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Longitudinal and temporal associations between daily pain and sleep patterns after major pediatric surgery

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Abstract

Around 20% of children develop persistent pain after major surgery. Sleep disruption has been implicated as a predictor of children's acute postsurgical pain. However, perioperative sleep patterns have not been longitudinally assessed, and the role of sleep in persistence of postsurgical pain has not been explored. We aimed to examine sleep patterns over 4 months in children having major surgery, and temporal relationships between daily sleep and pain. Sixty children age 10–18 ($M=14.7$) years having major surgery completed 7 days of actigraphy sleep monitoring (sleep duration, efficiency), twice daily electronic diaries (sleep quality, pain intensity, medication use), and validated questionnaires at pre-surgery, 2-weeks, and 4-months post-surgery. Generalized linear models, controlling for age, sex, naps, and medication, showed sleep quality ($B=-0.88$, $P<0.001$) and efficiency ($B=-1.50$, $P=0.036$) were significantly reduced at 2-weeks compared to pre-surgery, and returned to baseline by 4-months. Poorer nighttime sleep quality was significantly associated with greater next day pain intensity ($B=-0.15$, $P=0.005$). Sleep duration and efficiency were not associated with subsequent pain; daytime pain was not associated with subsequent sleep. Findings suggest sleep quality may be an important target for intervention after surgery in children; research is needed to understand how other sleep parameters may relate to recovery.

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INTRODUCTION

Despite dramatic advances in perioperative care, persistent pain is a frequent occurrence after surgery for individuals across the lifespan. Recent research in children has identified high rates (18–22%) of persistent postsurgical pain after major pediatric surgery^{3,24,32}. Several biopsychosocial risk factors have been identified as important predictors of pain persistence and poor long-term recovery after surgery^{3,13,14,24,32}. In adults, the role of sleep disruption has emerged as a relevant predictor of both acute and chronic postsurgical pain^{29,42}. Recent studies⁴ found that sleep disruption mediates the relationship between acute post-operative pain and subsequent recovery⁴, and that sleep disturbance after surgery is associated with persistent pain². This is consistent with research in other clinical populations demonstrating that sleep plays a central role in development and maintenance of chronic pain⁷, likely due to a number of mechanistic pathways. In healthy adults, sleep deprivation is associated with sympathetic activation and increased stress response⁹, and sleep fragmentation leads to decreased endogenous pain inhibition and increased pain sensitivity^{33,35,36,38}. Mechanistic human and animal studies also support significant interactions between sleep and inflammation^{18,22}, which may be particularly relevant during recovery and healing after surgery. However, there has been limited assessment of perioperative sleep patterns in children.

In prior research assessing sleep in children after surgery using parent-reported questionnaires¹¹ and actigraphy monitoring of sleep patterns¹⁰, sleep disturbances were found to occur commonly in young children in the initial days after surgery. In a cross-sectional study examining chronic pain in children after surgery a subgroup of children continued to perceive disrupted sleep several months after surgery⁸. Further, in our prior investigation in this sample of children undergoing major surgery, sleep disturbance *before* major surgery was a risk factor for acute postsurgical pain, with shorter duration of sleep in the week prior to surgery predicting higher acute postsurgical pain intensity at home after surgery³¹. A large portion of these children (18%) went on to develop persistent pain over 12 months after surgery³². However perioperative daily sleep patterns have not been longitudinally assessed in children, and the role of sleep in persistence of children's pain after surgery has not been explored.

This gap in understanding of sleep in children undergoing surgery is important because in other pediatric pain populations daily temporal associations have been found between sleep and pain, suggesting that sleep may be an important target for intervention. For example, in adolescents with chronic pain, greater sleep fragmentation as measured by actigraphy was associated with higher next day pain intensity. Interestingly, daytime pain was not associated with subsequent sleep, suggesting sleep may be a stronger predictor of pain than vice versa¹⁷.

Thus, the aims of the study were to examine longitudinal sleep patterns over four months in children having major surgery and to examine the temporal relationship between daily sleep and pain. A multimethod assessment including electronic diaries, questionnaire measures, and ambulatory actigraphy monitoring was used to comprehensively assess sleep during three data waves (baseline, 2 weeks, and 4 months) and control for factors which may

impact the relationship between sleep and pain in the context of surgery such as daytime sleep (naps) and medications (e.g. opioids). Understanding directional relationships between daily sleep and pain is critical to development of targeted interventions for children experiencing problems with pain, sleep, and recovery after surgery.

We hypothesized that children would demonstrate reduced sleep quality and sleep efficiency during the acute recovery period at home 2-weeks after surgery as compared to baseline (pre-surgery). We expected to find bidirectional daily relationships between pain and sleep over 4 months; however, based on research in other pediatric pain samples, we expected sleep to be a stronger driver of the relationship with poorer night-time sleep patterns (poorer sleep quality, shorter sleep duration, and poorer sleep efficiency) predicting greater next day pain intensity.

METHODS

Participants and setting

Sixty children scheduled for major surgery at a single tertiary children's hospital in the Pacific Northwest were enrolled into the study over a 21-month period. IRB approval was obtained, and children gave their assent and parents provided consent prior to study participation.

Inclusion/exclusion criteria: Children were eligible for inclusion in the study if they were 1) 10 to 18 years of age, 2) undergoing major spine or chest wall surgery (spinal fusion, pectus correction surgery), and 3) able to understand English. Children were excluded from the study if they 1) had developmental delay, 2) had a major comorbid illness (requiring a daily medication or prior major surgery), 3) did not reside with their legal guardian, or 4) the legal guardian was non-English speaking. Of children identified as meeting inclusion criteria, 32 were ineligible based on exclusions. Rate of participation was 67% among children approached for the study, with lack of time or interest cited as primary reasons for non-participation.

Procedures

Children completed three data waves (baseline, 2 weeks after hospital discharge, 4 months after surgery) during which sleep and pain was monitored using a 7-day actigraphy and daily diary protocol. Of the 60 children enrolled in the study, 59 (98%) completed the baseline assessment, 57 (95%) completed the 2-week assessment, and 54 (90%) completed the 4-month assessment. During each assessment period, children completed an electronic diary twice daily, once in the morning after waking, and once in the evening before going to bed, using a handheld customized diary program on a Palm PDA. Children concurrently wore an Actiwatch 2 to monitor sleep patterns for 7 days. Children also completed the Adolescent Sleep Wake Scale assessing sleep quality over the prior month at baseline, 2 weeks, and 4 months after surgery. Parents completed a demographic questionnaire at baseline. Study materials were sent to participants and returned by courier. Participants received gift cards on completion of each data wave. Clinical data were collected from the medical record by study personnel.

Short term and long term pain data have been reported for this sample^{31,32}. Baseline sleep duration was examined as a predictor of short term outcomes³¹. The present manuscript is the first to report on longitudinal sleep patterns and daily temporal relationships between sleep and pain after surgery.

Measures

Morning diary

Sleep quality: Upon waking each morning, children reported on sleep quality for the prior night on an 11-point numeric rating scale with anchors “0 extremely poor sleep” to “10 extremely good sleep”. Numeric rating scales of sleep quality have been used in healthy children and children with chronic pain^{17,39}.

Evening diary

Pain intensity: Children reported daily pain intensity each evening on an 11-point numeric rating scale with anchors “0 no pain” to “10 worst possible pain”. Numeric rating scales of pain intensity have been shown to be valid and sensitive to change in the perioperative setting at home in children of similar age range²³.

Daytime naps and medication use: Children indicated whether they had slept during the day (i.e. napped), reporting nap start and end times, and recorded medication use (names of medications taken that day). Total daytime nap duration was calculated from nap start and end times. Medications were coded into 9 categories (over the counter pain medications, opioids, other pain medications, sleep medications, antidepressants, anticonvulsants, benzodiazepines, antihistamines, other medication) by research staff as previously described³⁰. Consistent with prior studies, the total number of medication classes used each day was summed to reflect medication use.

Actigraphy monitoring—Objective sleep patterns were measured with wrist actigraphy using the Actiwatch 2 (Philips Respironics, Bend OR), a watch-like device, which was worn on the non-dominant wrist continuously for 7 days at each data wave. The Actiwatch contains an omnidirectional accelerometer, which senses movement in multiple planes and records movement counts in 1-minute epochs. Children were instructed to keep the watch on continuously, removing it only for swimming or bathing, and to press an event marker button on the watch at bedtime and on waking up, as well as when taking off the watch and when putting it back on. Children reported on additional items on the morning and evening diaries to assist with scoring the actigraphy data, including bedtimes and rise times.

Data were downloaded, cleaned, and scored according to a validated standardized algorithm using Actiware software (version 5.61.0010, Philips Respironics)⁴⁰ and a scoring protocol used in our laboratory in previous studies^{6,15,31,37}. With the aid of the event markers and diaries, sleep periods were identified on the actigraphy recordings for scoring. Sleep onset was defined as the first 10 minute segment with no more than 1 epoch of coded wake activity. Sleep offset was defined as the last 10 minute segment with no more than 1 epoch of coded sleep activity.

Two actigraphic sleep variables were calculated and used in the analyses: total sleep duration and sleep efficiency. **Total sleep duration** is the amount of time in minutes between sleep onset and sleep offset. **Sleep efficiency** is the ratio of minutes spent in sleep and time spent in bed, expressed as a percentage with higher values indicating more efficient sleep.

Self-report measures

Sleep quality: Children self-reported on their sleep quality experienced during the prior month on the Adolescent Sleep Wake Scale (ASWS), a 28-item multidimensional measure of sleep quality. Items on this scale represent five behavioral dimensions of sleep: going to bed (5 items, e.g. “I am ready to go to bed at bedtime”), falling asleep (6 items, e.g. “In general I have trouble going to sleep”), maintaining sleep, (6 items, e.g. “During the night I am very restless”), reinitiating sleep (6 items, e.g. “After waking up during the night I have trouble going back to sleep”), and return to wakefulness (5 items, e.g. “I wake up feeling rested and alert”). Children endorse each item on a 6-point Likert-type scale with response options “Never, has not happened”, “Once in Awhile – happened 20% of the time”, “Sometimes – happened 40% of the time”, “Quite Often – happened 60% of the time”, “Frequently, if not always – happened 80% of the time”, and “Always – happened 100% of the time”. Items indicating poorer sleep are reverse scored. Items are then averaged to yield a total score from 1 to 6 with higher scores reflecting better sleep quality over the preceding month. At 2-weeks after surgery children reported on sleep since surgery. The measure has been broadly used in adolescent populations, and internal consistency has been found to be good for the full scale ($\alpha = .80-.86$)^{16,21,25,27}.

Insomnia symptoms: Two items from the ASWS were used to assess insomnia: difficulty falling asleep (“I have trouble going to sleep”) and difficulty maintaining sleep (“After waking up during the night, I have trouble going back to sleep”). Consistent with previous studies, children who endorsed experiencing either of these symptoms at least “quite often” (i.e. indicating that this occurred at least 60% of the time) were considered to have symptoms of insomnia^{25,27}.

Sociodemographic characteristics: Parents reported on parent education, family income, and child race and ethnicity.

Clinical characteristics: Type of surgery, length of surgery, and hospital length of stay were collected from the medical record by research personnel.

Statistical Analysis

The median number of days of diary completion was 7 days at baseline, 7 days at 2-weeks, and 6 days at 4-months across participants. Median number of days of actigraphy completion was 7 days for each data wave. For descriptive statistics, we collapsed daily data by data wave (baseline, 2 weeks, and 4 months). Mean, and standard deviation were calculated for median daily actigraphy values and diary ratings across the 7 days at each data wave for each participant. Note we used medians instead of means for each period to reduce the impact of potential extreme values from certain days. To describe overall medication use,

mean was calculated for percentage of days that medication was used during the 7 days at each data wave for each participant.

To address our primary aims, six generalized linear models (GLMS) examining sleep patterns and pain across time were conducted to examine longitudinal sleep patterns over four months, and examine the temporal relationship between daily sleep and pain. All models used daily level data to take advantage of the granularity of our data. Generalized estimating equations (GEEs) were used for parameter estimation and inference, which allows us to account for the correlations in the data due to repeated assessments within individuals. This modeling procedure allows missing data and different numbers of observations for participants⁴¹. Separate models were conducted for each of three sleep variables: sleep quality (daily diary), sleep duration (actigraphy), and sleep efficiency (actigraphy). Thus three models examined each direction of the sleep-pain relationship: whether sleep quality, duration, and efficiency are associated with subsequent pain intensity, and whether intensity of pain is associated with subsequent sleep quality, duration, and efficiency during recovery after surgery. Data wave (baseline, 2 weeks, and 4 months) was entered into the model with baseline as the reference point. All models controlled for age, sex, nap duration, and medication use (number of medication categories). Pain intensity, sleep variables (sleep quality, sleep duration, sleep efficiency, nap duration), and age were entered as continuous variables. Data wave, sex, and medication use were entered as categorical variables.

Additional analyses were conducted to describe associations between subjective and objective sleep variables, and to examine sleep quality on the ASWS and insomnia symptoms at 2-weeks and 4-months after surgery. These analyses employed similar regression models controlling for data wave, age, and sex.

Analyses were conducted using STATA version 12.1 SE (StataCorp, Texas, USA). The STATA command “xtgee” was used to produce unstandardized beta coefficients (B) and associated 95% confidence intervals (95% C.I.) to estimate magnitude and direction of associations between changes in dependent and independent variables while accounting for clustering by individual.

RESULTS

Descriptive data

Sixty children ages 10–18 years ($M=14.7$, $SD = 1.9$), 66.7% female, and 83.4% white participated in the study. Fifty-five percent of families reported an annual household income above \$70,000. Fifty children underwent spine surgery (48 posterior spinal fusions and 2 anterior-posterior spinal fusion) and 10 underwent repair of pectus deformity (9 Nuss procedures, 1 Ravitch procedure). Surgeries lasted an average of 5.2 ($SD = 1.6$) hours and hospital length of stay was 4.5 ($SD = 1.1$) days on average.

Average pain intensity ratings on daily diaries were 2.8 ($SD = 2.8$) at baseline, 3.5 ($SD = 2.4$) at 2-weeks, and 1.1 ($SD = 1.8$) at 4-months after surgery. On average, children reported using any medication on 23% of days during the week before surgery, on 37% of days at 2-

weeks after surgery and on 10% of days at 4 months after surgery. Of note, 33% of children reported taking any opioids on the daily diaries at 2 weeks after surgery; however no children reported taking any opioids at baseline or at 4 months after surgery.

Children slept an average of 8.0 hours (SD = 1.0) per night during the week prior to surgery, 8.5 hours (SD = 1.1) hours per night at 2-weeks, and 8.0 hours (SD = 0.8) at 4 months after surgery. Multidimensional sleep quality as measured by total scores on the ASWS was 4.2 (SD = 0.6) at baseline, 4.0 (SD = 0.7) at 2-weeks, and 4.2 (SD = 0.7) at 4 months. Fifty-eight percent of children endorsed insomnia symptoms on the ASWS during the week prior to surgery, 68% endorsed symptoms at 2-weeks after surgery, and 45% at 4 months after surgery. In generalized linear models adjusting for age and sex, sleep quality and presence of insomnia symptoms on the ASWS were not significantly different at 2-weeks and 4-months compared to baseline (P 's > 0.05).

Daily subjective sleep quality ratings were significantly associated with objective sleep patterns as measured by actigraphy. Longer sleep duration ($B = 0.002$, 95% C.I. 0.000 – 0.004, $P < 0.001$) and higher sleep efficiency ($B = 0.06$, 95% C.I. 0.03 – 0.09, $P < 0.001$) at night were associated with higher sleep quality ratings, controlling for data wave, age, and sex. Children's median sleep quality ratings on daily diaries were also significantly associated with their total sleep quality and presence of insomnia symptoms as reported on the Adolescent Sleep Wake Scale, controlling for data wave, age, and sex. Higher sleep quality ratings were associated with higher total sleep quality scores ($B = 0.94$, 95% C.I. 0.55 – 1.34, $P < 0.001$) and lower incidence of insomnia symptoms ($OR = -0.93$, 95% C.I. -1.43 – -0.44, $P < 0.001$).

Generalized linear models examining daily sleep and pain over 4 months in youth undergoing major surgery

Generalized linear models analyzing daily sleep and pain over 4 months were conducted to examine change in sleep patterns by data wave (baseline, 2 weeks, 4 months) and to explore bidirectional temporal relationships between pain intensity and sleep patterns. Separate models were conducted for sleep quality (daily diary), sleep duration (actigraphy), and sleep efficiency (actigraphy). Age, sex, naps, and medication use were included as covariates.

Three models examined daytime pain intensity as a predictor of subsequent nighttime sleep quality, duration and efficiency (Table 1), while testing effect of time period and controlling for age, sex, naps, and medication use. As hypothesized, subjective sleep quality ($B = -0.88$, $z = -3.93$, $P < 0.001$) and objective sleep efficiency ($B = -1.50$, $z = -2.10$, $P = 0.036$) were significantly reduced at 2-weeks compared to pre-surgery levels. Sleep duration was significantly *increased* at 2-weeks compared to pre-surgery levels ($B = 25.54$, $z = 2.34$, $P = 0.019$). Sleep quality ($B = -0.08$, $z = -0.39$, $P = 0.70$), sleep duration ($B = 9.88$, $z = 0.99$, $P = 0.32$), and sleep efficiency (-0.00 , $z = -0.01$, $P = 0.99$) returned to baseline levels at 4 months. Consistent with hypotheses, daytime pain intensity was not associated with subsequent nighttime sleep patterns ($B = -0.07$, $z = -1.60$ for sleep quality; $B = 2.71$, $z = 1.82$ for sleep duration; $B = 0.13$, $z = 1.46$, for sleep efficiency; P 's > 0.05).

Separate models examined nighttime sleep quality, duration and efficiency as predictors of next day pain intensity, controlling for time period, age, sex, naps, and medication use (Table 2). As hypothesized, nighttime subjective sleep quality was significantly associated with greater subsequent daytime pain intensity ($B = -0.15$, $z = -2.81$, $P = 0.005$), with poorer sleep quality at night predicting greater pain intensity the next day. Contrary to hypotheses, sleep duration ($B = 0.00$, $z = 0.40$, $P = 0.69$) and sleep efficiency ($B = 0.01$, $z = 0.76$, $P = 0.45$) were not associated with next day pain intensity.

DISCUSSION

This study provides novel data on longitudinal sleep patterns over four months in children having major surgery and the daily temporal relationships between children's sleep patterns and their postsurgical pain. Findings demonstrated that, on average, children's sleep duration and quality returned to baseline by four months after surgery. However, at the individual level, significant temporal relationships were found between daily sleep and pain. Specifically, poor sleep quality predicted greater pain intensity the next day. These longitudinal findings suggest that poor sleep quality may continue to influence the experience of postsurgical pain within individual children even 4 months after surgery. Findings parallel prior studies conducted in youth with chronic pain where sleep was also found to effect subsequent pain but pain was not found to effect subsequent sleep¹⁷. Findings diverge in that associations were not found between actigraphic sleep patterns (sleep duration and efficiency) and pain. This fine-grained understanding of the temporal relationship between sleep and pain suggests that sleep quality may be an important target to direct interventions to help improve overall recovery after surgery.

A major strength of our study is the use of a multimethod sleep assessment including electronic diaries, subjective ratings, validated questionnaire measures, and ambulatory actigraphy monitoring. In particular the use of both subjective and objective sleep measures provides complementary information about patterns of sleep and children's own perceptions of sleep, extending knowledge on this topic. However, this multimethod assessment also revealed divergence of findings with subjective and objective sleep measures; this has also been found in other studies and may reflect several issues related to using actigraphy. Although used as a standard objective measure of sleep in children, low specificity has been found in accurately determining certain sleep parameters in children^{1,34}, and thus measurement issues could have accounted for some of our findings. Further, the divergence in findings could be due to differing relationships of subjective sleep quality and perception of one's sleep versus quantitative measures of sleep to child pain. Additional research is needed to understand how both subjective perceptions and quantitative measures of sleep may relate to subsequent pain experiences in children.

Our study extends the prior limited research examining perioperative sleep in children. In our own prior work we identified significant associations between pre-operative sleep and acute postoperative pain³¹. Our current findings extend this observation by examining longitudinal sleep patterns, and the relationship with postoperative pain over 4 months. Prior studies have characterized sleep patterns over the initial days after surgery^{10,11}. One existing study found concurrent relationships between pain and sleep during the initial days after

outpatient surgery¹⁰. Our findings build on this study by examining directional relationships between pain and sleep, finding that sleep has a stronger influence on subsequent pain, than pain does for subsequent sleep. While daily effect sizes were small (1 point lower sleep quality associated with 0.15 points higher pain intensity), the cumulative effect of sleep over time may influence postsurgical outcomes over the duration of recovery.

Potential mechanisms by which sleep disturbance may exacerbate pain during recovery from surgery include sympathetic activation, heightened stress response, augmented inflammatory pathways, and heightened pain sensitivity^{9,18,22,33,35,36,38}. Further mechanisms that have been hypothesized as mediators of the sleep-pain relationship include common pathways of dopaminergic signalling, and opioid signalling, as well as behavioural mediators, for example positive and negative affect⁷. In our study, only subjective sleep quality, but not actigraphy sleep patterns, was related to subsequent pain, which may suggest that behavioral mediators such as anxiety or depressed mood may play a role in this context. Further, the difference in findings compared to research in other samples of children with chronic pain, where both subjective and objective sleep patterns have shown association with subsequent pain, may be related to factors specific to the context of surgery, type of pain, or duration of illness. For example, during recovery from surgery, some children may sleep more, which may confound the relationship between sleep and pain. Further research is needed to understand how sleep patterns and quantitative measures of daytime and nighttime sleep are related to recovery after surgery.

Using a brief measure of insomnia symptoms, we found a high rate of insomnia symptoms in our pediatric surgery sample up to 4 months after surgery. Although insomnia symptoms returned to baseline, they were still elevated compared to published data in healthy samples on the Adolescent Sleep Wake Scale²⁵. This finding is intriguing because insomnia symptoms are highly comorbid with chronic pain across the lifespan^{20,36}, being reported by over 50% of youth with chronic pain²⁷. Insomnia is also associated with diminished physical function, poor quality of life, and increased depressive symptoms^{12,21,26}. Untreated, insomnia symptoms persist over a one-year period for youth with chronic pain²⁸, highlighting the importance of identification and treatment of insomnia. Fortunately there are efficacious treatments for insomnia, particularly cognitive-behavioral therapy for insomnia^{5,19}. Future studies are needed to more rigorously characterize insomnia symptoms using questionnaire and interview methods that provide assessment of both symptoms and impairment experienced due to insomnia in children undergoing major surgery. However, screening children for the presence of insomnia may serve a useful proxy to identify those children who are struggling with recovery after surgery.

The findings of this study should be considered in the context of several limitations. First, although we used robust statistical analyses to minimize loss of data from incomplete data waves, we did have some loss to follow-up that may have impacted longitudinal relationships found between sleep and pain. Second, while we accounted for important factors like naps and medication use, there may be additional individual factors (e.g., anxiety or behavioral changes after surgery), which may influence the relationship between sleep and pain in youth after surgery. Further, our sample size did not allow examination of analysis of effects of type of surgery on the outcomes of interest. In addition while we used

diary reported nap duration to control for naps, validity of self-reported nap duration is unknown.

Future research in this context should seek to replicate our preliminary findings in a larger sample of children, which would enable examination of potential behavioral and biological mediators of the pain-sleep relationship. Furthermore, studies should examine sleep patterns after a wider range of surgeries, and should examine the impact of sleep disturbance on additional postsurgical health outcomes. In addition, while we controlled for overall medication use, larger studies are needed to examine the relationships between specific medication types and postsurgical outcomes. Specifically, researchers should consider collecting more detailed information including number of doses of specific medications taken, to allow examination of relationships between medication use and sleep patterns during recovery.

Sleep problems are common in childhood, and emerging evidence links sleep dysfunction and chronic pain, where sleep disruption has been shown to lead to increased pain across childhood, adolescence and adulthood ⁷. Thus, among youth at increased risk for developing pain due to major surgery, poor sleep may contribute to the transition from acute to chronic pain.

In conclusion, children's sleep patterns were significantly impaired at 2 weeks after surgery. Significant temporal relationships were found between daily sleep and pain over 4 months after surgery, with poorer subjective sleep quality predicting greater pain intensity. These findings suggest that subjective sleep quality may be an important target to improve postsurgical pain and recovery in children. Further research is needed to understand how other quantitative sleep parameters (e.g. sleep duration and efficiency) are related to recovery after surgery.

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PERSPECTIVE

This study assessed longitudinal sleep patterns over 4 months after major pediatric surgery using actigraphy, diaries, and validated measures. Sleep quality and efficiency were significantly reduced at 2-weeks. Poorer sleep quality was associated with greater next day pain intensity suggesting that sleep quality may be an important target for intervention.

Children experienced significantly disrupted sleep at 2 weeks after major surgery

Sleep patterns returned to pre-surgery levels by 4 months after surgery

Children experienced high level of insomnia symptoms over 4 months after surgery

Poor subjective sleep quality predicted greater next day pain intensity over 4 months

Sleep quality may be an important target to improve postsurgical recovery in children

TABLE 1
Summary of generalized mixed models examining daytime pain as a predictor of nighttime sleep

PREDICTORS	OUTCOME					
	SLEEP QUALITY		SLEEP DURATION		SLEEP EFFICIENCY	
	BETA (95% C.I.)	WALD CHI2(DF)	BETA (95% C.I.)	WALD CHI2(DF)	BETA (95% C.I.)	WALD CHI2(DF)
Baseline	Reference		Reference		Reference	
2-weeks	-0.88 (-1.32 – [-0.44]) *		25.54 (4.16 – 46.92) *		-1.50 (-2.91 – [-0.10]) *	
4-months	-0.08 (-0.51 – 0.34)		9.88 (-9.74 – 29.50)		0.00 (-1.26 – 1.25)	
Pain Intensity	-0.07 (-0.15 – 0.02)		2.71 (-0.21 – 5.62)		0.13 (-0.05 – 0.31)	
Age	-0.05 (-0.22 – 0.12)		-7.01 (-12.76 – [-1.26]) *		-0.17 (-0.64 – 0.30)	
Gender	0.07 (-0.61 – 0.75)		23.59 (-5.74 – 52.92)		1.70 (-0.61 – 4.02)	
Nap Duration	0.00 (0.00 – [0.00])		-0.04 (-0.21 – 0.13)		0.00 (-0.01 – 0.00)	
Medication use	-0.03 (-0.18 – 0.13)		-1.80 (-8.19 – 4.59)		0.43 (-0.21 – 1.06)	
Total		21.98(7) *		28.62(7) *		9.47(7)

* $p < 0.05$

TABLE 2

Summary of generalized mixed models examining nighttime sleep as a predictor of next day pain

PREDICTORS	OUTCOME	
	NEXT DAY PAIN	
	BETA (95% C.I.)	WALD CHI2(DF)
Baseline	Reference	
2-weeks	0.77 (0.19 – 1.36) *	
4-months	–1.33 (–2.01 – [–0.65]) *	
Sleep Quality	–0.15 (–0.25 – [–0.04]) *	
Age	0.10 (–0.16 – 0.36)	
Gender	0.87 (–0.14 – 1.89)	
Nap Duration	0.01 (0.00 – 0.01) *	
Medication Use	0.40 (0.13 – 0.66) *	
Total		84.94(7) *
Baseline	Reference	
2-weeks	0.82 (0.31 – 1.33) *	
4-months	–1.37 (–2.12 – [–0.61]) *	
Sleep Duration	0.00 (0.00 – 0.00)	
Age	0.13 (–0.13 – 0.40)	
Gender	0.59 (–0.46 – 1.63)	
Nap Duration	0.00 (0.00 – 0.01) *	
Medication Use	0.39 (0.14 – 0.64) *	
Total		78.23(7) *
Baseline	Reference	
2-weeks	0.84 (0.32 – 1.36) *	
4-months	–1.36 (–2.12 – [–0.61]) *	
Sleep Efficiency	0.01 (–0.01 – 0.03)	
Age	0.13 (–0.13 – 0.40)	
Gender	0.58 (–0.47 – 1.64)	
Nap Duration	0.00 (0.00 – 0.01) *	
Medication Use	0.39 (0.14 – 0.64) *	
Total		76.02(7) *

*
p 0.05