7-Year Experience with Automated Pupillometry and Direct Integration With the Hospital Electronic Medical Record

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■ INTRODUCTION: **Manual pupillary assessments are an integral part of the neurologic evaluation in critically ill patients. Automated pupillometry provides reliable, consistent, and accurate measurement of the light response. We established a computer interface that allows for direct download of pupillometer information to our hospital electronic medical record (EMR). Here, we report our single-center experience.**

■ METHODS: **An interface allowing direct download of pupillometer data to our EMR was developed. We then performed a prospective study using an electronic survey distributed to nurses that used pupillometers in 2015, 2018, and 2020 using a 5-point Likert-style format to evaluate the acceptance of this implementation.**

■ RESULTS: **In 2015, 22 nurses were surveyed, with 50% of the respondents citing lack of pupillometers and 41% citing the labor intensity associated with data entry as the reason for the reluctance to use the pupillometer. The number of nurse responses in 2018 increased to 123, with 78% of nurses finding that the direct download to hospital EMR improved the efficiency of their neurologic exams. In 2020, 108 nurses responded with similar responses to those in 2018. We added 3 additional questions regarding utility of the pupillometer during the COVID-19 pandemic. Fifty-eight percent of nurses were reassured of the neurologic exam when using the pupillometer in lieu of a full exam to limit infectious exposure.**

■ CONCLUSIONS: **This is the first report of the implementation of a direct interface to download pupillometer data to the EMR. The positive effect on nursing workflow and documentation of pupillary findings is discussed.**

INTRODUCTION

Manual assessment of the pupils is an important yet routine part of the neurologic evaluation of the critical care patient. Pupil size and the pupillary light reflex are clinical parameters with diagnostic and prognostic significance.[1,2] Rapid and accurate assessment of the pupils of patients with neurologic injuries can lead to the detection of focal mass effect or increased intracranial pressure.[3,4] This information may guide the subsequent treatment paradigm. Pupillary assessments are traditionally done by physicians and nurses using a penlight or flashlight. Interpretations are subjective, and particularly difficult and frequently unreliable in patients with small, dark, or sluggish pupils.[5] This led to the development of the NeurOptics pupillometer (Irvine, CA), a U.S. Food and Drug Administration—approved hand-held infrared device, which automatically tracks and analyzes pupil dynamics over a short time period (Figure 1).

Pupillometer values have been shown to correlate with intracranial pressure[6] and another study has shown that pupillometry may aid in early detection of elevated intracranial pressure.[7] Pupillometer studies demonstrate a robust correlation between pupillometer measurements and poor neurologic outcomes after cardiac arrest.[8,9] Pupillometry is sensitive and changes may reflect the early onset of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage.[10] In contrast, pupillometry in patients with spontaneous intracranial

Key words
- ICU
- Neurocritical care
- Pupillometer

Abbreviations and Acronyms
EMR: Electronic medical record
HID: Hardware interface device
ICU: Intensive care unit
Npi: Neurological Pupil Index
NSICU: Neuroscience intensive care unit

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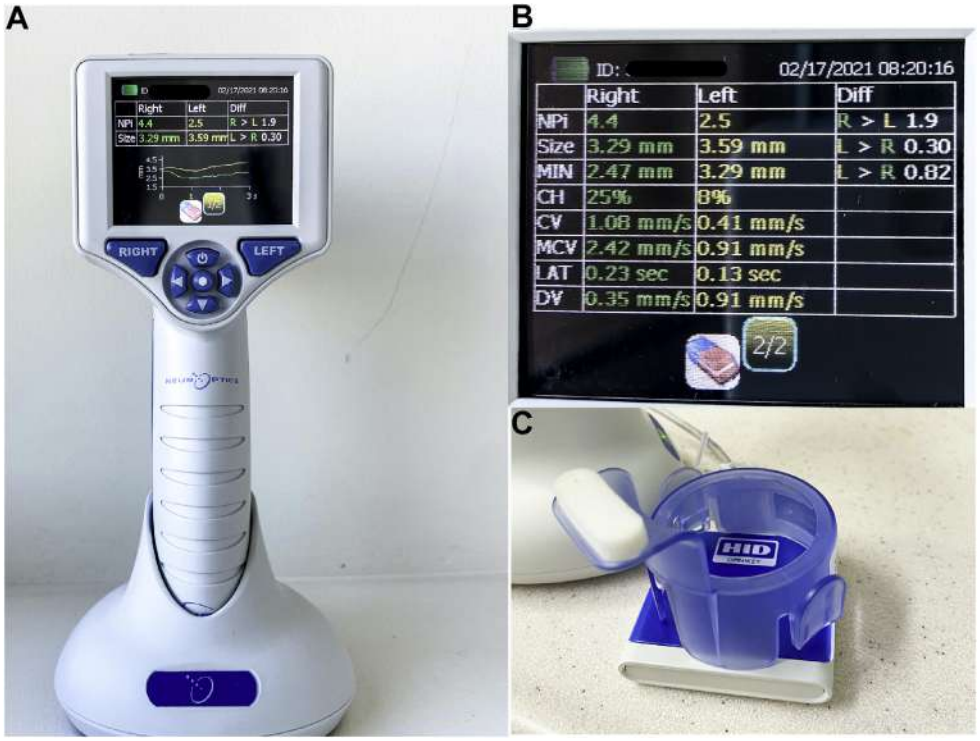

Figure 1. (**A**) NeurOptics NPi 200 pupillometer. (**B**) Example of parameters pupillometer measurements. As the standard of care in the ICU, these are done on an hourly basis. Only neurological pupil index (NPI) and pupil size are stored in the EMR. The other variables are stored in the UCI master server and archived and may be retrieved at a later date. This is part of the UCI "big data" set initiative. (**C**) HID reader.

hemorrhage has reassured physicians that there are not intracranial pressure concerns in most of these cases.[11,12] There have also been some recent findings with the pupillometer that suggest a correlation between pupil changes and the status of cerebral autoregulation.[13] There are many active areas of research extending the potential use of the pupillometer to assess cerebral function in a noninvasive manner. Careful and reliable acquisition of the information may clearly assist in this research.

The improved accuracy of the pupillometer over the visual inspection via the penlight has been demonstrated.[7,14-16] Automated pupillometry provides reliable, consistent, and accurate measurement of the pupillary light response. Nonetheless, there are barriers to the use of this device that have limited its widespread use in hospitals. We describe our experience with the pupillometer over a 7-year time period at a quaternary academic medical center. The introduction and modifications to pupillometer use that has led to its implementation are discussed. Nursing reception and attitudes were tracked with serial surveys. One of the key reasons for the resultant seamless use of the pupillometer across the hospital was the adoption of computer interfaces that allow the direct download of NeurOptics NPi-200 pupillometer data to the hospital electronic medical record (EMR). We describe the process of the implementation of the pupillometer at our institution as well as the evolution of nursing acceptance of it. We also describe the benefits of having the direct download of data into our hospital EMR system.

METHODS

The Pupillometer

The pupillometer used in this study is the NPi-200 model from NeurOptics (Irvine, CA) developed in 2015. The device has a detachable headrest (SmartGuard), which facilitates the placement of the pupillometer in front of the eye, stabilizing the device to allow administration of a flash of light of fixed intensity and duration to stimulate the pupillary response. Pupil size, along with variables of the pupillary light reflex and pupillary reflex dilation, is calculated by the instrument and displayed on a screen immediately after each measurement.[17]

Development of Pupillometer Direct Download to the Hospital EMR

The pupillometer device is connected to the hospital EMR via a small-form factor PC with a hardware interface device (HID; HID Global, Austin, TX) reader attached. The HID reader has a unique identifier that is associated to the patient in order to ensure that the specific HID reader only reports to that patient. The HID reader gathers the pupillometer information from a microchip

located in the SmartGuard on the device. Once this chip is put on the HID reader, it collects the data from the chip using iSirona (Irvine, CA) DeviceConX software. The program takes the data, packages it into HL7 format and then sends it to our EMR in near real-time. The neurosurgery team may access the pupillometer results remotely via EMR.

When a pupillary evaluation is performed on a patient, the data are time-stamped by the pupillometer. The initial implementation, done in January 2015, was created for our hospital's previous EMR system (Sunrise Allscripts, Chicago, IL). At that time, the nurses would have to log on to the EMR to manually type this data into the electronic flowsheet. The data could only be populated into a flowsheet from a device within 10 minutes from when it was taken. This ensured that the data were accurate and reliable. However, with the conversion to our new EMR (EPIC Hyperspace, Verona, WI) in November 2018, nurses no longer log on to the EMR to populate the data. The information now automatically imports to the EMR when the nurses place the chip on the HID reader (Figure 1C).

The data transmitted to the hospital EMR includes Neurological Pupil Index (NPi), diameter of pupil minimum, diameter of pupil maximum, percentage of pupil change, latency of pupil constriction, pupil constriction velocity, maximum pupil constriction velocity, and pupil dilation velocity (Figure 1B).

Surveying of the Nurses/Data Collection

To evaluate the ease and efficacy of implementation, an electronic survey was distributed to nurses in the neuroscience intensive care unit (NSICU) shortly after implementation of the direct download to the EMR. In this survey, nurses were surveyed on their reasons for lack of routine pupillometer measurements. In a follow-up survey 6 months later, nurses were surveyed on reasons for not using the pupillometer despite the implementation. In our final survey of that year, nurses were surveyed on a variety of factors with certain questions using a Likert scale based on nurses' comfort and preferences for the pupillometer. We then issued follow-up surveys in 2018 and 2020 using the same questions, with additional questions regarding COVID-19 in our 2020 survey.

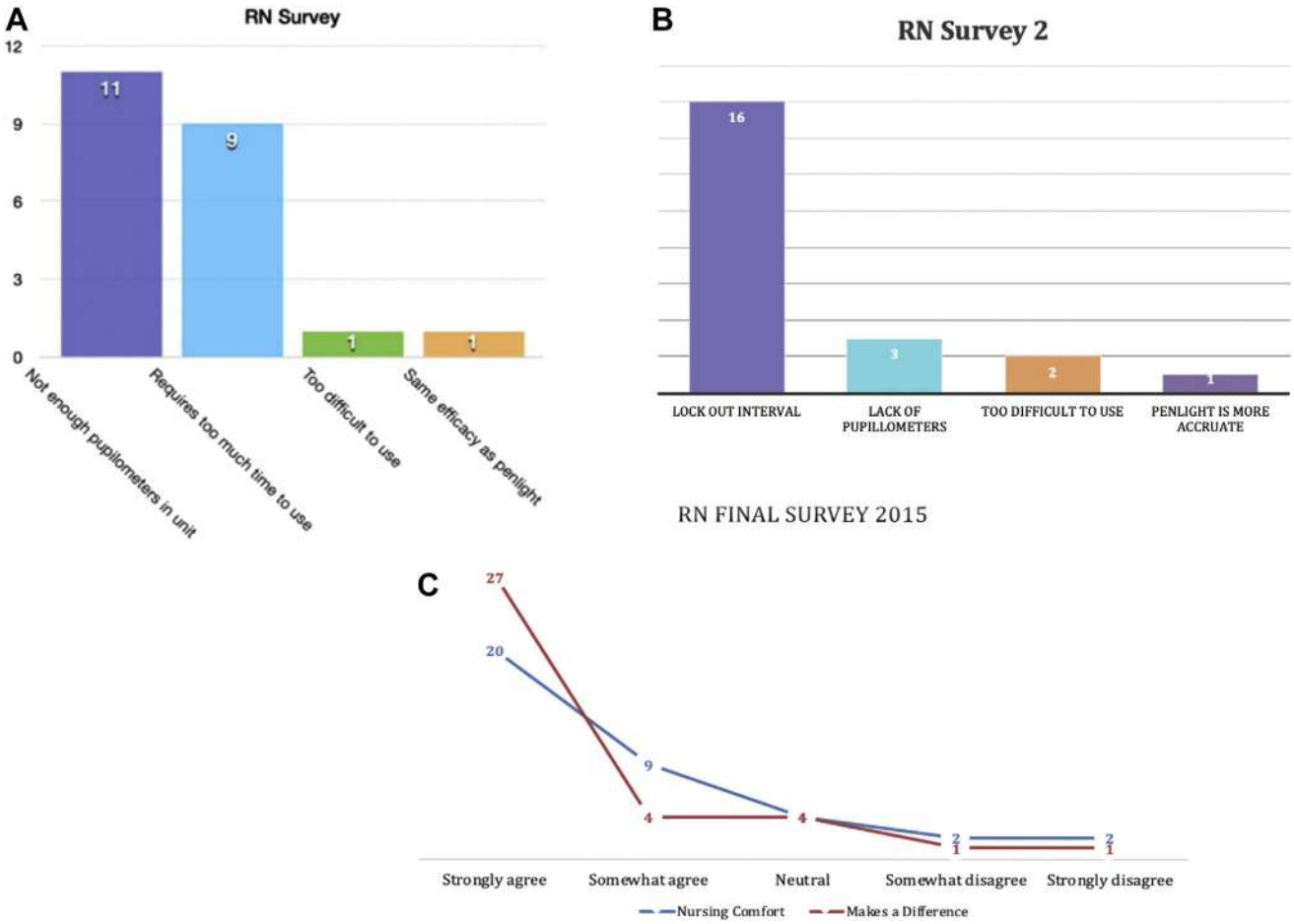

Figure 2. (**A**) Initial survey done in 2015 with 22 neuro ICU nurses. (**B**) Follow up survey done in 2015 with same 22 nurse. (**C**) Final survey done in 2015.

Evaluating Nursing Assessment with Pen Light versus Pupillometer

Four of the coauthors were then timed while performing pupil assessments with a traditional flashlight and then again with the NeurOptics pupillometer. These evaluations were repeated every hour for 4 hours and averaged. We then took the average and applied them to a 24-hour day and then 7-day intensive care unit (ICU) stay.

Evaluation of the Use of the Pupillometer Across Different Units Between 2017 and 2021.

The implementation of the pupillometry data to the EMR allows the ability to track the daily usage of the pupillometer in each unit. The time periods October 1, 2017–January 31, 2018, October 1, 2018–January 31, 2019, October 1, 2019–January 31, 2020, and October 1, 2020–January 31, 2021 were queried for number of days that the pupillometer were used. Each day that the pupillometer is used is counted.

RESULTS

In 2014 there were no pupillometers in the hospital. In 2015, 6 pupillometers were introduced into our hospital in the NSICU. In our preliminary survey shortly after the direct download implementation, only 22 NSICU nurses were surveyed, and 50% (n = 11) of the respondents cited lack of pupillometers and 41% (n = 9) cited the labor intensity associated with data entry as the reason for the reluctance to use the pupillometer (Figure 2A). In our secondary nursing survey, which was issued 6 months after the initial survey, 73% (n = 16) (Figure 2B) of nurses stated lock-out time as the number 1 reason for not using the pupillometer. However, 100% (n = 22) of nurses agreed that the new system is very user-friendly and does promote faster work flow in the ICU. Our final questionnaire of that year had 37 responses from the nursing staff. It showed that 78% (n = 29) of nurses are very comfortable with the use of pupillometer and 84% (n = 31) of nurses think that it has made a difference in patient outcomes (Figure 2C).

Although the survey was longer, with several additional questions, the number of nurse responses in 2018 increased to 123 (Table 1) with 96% (n = 118) of nurses finding that the automatic download to hospital EMR makes neurologic checks easier and saves time. Eighty-nine percent (n = 110) of nurses find pupillometry more useful than the penlight (Figure 3A). In the 2020 follow-up survey, 108 (Table 1) nurses responded with similar responses to those in 2018. There was a total of 15 questions in both surveys. Ten questions addressed nursing comfort and satisfaction (Figure 3B). These scored an average of 4.5 out of 5 in 2018 and 4.7 out of 5 in 2020 on a 5-point Likert scale (5 = most favorable) (Figure 4). The 2020 survey had 3 questions about use of pupillometers during the COVID-19 pandemic. Fifteen percent (n = 16) of the nurses felt pupillometers were helpful in these patients. Fifty-eight percent (n = 63) of nurses were reassured of the neurologic exam when using the pupillometer in lieu of a full exam to limit infectious exposure.

The total number of responses relative to the total number of nurses queried varied across the surveys. In 2015 this ratio was 22 of 22 (100%), in 2018 it was 123 of 280 (44%), in 2020 it was 108 of 204 (53%). The response rate for 2018 and 2020 is on par with most surveys.

With the introduction of the pupillometer, the total time it takes to assess a patient's pupils was reduced from an average of 266 minutes in a 7-day period to 105 minutes in a 7-day period. This saves the nurses about two and a half hours of total time in a seven-day period/patient (Table 2).

Since the expansion of the pupillometers in 2018, we noticed that there was increase in the usage of the device across all units (Figure 5A) across all queried periods, with the exception of October 2020–January 2021. We then queried an additional 3 months from February 2021 through April 2021 and noted that there was again an increase in the usage (Figure 5B).

When testing reproducibility of the results for the pupillometer, there was consistency in pupillary size and reactivity across all users.

DISCUSSION

Pupillary size, symmetry, and reactivity to light are important components of the neurologic assessment of patients with critical

Table 1. Nursing Demographics

	Nurses Surveyed 2015 (Initial)	Nurses Surveyed in 2015 (Final)	Nurses Surveyed 2018	Nurses Surveyed 2020
Neuro ICU	22	37	25	25
Neuro Step Down			8	12
MICU/CVICU			28	26
SICU			57	35
Burn ICU			5	10
Nurse for 0–1 year		3	7	9
Nurse for 1–3 years		8	17	11
Nurse for 3–5 years		3	17	16
Nurse for 5–10 years		5	32	29
Nurse for >10 years		18	50	41

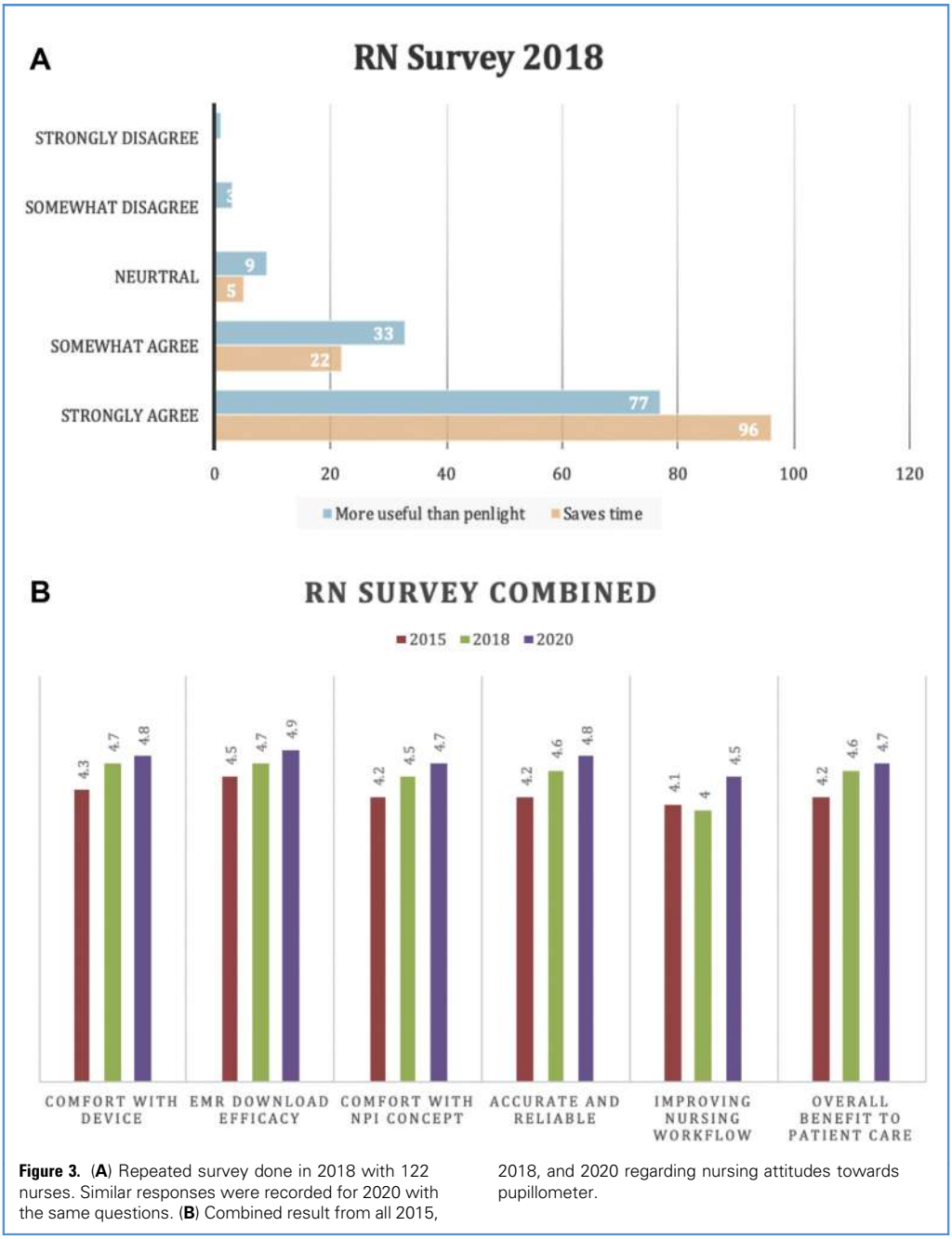

Figure 3. (**A**) Repeated survey done in 2018 with 122 nurses. Similar responses were recorded for 2020 with the same questions. (**B**) Combined result from all 2015, 2018, and 2020 regarding nursing attitudes towards pupillometer.

neurologic conditions. Manual pupillary assessment uses a penlight to evaluate pupil reactivity and a ruler to measure pupil size. Manual size measurements can be subjective and based on the examiner, leading to inconsistencies in the patient's medical chart. The automated pupillometer removes this subjectivity as well as intra- and interobserver variability and permits reliable, noninvasive examinations.[15,18-20] Despite the accuracy and reliability of this, there were still barriers to nurses using the pupillometer. A previous study reported in 2018 discussed several barriers.[21]

One of the early reported barriers to our nurses' use of pupillometer was the labor intensity of imputing the data into the EMR once this measurement is captured. As can be seen on the image of the pupillometer screen (Figure 1B) there are up to 8 parameters for each pupil that can be entered (16 total) each hour. If one selects to enter the most important variables (NPi, Max, Min, % reactivity—which are the 4 parameters that we use at this institution) there are 4 parameters for each pupil, or 8 values, that require computer entry into the EMR. To overcome this barrier, we introduced a method to directly download the

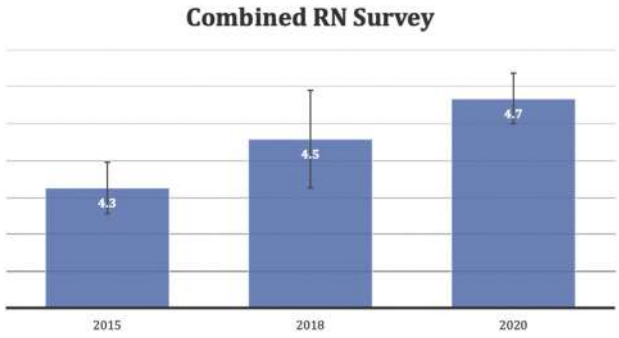

Figure 4. Combined results from Likert scale of 2015, 2018, and 2020 with standard deviations.

pupillometer data into our hospital's EMR in January 2015. In our study, we analyzed the effectiveness of this implementation and how this has affected the nurse work flow over the years. To the best of our knowledge, this is the first published report on this direct implementation system and also the first to show the acceptance of the direct download of pupillometer data to the hospital's EMR by the ICU nurses.

In 2015, there were only 6 pupillometers available in the entire hospital. In 2018, we increased that number to 32 for a 1:1 patient to pupillometer ratio in the NSICU (12), 4:1 ratio in the Surgical ICU (6), 3:1 ratio in our Medical/Cardiovascular ICU (8), 3.75:1 ratio in our Neuro Step Down unit (4), and 12:1 ratio in our Burn ICU (1). We have also recently added an additional pupillometer in the Emergency Department. With the increase in pupillometers, nursing staff are more readily able to use the pupillometer.

After implementing the direct download of pupillometer data into our hospital EMR, nurses were evaluated and timed performing the assessments using both penlight and pupillometer. Based on the nursing standards, when a penlight is used, nurses have to perform the assessment twice to ensure better accuracy. This was done to see if the pupillometer required more labor intensity than the traditional penlight assessments. Our results show that the pupillometer decreases the amount of time spent evaluating a patient's pupils by 149 minutes per patient in a 7-day ICU stay, which averages to about 21 minutes per patient saved in a 24-hour period. Most of the time saved is in the documentation phase. This frees up the nurses to attend to other duties. Our results also show that repetitive measurements with pupillometer provide more consistent results with pupillary size and reactivity as compared to penlight regardless of the user. This is consistent with the findings from other groups.[5,16]

Further surveys show increasing nursing comfort with pupillometer with each passing year. Each of the 10 questions that evaluated nursing comfort and satisfaction has an increase in the Likert score in 2018 and subsequently 2020, with all questions answered above 4. This is likely due to the fact that the direct download makes the nursing work flow easier and faster. Alternatively, this may be explained in part by the more widespread use of the pupillometer in all of the ICUs. However, it is notable that the pupillometer is available to the nurses and physicians as an option. Use of the pupillometer is driven either by physician request via an order in EPIC or by the bedside nurse.

As noted in the Results section, there was a difference in the percentage of responses in the 2015, 2018, and 2020 surveys. The 2015 survey had a 100% level of participation This is likely because it was limited to the NSICU, in which all of the nurses were very closely knit. One reason for the lower percentage participation in the 2018 (44%) and 2020 (53%) surveys is the use of a general list of ICU nurses that may include a large number of visiting nurses from outside who are at our institution transiently and may not have updated e-mails. It also included nurses who might be on leave. With this and any survey there is the concern that there is selection bias such that those that respond are more likely to either have favorable or unfavorable impressions of item in question. We found overall that we had mostly favorable impressions of the pupillometer.

Table 2. Nursing Timing for Standard Pupil Exam With Penlight Versus Pupillometer

Traditional Pupil Assessment	Time Spent (sec)	Pupillometer Assessment	Time Spent (sec)
Obtaining flashlight/penlight/ophthalmoscope	8	Obtaining pupillometer	6
Light (direct and consensual assessments performed on both eyes twice (averaged)*	22	Programming SmartGuard with scanner (once)	20 (once)
EMR Log on time	32	Pupillometer assessment (including attachment of SmartGuard)	27
Manual documentation of pupillary assessment on EMR	34	Docking headrest	4
Total penlight assessment	96	Total pupillometer assessment	37
Total 24 hours**	2304 (38 min)	Total pupillometer assessment including onetime programming of headrest	57
Total 7-day ICU stay	266 mins	Total 24 hours †	908 (15 min)
		Total 7-day ICU stay	105 min

*Pupil assessment based on current standard of care outlined in Mosby Nursing Skills 2014.
**Care of patient over the course of 24 hours with hourly pupillary neurological assessments.

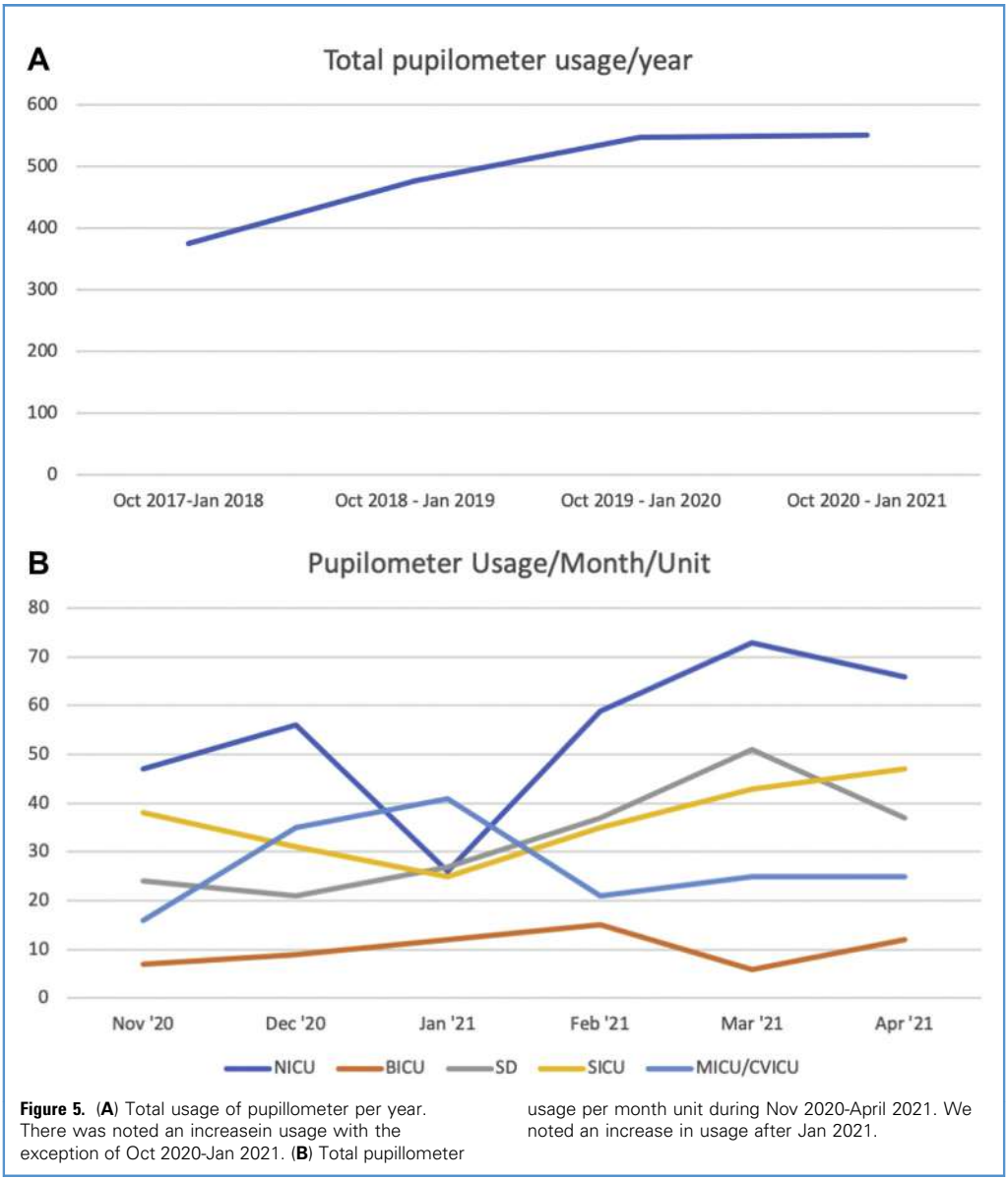

Figure 5. (**A**) Total usage of pupillometer per year. There was noted an increasein usage with the exception of Oct 2020-Jan 2021. (**B**) Total pupillometer usage per month unit during Nov 2020-April 2021. We noted an increase in usage after Jan 2021.

The addition of the automated pupillometer has improved nursing work flow as well as patient care in many ways. Because the pupillometer provides accurate and concrete information regarding pupil size and reactivity, nurses and physicians can reliably trust the data, particularly for complex patients. It is notable that the majority of these complex patients are intubated and sedated. The pupillometer measurements are readily obtainable as their movement is minimal. Furthermore, even in patients with delirium or combativeness, they can be examined with the pupillometer with little to no sedation because it can be done quickly. With the expansion of the number of pupillometers, there is 1 readily available in all ICUs as well as the Emergency Department. This is especially helpful when trauma patients who are unresponsive present to our Emergency Department and there is a question about pupil reactivity.

When querying the usage data, there was an increase in usage up until the period of October 2020—January 2021.The increase in usage is likely multifactorial. Because our institution adopted pupillometry in the NSICU in 2015, we have continued to adopt the technology across multiple critical care units in the hospital. Our critical care nursing staff have found that the pupillometer provides accurate, reliable, objective pupillary size and reactivity measurements in critically ill patients. Because the automatic download happens within seconds of placing the HID reader down, it provides a valuable time savings for the nursing staff, reducing time charting and increasing nursing's adoption of pupillometry into their workflow. This information is also available remotely to physicians who may be able to view the results remotely via EPIC. Lastly, having more pupillometers on hand ensures adequate equipment to support optimal nursing workflow

preferred by the staff. The nurses, particularly in the NSICU, where there is 1 pupillometer for each patient room, now have a pupillometer readily available for them to use in their patient care management.

We suspect the plateau of usage in October 2020—January 2021 is due to the COVID-19 pandemic. During that time, our hospital was over peak capacity for COVID patients. This resulted in fewer Emergency Department visits for patients as well as fewer hospital transfers for tertiary care. When the number of COVID patients in our hospital decreased, we noted an increase in pupillometer usage.

Another advantage with the implementation of the automatic download into our EMR is that we can observe the changes of thae patient's pupils over time. This can be done anywhere EPIC may be accessed. This is particularly useful as patients are spread out over the different ICUs in the hospital and the physician care team may also be spread out across the hospital. The improved accessibility to the pupillary data can improve patient care. Additionally, the ability to visualize the data graphically allows one to trend the changes over time (Figure 6).

The cost of the pupillometer is about $4995 and the HID reader is $120. These are built into the infrastructure of our ICUs. The NSICU has 1 pupillometer and 1 HID reader for each of the 12 rooms. As noted above, our other units have a lower ratio of pupillometers/room. This is by design as these other units may not have as many patients with neurologic issues. If these units have a higher-than-expected number of patients who require pupillary monitoring, the pupillometers may be shared between rooms as the SmartGuard is uniquely assigned to each patient. Our institute has placed an HID reader in each ICU room as it is difficult to predict whether a particular patient admitted may or may not need pupillometry measurements. The costs of the pupillometer and the HID set-up may make it difficult for many hospitals to apply a similar set-up. However, it may be implemented readily on a smaller scale, piecemeal, with a "sharing" of pupillometers across ICU beds, as we have done in some of our non-neuroscience ICUs. The key to the integration of the download to the hospital EMR is dependent upon the Information Technology department and its infrastructure. That cost has not been calculated as it was done by an Information Technology team that is dedicated at our institute to the routine maintenance and integration of devices (i.e., blood pressure monitors, ventilators) in the ICU.

We have found that the pupillometers and HID readers have a rather long life and do not require frequent replacements. In our series, a couple of the pupillometers were replaced when they were inadvertently lost when they were misplaced in the laundry. Those mishaps have been corrected. The infrastructure costs of the pupillometer system may vary depending on the set-up of a particular hospital. However, the detachable SmartGuard is disposable and single-patient use. The cost of that is $25 and has the memory capacity that can record hourly measurements for 7 days.

Limitations of Study

As with any study involving surveys, our study has inherent bias and limitations. Because this study is based on a Likert scale, there is selection bias. Nurses who are more likely to use the pupillometer are also more likely to fill out the survey, which means we may not necessarily have an accurate representation of all nurses.

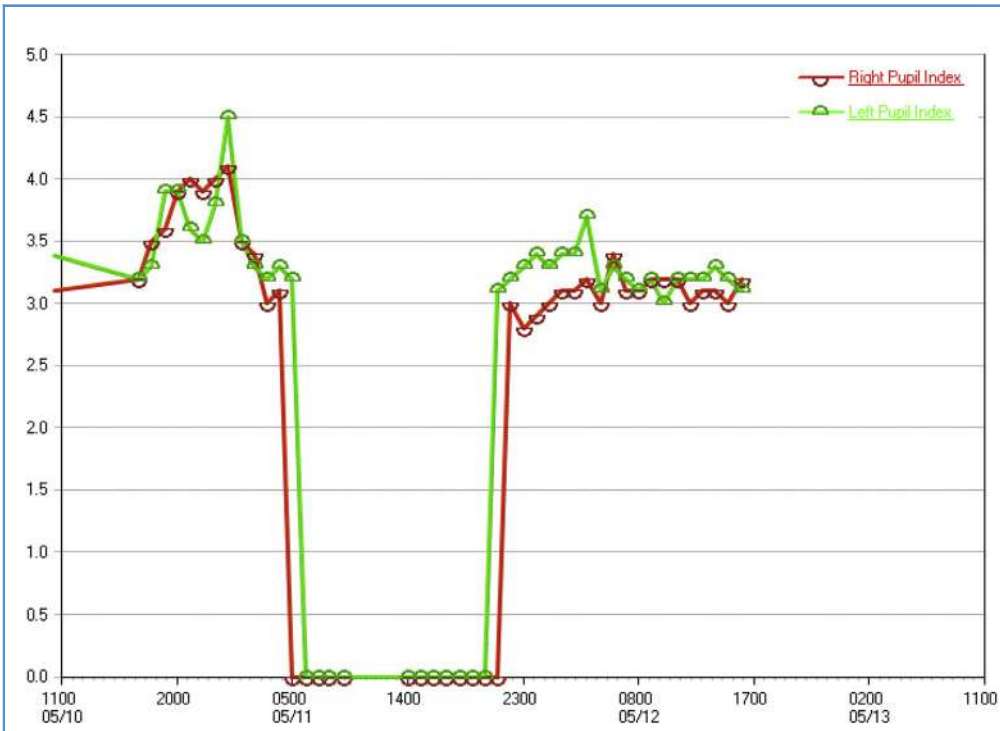

Figure 6. Example of pupillometer data trends for a specific patient in the ICU.

However, those who use the pupillometer certainly had the opportunity to voice their opinions about the device. We found that most of the responses were favorable. The second limitation is that this is a small study at a single center. Part of the impetus to publish this is that there have been no reports of the use of this direct download of pupillometer data to the EMR. We report a 7-year experience as well as the nursing response. We hope this will encourage multicenter collaborative reports on a larger experience with this new technology largely to improve documentation.

CONCLUSIONS

Implementation of a direct interface to download pupillometer data to the EMR improves ICU workflow and improves documentation of pupillary findings and changes. Improved access to pupillometer data in a near real-time fashion by the physicians at bedside or remotely may help them in their decision-making paradigms.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Diem Kieu Tran: Conceptualization, Methodology, Formal analysis, Writing — original draft, Writing — review & editing. **Cassie Poole:** Validation, Writing — review & editing. **Evan Tobias:** Software. **Lisa Moores:** Resources. **Maurice Espinoza:** Resources. **Jefferson W. Chen:** Conceptualization, Methodology, Formal analysis, Writing — review & editing, Supervision.

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