000000614.
[2] Miroz J-P, Ben-Hamouda N, Bernini A, Romagnosi F, Bongiovanni F, Roumy A, et al. Neurological Pupil index for Early Prognostication After Venoarterial Extracorporeal Membrane Oxygenation. Chest 2020;157(5):1167–74.
[3] Campbell WW, Barohn RJ. DeJongs The Neurologic Examination. 8th ed. Wolters Kluwer; 2020.
[4] Olson DM, Stutzman S, Saju C, Wilson M, Zhao W, Aiyagari V. Interrater reliability of pupillary assessments. Neurocrit Care Apr 2016;24(2):251–7. https://doi.org/10.1007/s12028-015-0182-1.
[5] McGetrick ME, Schneider N, Olson DM, Aiyagari V, Miles D. Automated Infrared Pupillometer Use in Assessing the Neurological Status in Pediatric Neurocritical Care Patients: Case Reports and Literature Review. J Child Sci 2021;11(01):e125–32.
[6] Oddo M, Taccone F, Galimberti S, Rebora P, Citerio G. Outcome Prognostication of Acute Brain Injury using the Neurological Pupil Index (ORANGE) study: protocol for a prospective, observational, multicentre, international cohort study. BMJ Open 2021;11(5):e046948.
[7] Cortes MX, Siaron KB, Nadim HT, Ahmed KM, Romito JW. Neurological Pupil Index as an Indicator of Irreversible Cerebral Edema: A Case Series. J Neurosci Nurs 2021;53(3):145–8. https://doi.org/10.1097/jnn.0000000000000584.
[8] Hall CA, Chilcott RP. Eyeing up the Future of the Pupillary Light Reflex in Neurodiagnostics. Diagnostics 2018;8(1). https://doi.org/10.3390/diagnostics8010019.
[9] Olson DM, Stutzman SE, Atem F, Kincaide JD, Ho T-T, Carlisle BA, et al. Establishing Normative Data for Pupillometer Assessment in Neuroscience Intensive Care: The "END-PANIC" Registry. J Neurosci Nurs 2017;49(4):251–4.
[10] Clark A, Clarke TN, Gregson B, Hooker PN, Chambers IR. Variability in pupil size estimation. Emerg Med J Jun 2006;23(6):440–1. https://doi.org/10.1136/emj.2005.030247.
[11] Litvan I, Saposnik G, Maurino J, et al. Pupillary diameter assessment: need for a graded scale. Neurology 2000;54(2):530–1.
[12] Menozzi M, Oddo M, Peluso L, et al. Early Neurological Pupil Index Assessment to Predict Outcome in Cardiac Arrest Patients Undergoing Extracorporeal Membrane Oxygenation. ASAIO J 2021. https://doi.org/10.1097/mat.0000000000001569.
[13] Olson DM, Fishel M. The Use of Automated Pupillometry in Critical Care. Crit Care Nurs Clin North Am Mar 2016;28(1):101–7. https://doi.org/10.1016/j.cnc.2015.09.003.
[14] Zhao W, Stutzman S, DaiWai O, Saju C, Wilson M, Aiyagari V. Inter-device reliability of the NPi-100 pupillometer. J Clin Neurosci Nov 2016;33:79–82. https://doi.org/10.1016/j.jocn.2016.01.039.
[15] Lussier BL, Stutzman SE, Atem F, Venkatachalam AM, Perera AC, Barnes A, et al. Distributions and Reference Ranges for Automated Pupillometer Values in Neurocritical Care Patients. J Neurosci Nurs 2019;51(6):335–40.
[16] Morelli P, Oddo M, Ben-Hamouda N. Role of automated pupillometry in critically ill patients. Minerva Anestesiol Sep 2019;85(9):995–1002. https://doi.org/10.23736/s0375-9393.19.13437-2.
[17] Zafar SF, Suarez JI. Automated pupillometer for monitoring the critically ill patient: a critical appraisal. J Crit Care Aug 2014;29(4):599–603. https://doi.org/10.1016/j.jcrc.2014.01.012.
[18] Giantin V, Toffanello ED, Enzi G, Perissinotto E, Vangelista S, Simonato M, et al. Reliability of body temperature measurements in hospitalised older patients. J Clin Nurs 2008;17(11):1518–25.
[19] Siaron KB, Cortes MX, Stutzman SE, Venkatachalam A, Ahmed KM, Olson DM. Blood Pressure measurements are site dependent in a cohort of patients with neurological illness. Sci Rep 2020;10(1).
[20] Samudra NP, Park SM, Gray SE, Sebai MA, Olson DM. Inconsistency in Reporting Variables Related to Intracranial Pressure Measurement in Scientific Literature. J Nurs Meas Dec 2018;26(3):415–24. https://doi.org/10.1891/1061-3749.26.3.415.
[21] Olson DM, Batjer HH, Abdulkadir K, Hall CE. Measuring and monitoring ICP in Neurocritical Care: results from a national practice survey. Neurocrit Care Feb 2014;20(1):15–20. https://doi.org/10.1007/s12028-013-9847-9.
[22] Howell JD, The CT. Scan after 50 years - Continuity and Change. N Engl J Med 2021;385(2):104–5. https://doi.org/10.1056/NEJMp2033374.
[23] Gerke O. Reporting Standards for a Bland-Altman Agreement Analysis: A Review of Methodological Reviews. Diagnostics (Basel) 2020;10(5). https://doi.org/10.3390/diagnostics10050334.
[24] El Ahmadieh TY, Bedros N, Stutzman SE, Nyancho D, Venkatachalam AM, MacAllister M, et al. Automated Pupillometry as a Triage and Assessment Tool in Patients with Traumatic Brain Injury. World Neurosurg 2021;145:e163–9.
[25] McNett M, Moran C, Janki C, Gianakis A. Correlations Between Hourly Pupillometer Readings and Intracranial Pressure Values. J Neurosci Nurs : J Am Assoc Neurosci Nurses Aug 2017;49(4):229–34. https://doi.org/10.1097/jnn.0000000000000290.
[26] Al-Obaidi SZ, Atem FD, Stutzman SE, Olson DM. Impact of Increased Intracranial Pressure on Pupillometry: A Replication Study. Crit Care Explor Oct 2019;1(10):e0054.
[27] McNett M, Moran C, Grimm D, Gianakis A. Pupillometry Trends in the Setting of Increased Intracranial Pressure. J Neurosci Nurs : J Am Assoc Neurosci Nurses Dec 2018;50(6):357–61. https://doi.org/10.1097/jnn.0000000000000401.
[28] Osman M, Stutzman SE, Atem F, Olson DaiWai, Hicks AD, Ortega-Perez S, et al. Correlation of Objective Pupillometry to Midline Shift in Acute Stroke Patients. J Stroke Cerebrovasc Dis 2019;28(7):1902–10.
[29] Martineau-Lessard C, Arbour C, Germélus N, Williamson D, De Beaumont L, Bernard F. Pupil Light Reflex for the Assessment of Analgesia in Critically Ill Sedated Patients With Traumatic Brain Injury: A Preliminary Study. J Neurosci Nurs : J Am Assoc Neurosci Nurses 2022;54(1):6–12. https://doi.org/10.1097/jnn.0000000000000627.
[30] Shoyombo I, Aiyagari V, Stutzman SE, Atem F, Hill M, Figueroa SA, et al. Understanding the Relationship Between the Neurologic Pupil Index and Constriction Velocity Values. Sci Rep 2018;8(1).
[31] Bremner FD. Pupillometric evaluation of the dynamics of the pupillary response to a brief light stimulus in healthy subjects. Invest Ophthalmol Vis Sci 2012;53(11):7343–7. https://doi.org/10.1167/iovs.12-10881.
[32] Dance S, Scholefield BR, Morris KP, Kanthimathinathan HK. Characteristics of a Brisk or Sluggish Pupillary Light Reflex: A Nursing Perspective. J Neurosci Nurs Jun 2020;52(3):128–31. https://doi.org/10.1097/jnn.0000000000000501.
[33] D'Andrea A, Conte M, Scarafile R, Riegler L, Cocchia R, Pezzullo E, et al. Transcranial Doppler Ultrasound: Physical Principles and Principal Applications in Neurocritical Care Unit. J Cardiovasc Echogr 2016;26(2):28.
[34] Ong C, Hutch M, Smirnakis S. The Effect of Ambient Light Conditions on Quantitative Pupillometry. Neurocrit Care Apr 2019;30(2):316–21. https://doi.org/10.1007/s12028-018-0607-8.
[35] Leuchs L, Schneider M, Czisch M, Spoormaker VI. Neural correlates of pupil dilation during human fear learning. Neuroimage 2017;147:186–97. https://doi.org/10.1016/j.neuroimage.2016.11.072.
[36] Matsui T, Hara K, Kayama T, Iwata M, Shitara N, Hojo S, et al. Cervical muscle diseases are associated with indefinite and various symptoms in the whole body. Eur Spine J 2020;29(5):1013–21.