Orthopaedics & Traumatology: Surgery & Research 106 (2020) 61–66

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Objective assessment of sleep quality in patients with rotator cuff tears

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ARTICLE INFO

Article history:
Received 3 March 2019
Accepted 26 September 2019

Keywords:
Shoulder
Rotator cuff tears
Sleep quality
Objective measures
Pittsburgh Sleep Quality Index
Actigraphy

ABSTRACT

Introduction: Sleep dysfunction in patients with rotator cuff tears has been previously evaluated only using subjective measures. Objective parameters of sleep quality amongst rotator cuff tear patients are scarce in the literature. The aim of this study is to compare objective sleep data to historical controls and to subjective patient-reported sleep quality in patients with rotator cuff tears.
Hypothesis: We hypothesized that patients with rotator cuff tears would demonstrate objectively poor sleep quality based on actigraphy when compared to a historical control group. Secondarily, we hypothesize that objective sleep quality measures will correlate poorly with traditionally used questionnaires and other subjective assessments.
Materials and methods: Twenty patients with full-thickness rotator cuff tears wore a highly validated activity monitor for 2 consecutive weeks for objective assessment and completed a sleep diary during the same period. Patients completed multiple questionnaires pertaining to their shoulder function and subjective assessment of sleep quality. Objective sleep assessments were compared to patients' sleep diary data and to subjective sleep data from a historical cohort of 969 healthy adults aged 57–97 years.
Results: Mean total sleep time, sleep onset latency, wake after sleep onset (WASO), and sleep efficiency were all significantly worse in the study cohort compared to the historical cohort ($p = 0.0338$, $p = 0.0040$, $p < 0.0001$, and $p = 0.0474$, respectively). Pittsburgh Sleep Quality Index (PSQI) scores did not correlate with sleep efficiency ($r = 0.3143$, $p = 0.2040$) or WASO ($r = -0.3068$, $p = 0.2153$). Visual analog scale scores correlated with PSQI scores ($r = 0.5260$, $p = 0.0249$) and Epworth Sleepiness Scale scores ($r = 0.4863$, $p = 0.0407$). Patients tended to overreport their time spent asleep via a sleep diary compared to objective time asleep ($p = 0.0050$).
Discussion: This study of objective sleep measures demonstrated poor sleep quality in patients with rotator cuff tears with shorter sleep duration, frequent awakenings, and decreased efficiency. Subjective assessments of sleep did not correlate with objective findings.
Level of evidence: Level II, prospective cohort study.

1. Introduction

Among the nearly 4.5 million American patients who seek treatment for rotator cuff disease annually, night pain is a frequent complaint [1]. Such patients consistently report difficulty falling and staying asleep and cite sleep dysfunction as their primary reason for seeking orthopedic consultation [2]. Studies that evaluated sleep quality in patients with rotator cuff disease have only utilized subjective measures, such as the Pittsburgh Sleep Quality Index (PSQI) and Epworth Sleepiness Scale (ESS) [3–6]. These studies attempted to demonstrate that operative repair of rotator cuff tears consistently results in improved sleep quality; however, the PSQI and ESS also have been shown to correlate more highly with psychologic symptoms than with objective sleep measures [7].

Objective parameters of sleep quality amongst rotator cuff tear patients are scarce in the literature, making it difficult to determine whether patients with rotator cuff disease truly demonstrate poor sleep quality. The objective assessment of sleep quality has become markedly easier with the advent of wrist-based accelerometers and actigraphy recording. Polysomnography requires a stay in a sleep laboratory and can disrupt the normal sleep-wake cycle

Abbreviations: ASES, American Shoulder and Elbow Surgeons; ESS, Epworth Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index; SANE, single assessment numerical evaluation; SD, standard deviation; SOL, sleep onset latency; WASO, wake after sleep onset.

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https://doi.org/10.1016/j.otsr.2019.09.033
1877-0568/

of the subject. While polysomnography remains the gold standard, the wrist-based devices are less expensive, more convenient, and allow for a longer period of assessment [8]. Actigraphy provides detailed information regarding sleep efficiency, sleep onset latency (SOL; the time spent in bed before achieving sleep), and wake after sleep onset (WASO; the time spent awake after initially achieving sleep). Actigraphy has been validated as a sensitive and accurate tool for assessing sleep [9] with greater reliability than a sleep diary [10]. Sleep diaries remain useful tools especially as a comparison to objective data [11]. Although consumer-level activity monitors such as a Fitbit (Fitbit Inc, San Francisco, CA) tend to overestimate daytime activity and sleep efficiency while underestimating SOL and WASO [12–14], the Actiwatch Spectrum Plus (Philips Respironics, Murrysville, PA) has been validated for the research of sleep quality [13].

To our knowledge, this is the first study to utilize Actigraphy to objectively measure sleep quality in patients with rotator cuff tears as compared to a historical cohort and subjective assessments. We hypothesized that patients with rotator cuff tears would demonstrate objectively poor sleep quality based on actigraphy when compared to a historical control group. Secondarily, we hypothesize that objective sleep quality measures will correlate poorly with traditionally used questionnaires and other subjective assessments.

2. Patients and methods

2.1. Patients

Patients were recruited from the clinic of a single fellowship-trained orthopaedic surgeon specializing in shoulder and elbow surgery. All patients over age 18 years with a diagnosis of a full-thickness rotator cuff tear as determined by ultrasound or magnetic resonance imaging were screened for participation from September 2016 to March 2017. The size of the rotator cuff tear was documented clearly in the electronic medical record by the radiologist who generated the report. Exclusion criteria included prior rotator cuff repair, previously diagnosed primary sleep disorder, severe glenohumeral osteoarthritis, and adhesive capsulitis. Of the 35 patients who met criteria for enrollment, 20 provided informed consent for elective participation while the remainder declined to participate. Patients did not receive compensation for their participation.

2.2. Methods

This cohort study measured the objective sleep of patients as compared with subjective sleep measures in these patients and also with a historical control group. The primary endpoint of this study was to compare average sleep efficiency, total sleep time, SOL, and WASO between these cohorts and to compare differences between patients' subjective reports in their sleep diaries with objective actigraphic measures. Approval for this study was obtained by the institutional review board.

2.3. Methods of assessment

Upon enrollment, patients completed a series of questionnaires pertaining to their shoulder function and subjective assessment of sleep quality. These included the American Shoulder and Elbow Surgeons (ASES) standardized shoulder assessment, single assessment numerical evaluation (SANE), visual analog scale, ESS, and PSQI. The PSQI consists of 19 questions to be scored from 0 to 3, with 0 representing no sleep problem and 3 the worst sleep quality. The questions are separated into 7 subcategories which are totaled to provide a global PSQI score, where a total score of greater than 5 indicates poor sleep. The shoulder-specific patient-reported outcomes were selected based on their specificity and efficiency [15].

Fig. 1. Philips respironics actiwatch spectrum plus (website: http://www.lintoninst.co.uk/Products/tabid/63/ProdID/676/Language/enUS/CatID/91/Actiwatch_Spectrum_Plus.aspx).

Patient demographic data collected included gender, race, age, body mass index, medical comorbidities, tobacco use, and employment status. Other data collected included shoulder range of motion, presence of physical exam signs, and size of rotator cuff tear.

For objective assessment of sleep quality, patients were provided with a Philips Respironics Actiwatch Spectrum Plus (Fig. 1). Patients were instructed to wear the device on their non-dominant wrist continuously (including bathing) for 2 weeks. A press of a single button on the device allowed patients to indicate their time of intent to sleep and their time of awakening. An example recording from the device is shown in Fig. 2. Patients were also given and instructed to complete a Consensus Sleep Diary during the same 2-week period.

For analysis, in cases where patients had not marked their sleep epoch with the device, their sleep diary was used as a surrogate instead. Analysis of sleep epochs was performed using the automatic scoring method initially described by Cole and since extensively validated [16].

Data obtained from the study cohort were compared to a historical cohort of 969 community-dwelling adults between the ages of 57 and 97 years [17]. This cohort has provided the basis for over 50 other studies utilizing actigraphy as an assessment of sleep measures.

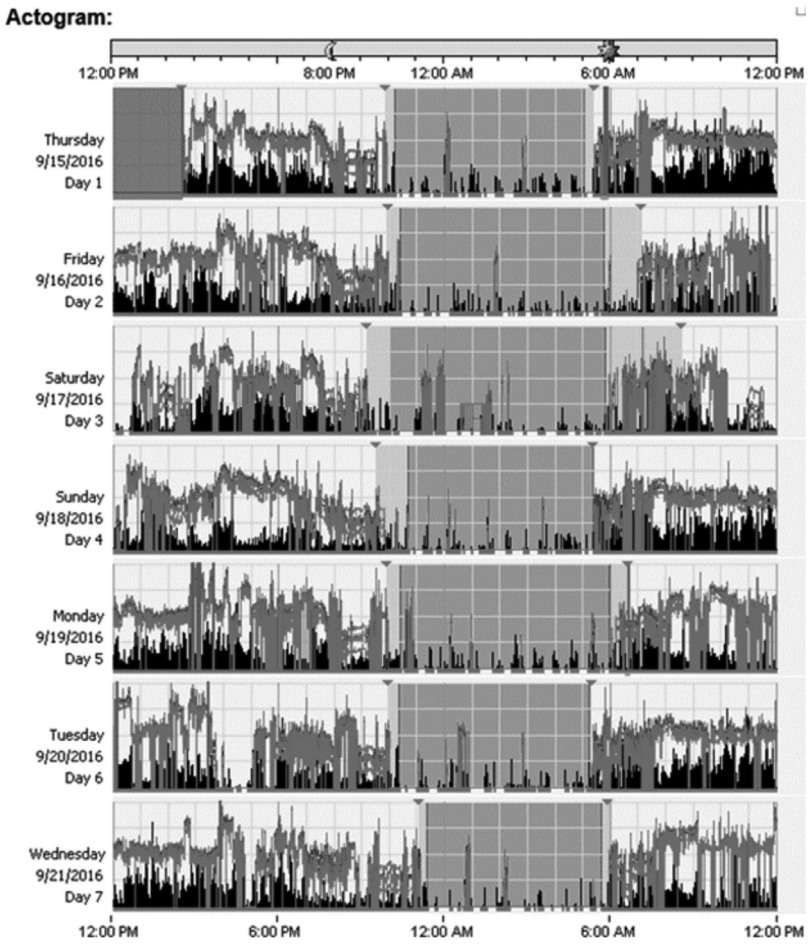

Fig. 2. Example actogram. Dark grey areas represent a period of deep, restful sleep. Light grey areas indicate time spent in bed but not asleep. Spikes of activity during deep sleep indicate periods of awakening.

2.4. Statistical analysis

All continuous data were analyzed using independent two-group *t*-test utilizing means and standard deviations. Categorical data were compared between the 2 groups using Chi^2 tests utilizing counts and percentages. A preliminary test to confirm the quality of variances was conducted prior to utilizing the *t*-test to confirm the appropriate statistical analysis. Non-parametric equivalents Wilcoxon rank-sum and Fischer's exact test were used as needed for non-normal distributions and low variable numbers, respectively. In all analyses, a p-value < 0.05 was considered statistically significant.

3. Results

3.1. Group demographics

Of the 20 patients enrolled, 18 were included for final analysis as 2 patients were unable or unwilling to wear the activity monitor for the duration of the study period. Two other patients did not complete a sleep diary; however, their actigraphic data were included for analysis. There were no significant demographic differences between the patients who chose to participate in the study and those who did not. The mean age of patients in our cohort (61.89 years ± 11.29) was significantly younger than the historical cohort (68.5 years ± 6.9, $p = 0.001$). Our cohort included 11 males and 7 females; the historical cohort included 463 males and 506 females ($p = 0.16$). Mean body mass index of our cohort was 31.8 kg/m^2 (range 21.08–54.42, SD 7.23). Twelve patients had tears of their dominant shoulder and 6 had tears of their non-dominant shoulder. The mean tear size was 2.46 cm (range 1.0–4.6, SD 1.27) in the medial-lateral dimension and 2.37 cm (range 0.8–5, SD 1.26) in the anterior-posterior dimension. Eight patients were classified as having large or massive tears (≥3 cm in sagittal plane), and 10 with small tears.

Table 1
Cohort demographics.

	Average	Standard deviation
Age	61.89	11.29
Gender	11 males	7 females
BMI	31.80	7.23
VAS	7.08	2.02
ASES	39.20	11.16
SANE	37.22	18.33
ESS	6.39	3.68
PSQI	8.44	3.13

Age represented in years. BMI: Body Mass Index, represented in Kg/m^2; VAS: Visual Analogue Score; ASES: American Shoulder Elbow Surgeons Score; SANE: Single Assessment Numerical Evaluation; ESS: Epworth Sleepiness Scale; PSQI: Pittsburgh Sleep Quality Index.

3.2. Subjective assessments

The subjective assessment scores of sleep quality are shown in Table 1. For our cohort, the mean visual analog scale was 7.08 (range 3–10, SD 2.02), indicating moderate to severe pain. The mean ASES

Table 2
Comparison to Historical Control.

	Study group		Historical control		
	Average	St.Dev.	Average	St.Dev	*p*-value
Age	61.89	11.29	68.5	6.9	**0.0010**
Mean TST (min)	365.55	67.22	391	50	**0.0338**
Mean time in bed (min)	529.78	62.12			
Mean SOL (min)	30.68	19.27	21	14	**0.0040**
Mean sleep efficiency (%)	74.89	8.53	78.4	7.4	**0.0474**
Mean WASO (min)	78.36	34.92	43.57	18.7	**<0.0001**

TST: total sleep time; SOL: sleep onset latency; WASO: wake after sleep onset; St. Dev.: Standard Deviation. Bold values indicate statistical significance ($p < 0.05$).

score was 39.20 (range 25.0–60.0, SD 11.16). The mean SANE was 37.22 (range 0–65, SD 18.33). The mean PSQI was 8.44 (range 5–13, SD 3.13), where a score greater than 5 indicates "poor" sleepers. The ESS was 6.39 (range 2–13, SD 3.68), where a score of 6–10 indicates higher normal daytime sleepiness.

3.3. Assessment of sleep quality

Table 2 provides the objective actigraphic and subjective sleep diary data. Patients tended to overreport their duration of sleep by an average of 89.73 min (SD ± 62.68 min), which was statistically significant ($p < 0.0001$). They also tended to overreport their sleep efficiency by an average of 17.72% (SD ± 8.34, $p = 0.0093$). WASO was typically underreported by an average of 39.72 min (SD ± 29.01 min, $p < 0.0001$). The difference in subjective and objective SOL was not significant.

The historical cohort used for this study has established normal parameters in middle-aged and elderly adults for total sleep time (391 ± 50 min), sleep efficiency (78.4% ± 7.4%), SOL (21 ± 14 min), and WASO (43.57 ± 18.7 min). Our cohort of patients with full-thickness rotator cuff tears demonstrated significantly worse sleep duration, sleep efficiency, SOL, and WASO ($p = 0.0338$, $p = 0.0474$; $p = 0.0040$, and $p < 0.0001$, respectively).

There were no objective measures of sleep quality that correlated with either the PSQI or ESS. Rather, the PSQI was associated with pain, as assessed by the visual analog scale ($r = 0.5250$; $p = 0.0249$) (Fig. 3). A similar relationship was noted with the ESS ($r = 0.4863$; $p = 0.0407$). A significant correlation between the sleep efficiency and the ASES ($r = 0.4986$; $p = 0.0352$) and SANE ($r = 0.5231$; $p = 0.0259$) were noted (Fig. 4). The SANE negatively correlated with SOL, such that a lower SANE corresponded with a greater time to restful sleep ($r = -0.6109$, $p = 0.0071$) (Table 3).

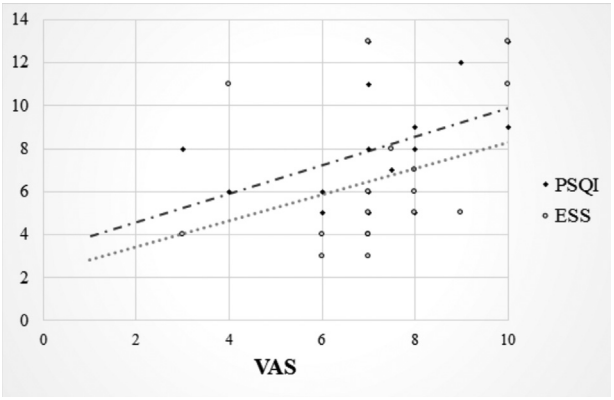

Fig. 3. Correlation of visual analogue score (VAS) with Pittsburgh Sleep Quality Index (PSQI) and Epworth Sleepiness Scale (ESS). r(PSQI) = 0.5260; $p = 0.0249$; r(ESS) = 0.4863; $p = 0.0407$.

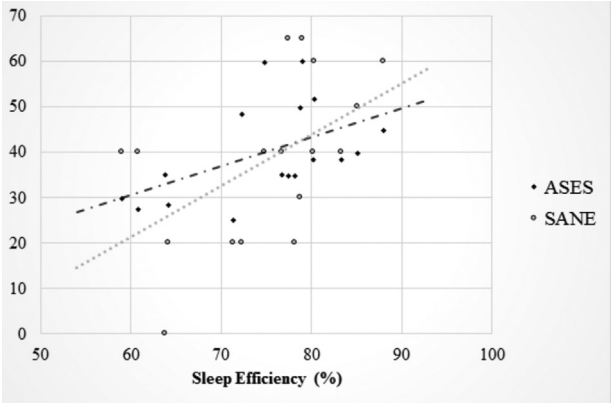

Fig. 4. Correlation of American Shoulder and Elbow Score (ASES) and single assessment numerical evaluation (SANE) to sleep efficiency. r(ASES) = 0.4986; $p = 0.0352$; r(SANE) = 0.5231; $p = 0.0259$.

4. Discussion

Our study demonstrates objectively dysfunctional sleep in patients with rotator cuff tears. Actigraphy in these patients showed a significant decrease in total sleep time and sleep efficiency and increase in SOL and WASO when compared to a historical cohort of healthy subjects. This study also showed that patients' subjective assessments of sleep quality appeared to relate more to

Table 3
Correlation of Subjective Assessments to Objective Findings

	PSQI/TST	PSQI/SOL	PSQI/WASO	PSQI/Eff
Correlation	0.2059	0.2187	−0.3068	0.3143
p-value	0.4124	0.3833	0.2153	0.2040
	ESS/TST	ESS/SOL	ESS/WASO	ESS/Eff
Correlation	−0.1710	−0.1370	−0.2285	0.0062
p-value	0.4975	0.5878	0.3618	0.9805
	ASES/TST	ASES/SOL	ASES/WASO	ASES/Eff
Correlation	0.3932	−0.1736	−0.4183	0.4986
p-value	0.1065	0.4909	0.0841	**0.0352**
	SANE/TST	SANE/SOL	SANE/WASO	SANE/Eff
Correlation	0.1812	−0.6109	−0.3624	0.5231
p-value	0.4718	**0.0071**	0.1394	**0.0259**

ESS: Epworth Sleepiness Scale; PSQI: Pittsburgh Sleep Quality Index; ASES: American Shoulder Elbow Surgeons Score; SANE: Single Assessment Numerical Evaluation; TST: total sleep time; SOL: sleep onset latency; WASO: wake after sleep onset; Eff: sleep efficiency. Bold values indicate statistical significance ($p < 0.05$).

shoulder function and pain than sleep quality, with poor correlation of these subjective assessments to the objective data obtained by the activity monitor actigraphy. This study provides data that physicians may use in their daily practice when counseling patients of the treatment algorithms for rotator cuff tears, addressing contributing factors such as pain and shoulder dysfunction, and the interpretation of sleep disturbance and subjective outcome scores.

Sleep disturbance in patients with rotator cuff disease was first reported by Austin et al. in 2015 in a cohort of 56 patients evaluated pre- and post-operatively using the PSQI [3]. At 6 months postoperatively, 38% of patients continued to report "poor" sleep despite a statistically significant decrease in PSQI. Similar findings were noted by Serbest et al., in which 58% of the 31 patients continued to have PSQI scores greater than 5 ("poor" sleep) at 6 months postoperatively [6]. The PSQI is subject to a prominent recall bias and can be heavily influenced by depression, anxiety, and fatigue [18–20]. The PSQI categorizes only "good" from "poor" sleepers and in our cohort, all patients would be classified as "poor" sleepers including those who had a near-normal sleep efficiency greater than 78%, indicating that actigraphy objective data is a better tool to utilize in sleep assessment than the PSQI [21].

Our study found that the PSQI, and the ESS, correlated more with pain as measured by the VAS, than with objective sleep quality. A great deal of research has demonstrated an intimate association between sleep quality and the perception of pain. A study of 971 subjects demonstrated that sleeping fewer than 6 hours or greater than 9 hours was regularly followed by a subjective increase in pain the following day [22]. Similarly, Haack et al. found that sleep deprivation results in increased serum iterleukin-6 and C-reactive protein levels, along with increased pain ratings [23]. More specific to rotator cuff syndrome, Ha et al. found increased melatonin-receptor expression in patients with rotator cuff tears, and reversal of interleukin-6 production when treated with luzindole, a melatonin-receptor antagonist [24,25]. This elevation in inflammatory markers reveals a clear biologic basis for the increased perception of pain associated with poor sleep quality. Most recently, Khazzam et al. conducted a cross-sectional study of 117 patients with rotator cuff tears and 274 with tendinitis, 91% of whom complained of nocturnal shoulder pain. Similar to our study, they concluded that poor sleep quality, as indicated by PSQI, was not correlated with rotator cuff tear status but rather with higher VAS pain scores [26].

Rotator cuff tears are a pain generator, with previous studies suggesting that patients with smaller tears experience greater intensity of pain. In a study of 324 consecutive patients discovered that patients with smaller rotator cuff tears had higher PSQI and ESS scores than those with large or massive tears [27]. In their series, they did not find significant differences in sleep duration, sleep efficiency, or SOL in an age-matched control group of 184 patients; however, it is important to note that these conclusions were reached using 1 or 2 subcategories from the PSQI. Our study did not demonstrate a significant relationship between tear size and objective sleep quality.

To obtain objective assessment of sleep quality, wrist-based accelerometry has been extensively utilized since its advent in the early 1990s. Marino et al. demonstrated very high sensitivity (0.965) and accuracy (0.863) when comparing actigraphy to polysomnography in a cohort of 77 healthy adults [9]. In 2009, the American Academy of Sleep Medicine elevated actigraphy to the highest category of evidence in sleep research [8]. The use of a wrist-based device allows for a more convenient method of assessment and provides a greater duration of data. Because patient sleep quality can vary significantly from day to day, it is highly advantageous to study sleep for a greater duration. Of the few orthopedic studies that utilized actigraphy, all evaluated patients undergoing total joint arthroplasty [28–31]. Our study provides high-quality objective data over an extended period of 2 weeks which demonstrates poor sleep quality in patients with rotator cuff tears using actigraphy.

Discrepancy between objective and subjective sleep has been a topic of discussion for many years. Kay et al. compared 63 patients with a diagnosis of insomnia to 51 healthy controls and found no objective differences in their total sleep time or SOL based on actigraphy; however, profound disparities were noted in their sleep diaries ($p < 0.001$ for all sleep variables) [32]. Healthy patients tended to overestimate their total sleep time and efficiency, while patients with insomnia, depression, or anxiety tended to underestimate these values [33]. This is consistent with our cohort, with the majority of patients believing their sleep to be longer and more efficient than demonstrated by actigraphy. Additionally, actigraphy tends to overestimate total sleep time and sleep efficiency, as periods of quiet rest may be erroneously included as sleep.

This study has limitations. First, the size of our cohort was modest. Recruitment was limited to a single site given the high cost, and thus limited number, of Actiwatch devices purchased for the study. Also, patient diaries were used as an alternative in the instances where patients forgot to press the button on their device. To address these limitations, patients wore the activity monitors for an extended time to ensure obtainment of high-quality data. There is a certain degree of selection bias for this cohort, as those inclined to participate are perhaps those with greater sleep dysfunction. Another concern is whether wearing an activity monitor may influence sleep quality, although previous studies have shown that the Hawthorne effect from use of a wrist-worn activity monitor is minimal [8]. Our study was also limited by the use of a historical cohort rather than age-matched controls. However, dozens of studies have made use of Van den Berg et al.'s data set, which is considered to be representative of our study population. It is felt to be a better comparison than a similar study that consisted of 669 adults aged 38–50 whose mean sleep efficiency was 80.8% ± 11.3% [34]. Lastly, our study was not intended to investigate associated pathologies such as attenuation of the long head of the biceps, labral injuries, or osteoarthritis, and as such was likely underpowered to include these sub-group analysis. Our study was strengthened by the objective and highly detailed actigraphy data, the high compliance from participants in the study, and the prospective nature of the study. Patients anecdotally reported high satisfaction with use of the wrist-worn activity monitors, and this study provides a strong basis for further orthopedic research utilizing actigraphy for objective sleep assessment.

5. Conclusion

This study prospectively analyzed objective sleep quality in a cohort of patients with full-thickness rotator cuff tears. Objective sleep measures demonstrated poor sleep quality in patients with rotator cuff tears with shorter sleep duration, frequent awakenings, and decreased efficiency. Subjective assessments of sleep did not correlate with objective findings.

Disclosure of interest

The authors declare that they have no competing interest.

Funding

Henry Ford Health System Graduate Medical Education, grant #202199. Total funds of $4665 utilized to procure activity monitors used in this study. No outside source of funds was involved in data collection, data analysis, or the preparation of or editing of the manuscript.

Contributions

CA and LK carried out the data collection and created the database. CA and LK participated in detailing the statistical analysis request, analysing the results, and synthesizing tables and figures. All authors carried out literature review, drafted the manuscript and contributed to multiple revisions of the manuscript. SM is the attending physician who approved each step of the study, reviewed the literature cited and statistical analysis requested, revised each draft of the manuscript, and provided mentorship throughout the course of the study. All authors read and approved the final manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version at: https://doi.org/10.1016/j.otsr.2019.09.033.

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