Journal of Pediatric Surgery 55 (2020) 1846–1849

Contents lists available at ScienceDirect

Journal of Pediatric Surgery

journal homepage: www.elsevier.com/locate/jpedsurg

Thoracic Conditions

Quantifying postoperative sleep loss associated with increased pain in children undergoing a modified Nuss operation☆

Benjamin T. Many [a,b,*], Yazan K. Rizeq [a], Soyang Kwon [a], Jonathan C. Vacek [a,b], Seth D. Goldstein [a,b], Catherine J. Hunter [a,b], Hassan Ghomrawi [b,c], Fizan Abdullah [a,b]

[a] Ann and Robert H. Lurie Children's Hospital of Chicago, Division of Pediatric Surgery, Chicago, IL, USA
[b] Department of Surgery, Northwestern University, Chicago, IL, USA
[c] Department of Pediatrics, Northwestern University, Chicago, IL, USA

ARTICLE INFO

Article history:
Received 12 July 2019
Received in revised form 10 November 2019
Accepted 2 December 2019

Key words:
Wearable telemetry
Pectus excavatum
Pediatric surgery
Children
Accelerometers
Pain
Sleep

ABSTRACT

Purpose: The presence of pain may interrupt sleep and impede normal postoperative recovery; however, no prior studies have quantified sleep loss due to pain in children undergoing inpatient surgery. Wearable accelerometers objectively measure sleep patterns in children. We aimed to quantify sleep loss associated with patient reported pain scores after a Modified Nuss operation.
Methods: Ten patients undergoing Modified Nuss operations were recruited during their inpatient stay. Children wore an Actigraph GT3X-BT accelerometer postoperatively during their hospital stay. Hourly sleep minutes were recorded using the Actigraph between 10 pm and 6 am. Patient reported pain scores were abstracted from patient charts. Mixed linear regression models, adjusting for within-subject random effects, were estimated to quantify the association between hourly sleep minutes and patient reported pain scores.
Results: Patients were 30% female, with an average age of 15.7 years (range 13–22). The majority (70%) of patients were white non-Hispanic. All patients received a patient controlled analgesic pump. Average postoperative length of stay was 4.8 days (range 4.0–6.0; SD = 0.8). A total of 240 sleep hours and associated pain scores were analyzed. Patients slept on average 48 min per hour. Mixed model analysis predicted that a 1-point increase in pain score was associated with 2.5 min per hour less sleep time.
Conclusion: Increases in patient-reported pain scores are associated with sleep loss after a Modified Nuss operation. Objectively quantifying sleep loss associated with postoperative pain using accelerometer data may help clinicians better understand their patient's level of pain control. Our findings provide the basis for future studies aimed at more accurately titrating pain medication to optimize sleep and speed up recovery.
Level of Evidence: Case Series Without Comparison Group, Level IV.

1. Background

First described in 1988, the Nuss operation involves the insertion of a steel bar underneath the sternum to correct a "sunken chest" [1]. This operation was later modified (known as the Modified Nuss) with additional efforts to improve safety during passage of the bar across the sternum [2]. Patients undergoing a Modified Nuss operation to correct pectus excavatum (PE) experience significant pain after surgery. Repositioning of the sternal bone and cartilage during surgery causes severe pain, and patients typically remain inpatient for at least 3 days, primarily for pain control. Patients are often administered a patient controlled analgesic pump and receive oral opioids to control their pain.

Postoperative pain can interrupt sleep and diminish its restorative benefits [3]. Disordered sleep from pain can prolong recovery, cause disordered inflammatory and immune responses and cognitive dysfunction [4–7]. Poor postoperative sleep quality and pain control also increase the risk for opioid use and potential abuse in the long term [8]. Sleep time and quality are typically subjectively assessed by patient and nurse input. This inability to objectively assess sleep prohibits clinicians from fully understanding and optimizing their patient's recovery.

Accelerometers are validated wearable devices by which sleep can be objectively quantified [9, 10] and have demonstrated applicability in the clinical setting [11, 12]. This study used accelerometers to estimate the association between hourly sleep minutes and patient-reported pain scores in children and young adults after a Modified Nuss operation during their inpatient stay. We hypothesized that accelerometer-assessed sleep minutes per hour are inversely associated

☆ The authors report no disclosures. Preliminary results of this work have been accepted for presentation at World Congress of Surgery August 2019 in Krakow, Poland.

* Corresponding author at: Pediatric Surgery Research Fellow, 225 East Chicago Avenue Box 63, Chicago, IL 60611-2991. Tel.: +1 312 227 4210; fax: +1 312 227 9678.
E-mail address: bmany@luriechildrens.org (B.T. Many).

https://doi.org/10.1016/j.jpedsurg.2019.12.003
0022-3468/

with pain scores in pediatric patients undergoing a Modified Nuss operation.

2. Methods

After obtaining approval from our institutional review board, we consented and recruited pediatric patients undergoing a Modified Nuss operation between June 2018 and January 2019. Study personnel monitored operating room cases to identify potential participants and then approached, consented and enrolled patients if they fulfilled our inclusion criteria. Patients 10 years of age or older were eligible for the study, since younger patients cannot reliably report pain [13]. Patients who were non-ambulatory, missing both arms, could not report pain or suffered from a sleep–wake disorder were excluded. Patients were approached and enrolled during their inpatient stay on postoperative day (POD) one. Recruitment was limited only by availability of research personnel; there was no patient selection process other than specified inclusion and exclusion criteria. All patients had only one bar placed during repair of PE.

All participants were asked to wear a research grade accelerometer, the Actigraph wGT3x-BT (Pensacola, FL) on their non-dominant wrist during all hours of their inpatient hospitalization (day and night). The Actigraph accelerometer is a commonly used research grade wrist worn accelerometer capable of assessing physical activity and sleep and is a validated measure of hourly sleep minutes [14]. The Actigraph accelerometer estimates sleep minutes by recording sleep data in epochs every few seconds and demonstrates high agreement (85–95%) with polysomnography [15]. Sleep data are derived from the accelerometers using the Cole-Kripke algorithm, a validated algorithm to classify minute-by-minute sleep or wake status [15, 16]. Sleep was assessed as hourly sleep minutes (minutes/h) during nighttime, defined as between 10 pm and 6 am for all patients as a conservative estimate for when patients should be sleeping. These hours match "quiet hours" on the inpatient wards at our center. Accelerometer data were processed using the ActiLife version 6.2 software.

Pain scores were extracted from the electronic medical record (Epic Systems Corporation, Madison, Wisconsin). The pain score was assessed on the numerical pain scale, with 0 representing no pain, and 10 representing severe pain [17], at varying intervals by inpatient pediatric nursing staff.

Nurses intermittently enter patient rooms during sleep hours to provide care, dispense ordered medications, or assess pain levels; however, patient reported pain scores are not recorded every hour. Because pain scores were not recorded every nighttime hour of the inpatient stay, only nighttime hours that had a reported pain score were included for analysis. Descriptive analyses were conducted to calculate average hourly sleep minutes by pain score. To examine the association between hourly sleep minutes and pain scores, a linear mixed model was used to account for within-subject random effects, as repeated measures within a participant are correlated. The model was adjusted for age, sex, length of operation, and Haller Index as these factors may confound the relationship between pain scores and sleep minutes. [18–20] Haller Index is a measure of severity of pectus excavatum deformity, and is determined by dividing the chest transverse diameter by the anterior–posterior diameter on imaging. [21] Because teenagers may "sleep in" more than other patients, we conducted a linear mixed model sensitivity analysis including patient reported pain scores and hourly sleep minutes from the extended hours of 10 pm to 10 am. All analyses were conducted in SAS 9.4 (Cary, NC).

3. Results

The study sample consisted of 10 patients. Two experienced surgeons performed all the operations; both surgeons were trained in the same pediatric surgery fellowship program. The patients were 30% female (n = 3) and the majority of participants were white, non-Hispanic (n = 7, 70%). The average age of participants in our study was 15.7 years old (range 13–22; SD = 2.6). The average operation length was 124.2 min (range 78–200; SD = 37.1); the average length of inpatient stay was 4.8 days (range 4.0–6.0; SD = 0.8). Average Haller Index was 4.1. All patients remained on a patient-controlled analgesia (PCA) pump until POD three at which time it was discontinued. PCA pumps administered hydromorphone in most cases (n = 9, 90%) and fentanyl in one patient. All patients were discharged home with an oral opioid medication, usually oxycodone (n = 9, 90%).

There were 30 inpatient "nights" with an associated 240 sleep hours available for analysis. Only sleep hours with an associated pain score were used in the final analysis. Thus, a total of 72 sleep hours with associated pain scores were included in the final analysis. There was significant variability in hourly sleep minutes between the 10 participants (range: 3–60 min/h) (Fig. 1). Patients with a pain score of 0/10 (no pain) slept, on average, 50.8 min per hour (range 3.0 to 60.0; SD = 13.3). Patients with a pain score of 5/10 (moderate pain) slept, on average, 34.4 min per hour (range 13.0–56.0; SD = 18.0). Patients with a pain score of 9/10 (severe pain), slept on average only 13.0 min per hour between the hours of 10 pm and 6 am (Fig. 2). Regression model indicated that a one-point increase in pain score was associated with 2.5 min less sleep per hour in PE patients after a Modified Nuss operation ($p < 0.01$) when controlling for age, sex, length of operation, and Haller Index. No other variable, besides pain scores, was significantly associated with hourly sleep minutes (Table 1). When we included the hours 10 pm to 10 am, which may account for teenagers who like to "sleep in", in a sensitivity analysis, every one-point increase in pain scores was associated with 1.9 min less sleep per hour in PE patients after a Modified Nuss Operation.

4. Discussion

The present study examined the relationship between patient reported pain scores and objectively assessed sleep (using accelerometers) in patients undergoing a Modified Nuss operation. We found that a one-point increase in pain score is associated with 2.5 min less sleep per hour in children after controlling for age, sex, length of operation, and Haller Index. These findings pave the way for developing novel methods to interpret pain and develop pain control strategies.

To our knowledge, this study is the first to use accelerometer data to objectively quantify sleep loss associated with pain in the inpatient setting. Previous studies have demonstrated the relationship between postoperative pain and sleep disturbance in children in the outpatient setting, and demonstrated the importance of regaining a normal sleep pattern [22]. However, these studies assessed pain infrequently, and pain reporting may be subject to significant bias since it was not captured by a nurse [23]. By implementing accelerometers during the inpatient stay after children's surgery, clinicians can use accelerometer derived sleep data to make real-time inferences about a patient's pain control, thus informing decisions around pain management and readiness for discharge. A recent study using accelerometers to measure recovery focused on postoperative ambulation in adults [24], and found thresholds of objectively assessed ambulation that indicated readiness for discharge.

The use of accelerometer data to objectively characterize recovery after surgery is becoming more popular as technology advances and clinical applications expand [24–26]. Historically, characteristics of recovery like postoperative ambulation and sleep were assessed subjectively by patient report and clinician assessment. Wearable devices like the Actigraph accelerometer allow for objective measurement of sleep and activity after an operation, and thus can objectify historically subjective assessment [12, 27]. In fact, wearable devices have evolved and improved far beyond the Actigraph accelerometer [28]. Now lightweight and unobtrusive, novel wearable devices are capable of transmitting real-time patient data to cloud based servers [29]. As implementation of wearable devices expands, clinicians and researchers

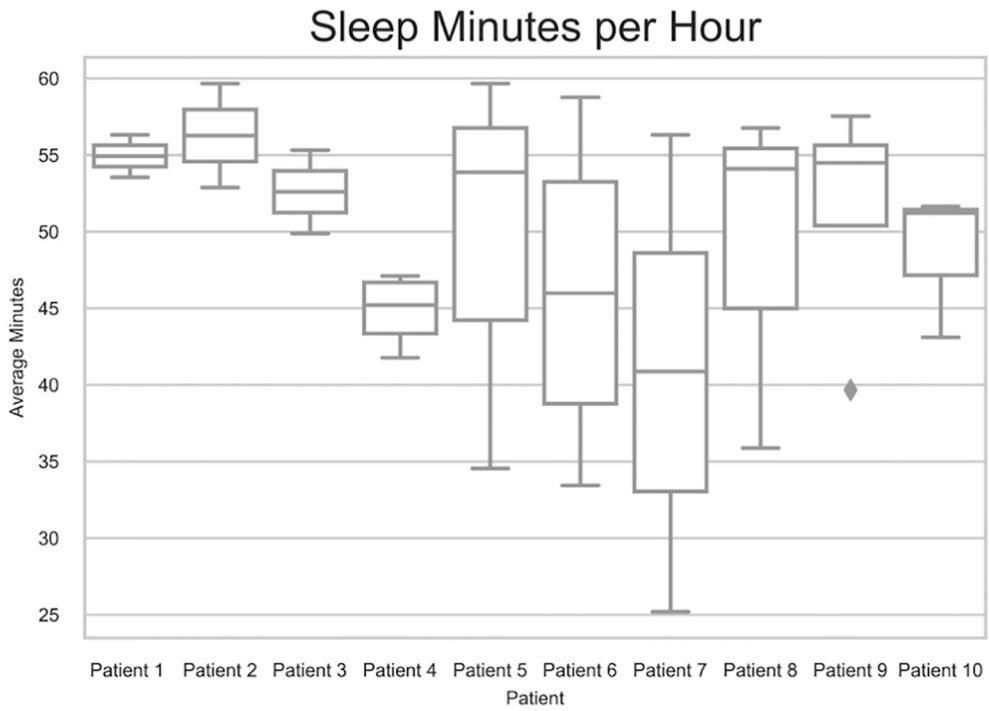

Fig. 1. Average hourly sleep minutes for postoperative pectus patients.

will be well served by setting data thresholds for alert, identifying appropriate personnel for the receipt of such data, and ensuring providers are not overburdened with extraneous patient data points.

The opioid epidemic has sharpened focus on the understanding and management of postoperative pain [30]. Persistent opioid use after surgery may represent a mechanism by which addiction is established among pediatric patients [31]. The assessment of pain in children and young adults has been a longstanding challenge, because children are often unable to reliably report their pain [32]. Using accelerometers to objectively assess pain using sleep data improves clinician's comprehension of their patient's recovery and pain control, and may help establish discharge readiness.

Our study has a number of limitations. Although we were able to accumulate 240 sleep hours for analysis, more consistent pain assessment is still needed to fully examine the pain-sleep relationship. Variability in hourly sleep minutes between our participants is noted; a future larger study will allow for more precise categorization of sleep patterns and their association with pain. Our work also only focuses on the sleep time, and thus provides a crude measure of pain. Further work is needed to examine the association of pain with sleep quality and sleeping patterns. Further, our study did not examine narcotic usage and its effect on hourly sleep minutes, which may represent an important next step. Our findings are from a single institution with a small sample size, and derive primarily from two surgeons who perform the Modified Nuss operation. It is plausible that other institutions with different surgeons may employ practices with implications for both postoperative sleep and pain management. It is possible that variations in operative approach may also be associated with less postoperative pain, or vice versa. Though we included Haller Index in our regression analysis, we acknowledge the availability of other indices such as the correction index, which is known to be more accurate for predicting normal verses abnormal anatomy in patients with PE. Unfortunately, correction index is not routinely reported at our institution. Finally, to our knowledge, typical hourly sleep minutes in patients with PE before repair have not been characterized, and so we lack a comparison group for the study.

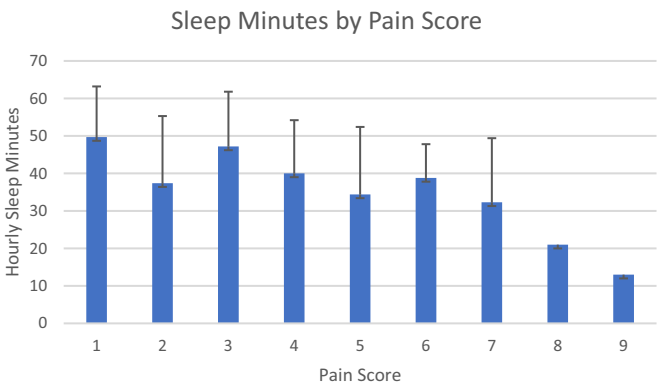

Fig. 2. Average hourly sleep minutes during nighttime hours by pain score with standard deviation.

5. Conclusion

We found that accelerometer derived sleep data is associated with patient-reported pain scores in postoperative pectus patients. For every one-point increase in patient reported pain score, there is a quantifiable reduction in hourly sleep minutes in patients after a Modified Nuss operation. Using accelerometers to objectively assess sleep minutes improves a clinicians understanding of patients pain control. These data can be used to measure postoperative recovery and benchmark readiness for discharge.

Table 1
Depicts mixed linear regression model analysis for hourly sleep minutes that includes the predictors listed below.

Predictors	Coefficient	Standard error	p-Value
Intercept	19.0	25.2	0.48
Pain (0–10)	−2.5	0.8	**0.002**
Age (years)	1.5	1.0	0.20
Sex (female)	3.2	5.2	0.56
Length of operation (min)	0.0006	0.07	0.99
Haller Index	1.5	2.4	0.55

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