Using Clinically Accessible Tools to Measure Sound Levels and Sleep Disruption in the ICU: A Prospective Multicenter Observational Study

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Objectives: To use clinically accessible tools to determine unit-level and individual patient factors associated with sound levels and sleep disruption in a range of representative ICUs.

Design: A cross-sectional, observational study.

Setting: Australian and New Zealand ICUs.

Patients: All patients 16 years or over occupying an ICU bed on one of two Point Prevalence study days in 2015.

Interventions: Ambient sound was measured for 1 minute using an application downloaded to a personal mobile device. Bedside nurses also recorded the total time and number of awakening for each patient overnight.

Measurements and Main Results: The study included 539 participants with sound level recorded using an application downloaded to a personal mobile device from 39 ICUs. Maximum and mean sound levels were 78 dB (SD, 9) and 62 dB (SD, 8), respectively. Maximum sound levels were higher in ICUs with a sleep policy or protocol compared with those without maximum sound levels 81 dB (95% CI, 79–83) versus 77 dB (95% CI, 77–78), mean difference 4 dB (95% CI, 0–2), $p < 0.001$. There was no significant difference in sound levels regardless of single room occupancy, mechanical ventilation status, or illness severity. Clinical nursing staff in all 39 ICUs were able to record sleep assessment in 15-minute intervals. The median time awake and number of prolonged disruptions were 3 hours (interquartile range, 1–4) and three (interquartile range, 2–5), respectively.

Conclusions: Across a large number of ICUs, patients were exposed to high sound levels and substantial sleep disruption irrespective of factors including previous implementation of a sleep policy. Sound and sleep measurement using simple and accessible tools can facilitate future studies and could feasibly be implemented into clinical practice. (*Crit Care Med* 2017; XX:00–00)

Key Words: critical care; delirium; earplugs; noise; sleep

Sleep disruption can result in immune, metabolic, endocrine, and psychomotor dysfunction. In patients admitted to the ICU, sleep disruption is common and is associated with delirium (1, 2). There is some evidence to suggest ICU sound levels consistently exceed World Health Organization (WHO) hospital recommendations of 30 and 40 dB for baseline and sound events, respectively, and are a potentially modifiable contributor to sleep disruption in the ICU (3–5). However, the ICU and patient determinants of sound remain uncertain at least in part because established methods to measure sound and sleep, such as sound level meters and polysomnography (PSG), are expensive, cumbersome, time consuming, and have generally only been undertaken in small numbers of patients and ICUs. Furthermore, studies reporting ICU noise reduction initiatives during the implementation phase may not reflect longer term translation into practice reducing generalizability of the findings.

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The aim of this study was to use clinically accessible sound and sleep measuring tools to determine unit-level and individual patient factors associated with sound levels and sleep disruption in a range of representative ICUs.

MATERIALS AND METHODS

We undertook a cross-sectional, observational study in 49 ICUs in Australia and New Zealand as part of the Australian and New Zealand Intensive Care Society Clinical Trials Group Point Prevalence Program (PPP). Of these, 39 contributed to the sound and sleep recording. A full list of participating sites and study investigators is provided in the supplementary appendix (**Appendix 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/C553). Participating sites collected prespecified data over a 24-hour period in all patients 16 years or over occupying an ICU bed at 10 AM on one of two PPP study days (September 15, 2015 or October 14, 2015).

Demographic and physiologic data including mechanical ventilation status, Acute Physiology and Chronic Health Evaluation II score, and Sequential Organ Failure Assessment (SOFA) score were collected from the medical notes and ICU bedside charts and scored without the neurologic component. Participants were followed up to hospital discharge, censored at 28 days post the nominated point prevalence day. Data were entered into an electronic data capture system (REDCap; Vanderbilt University, TN) hosted at The George Institute for Global Health (6). Measurements of ambient sound levels were made by data collectors at participating sites using a sound measurement application (app) downloaded to a personal mobile device. The nominated apps (Decibel 10th for iOS and Sound Meter for Android) were chosen for the accuracy of sound recording based on previously published comparative reports (7, 8). Continuous equivalent sound levels (LAeq) and maximum sound levels (LAmax) were measured in A-weighted decibels (dB [A]) with the measurement device placed within 1 m of the head of each study participant and recorded continuously for 1 minute. No prespecified time of recording was mandated. Details of sound collection protocol provided to site research staff are found in the supplementary appendix (Supplemental Digital Content 1, http://links.lww.com/CCM/C553). Bedside nurses also recorded time awake overnight (22:00-06:00), recorded on the night preceding the point prevalence day using an adapted version of a previously published bedside sleep assessment tool (9). A prolonged disruption was defined as an overnight period of wakefulness following a period of sleep of 15 minutes or more. A full description of the sound recording apps, methods, and bedside assessment tool is provided in the supplementary appendix (Supplemental Digital Content 1, http://links.lww.com/CCM/C553).

Data are presented as mean and SD for normally distributed data, with differences tested using the Student *t* test or repeated analysis of variance as appropriate. Nonnormally distributed data are presented as median and interquartile range (IQR) with differences assessed using the Mann-Whitney *U* test. CIs for median differences were calculated using the Bonett-Price method. Categorical data are presented as number and percentages and assessed using chi-square or Fisher exact tests as appropriate. Outcome data were censored at 28 days. No assumptions were made for missing data. The data were analysed using Stata SE 14.1 (StataCorp, College Station, TX). All participating sites received institutional approval prior to undertaking the study. The article was prepared according to STROBE guidelines (10).

RESULTS

The study included 539 participants with sound measurement recordings who were being treated in 39 ICUs (20 tertiary, 10 metropolitan, three rural, six private ICUs, range of funded ICU beds 6–51). Recording of total time awake overnight occurred in all 39 ICUs and was available for 376 participants (67%). The characteristics of the cohort and subgroup with recording of total time awake overnight are presented in **Table 1**.

Unit-Level Sleep-Related Interventions

Only six ICUs (15%) reported using a sleep protocol or policy. Of the total study cohort, earplugs and eye masks were used in five (0.9%) and seven (1%) participants, respectively. Specified times at which lights were dimmed and brightened during the overnight period were reported by 34 ICUs (87%). The most common times for dimming and brightening lights were 22:00 (63%) and 07:00 (40%), respectively.

TABLE 1. Participant Characteristics

Variable	Entire Cohort[a] (*n* = 539)	Sleep Measurement Subgroup[a] (*n* = 376)
Age	62 (48–72)	62 (47–72)
Male sex, *n* (%)	304 (56)	219 (58)
Source of admission, *n* (%)		
Emergency department	149 (28)	103 (27)
Operating theater (elective)	117 (22)	77 (20)
Operating theater (emergency)	90 (17)	64 (17)
Ward	116 (22)	86 (23)
Other hospital	42 (8)	28 (7)
Other ICU	25 (5)	18 (5)
Acute Physiology and Chronic Health Evaluation II	17 (12–22)	17 (12–22)
Sequential Organ Failure Assessment	7 (3–11)	7 (3–11)
Mechanical ventilation, *n* (%)	211 (39)	146 (39)
Length of stay ICU, d	6 (3–15)	6 (3–16)
Length of stay hospital, d	16 (9–31)	17 (10–31)
Mortality ICU, *n* (%)	37 (7)	21 (6)
Mortality hospital, *n* (%)	59 (11)	38 (10)

[a]Median and interquartile range unless otherwise specified.

Sound Levels

Overall, maximum and mean sound levels were 78 dB (SD, 9) and 62 dB (SD, 8), respectively. Sound measurements were recorded at time points throughout the 24-hour cycle, with 474 individual patient measurements occurring between 08:00 and 22:00 and 65 measurements occurring between 22:00 and 08:00. Maximum and mean sound levels according to time of day are presented in **Figure 1**.

Maximum sound levels varied significantly according to ICU (range, 58–91 dB; $p < 0.01$) (**Fig. 2**). The association remained significant when time of recording was accounted for ($p < 0.01$). There was no significant correlation between maximum sound levels and number of occupied ICU beds ($p = 0.85$). Structural and individual factors associated with sound levels are presented in **Table 2**.

Overnight Wakefulness

The median time awake overnight was 3 hours (IQR, 1–4). The median number of disruptions was three (IQR, 2–5). The median hours awake overnight was 2 hours (IQR, 0–4) versus 3 hours (IQR, 2–4) for ventilated and nonventilated patients, respectively (median difference 1 hr [95% CI, 0–2]; $p < 0.001$]).

Additional unit-level and individual factors associated with overnight total time awake are presented in **Table 3**.

DISCUSSION

We have conduced a large, prospective multicenter study that measured sound levels in the ICU using a simple app downloaded to a personal mobile device. The use of simple, standardized download and measurement instructions achieved clinically useful sound recordings in 539 ICU patients in 39 different ICUs. This suggests broad generalizability of the methodology and the potential for replication in a wide variety of clinical and research settings. Furthermore, we found that clinical nursing staff across all 39 participating ICUs were consistently able to record sleep assessment in 15-minute intervals. This provides evidence of the feasibility of pragmatic documentation of sleep both in a large study setting, and potentially in everyday clinical practice, for example, to improve prediction of delirium (11). Future studies should examine whether consistent measurement and documentation of sound and sleep in the ICU are also associated with improvements in both, and, consequently, patient outcomes.

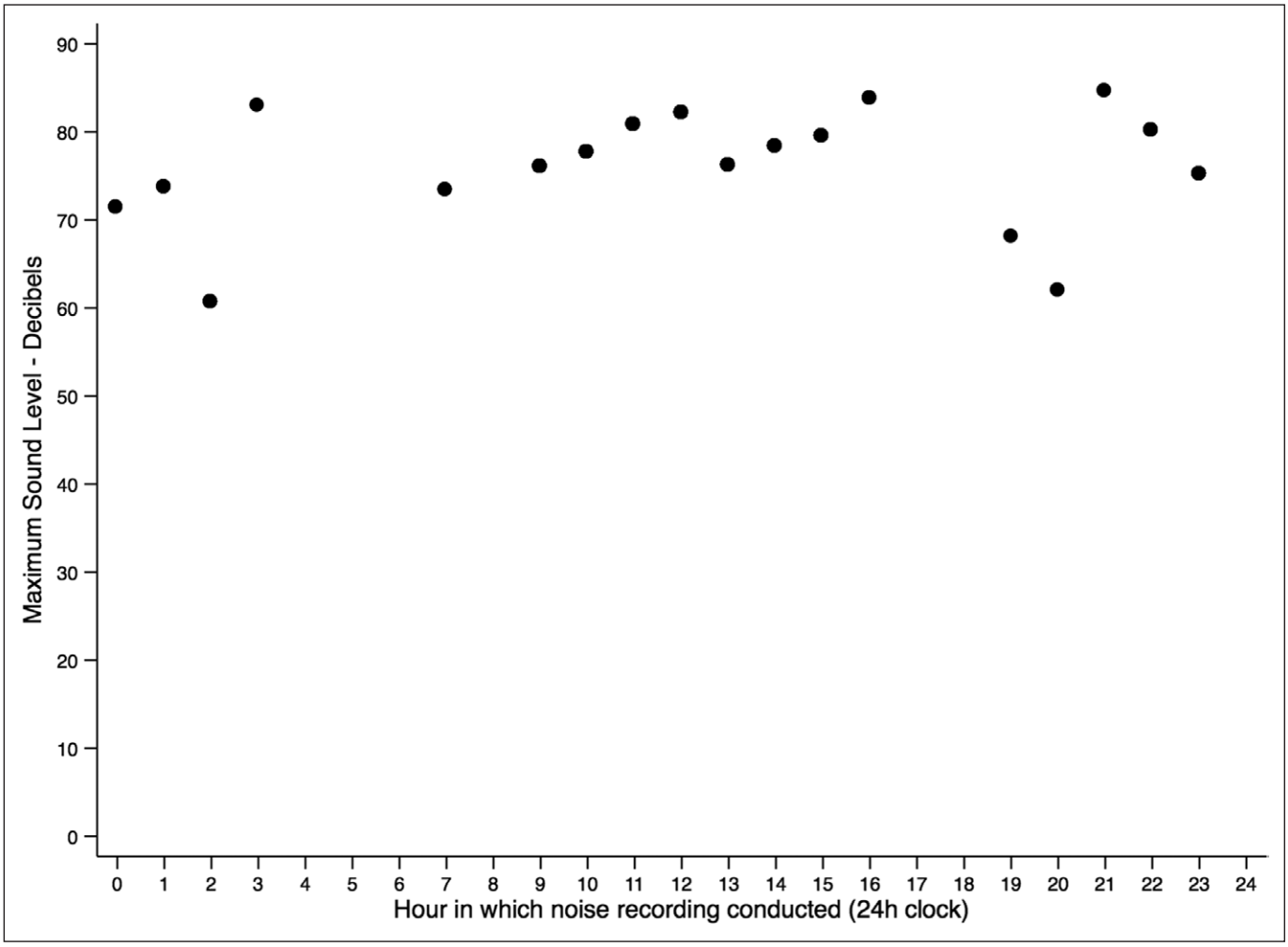

Figure 1. Maximum and mean sound levels by time of day.

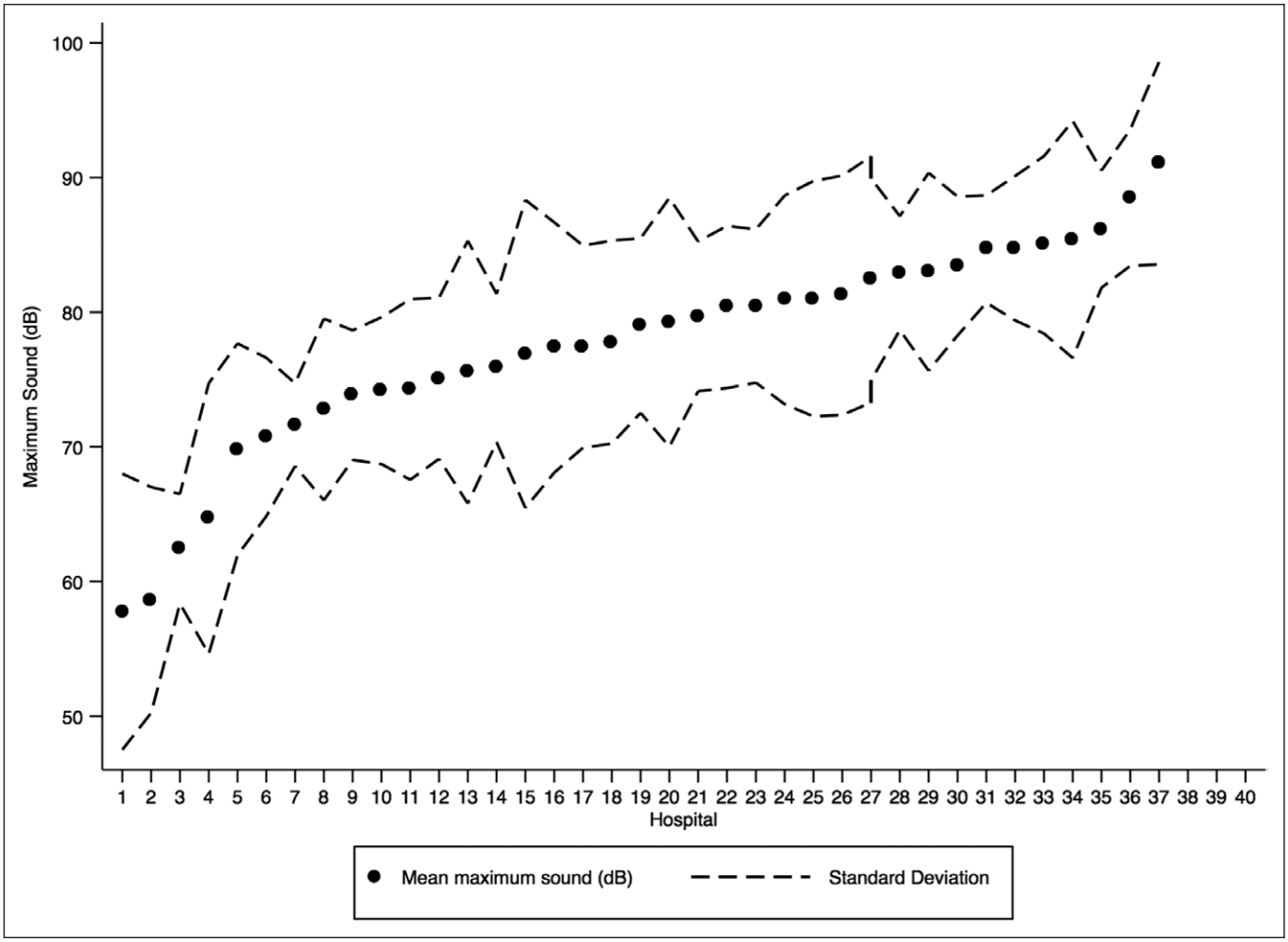

Figure 2. Hospital variation in mean maximum sound levels.

We found that sound levels in the ICU were universally high and exceeded WHO recommendations at all time points measured in both the day and the night (4). Sound levels were similar when comparing patients in a single bed and open ward area and were not dependent on mechanical ventilation status or SOFA score. Our findings suggest that high sound levels are a ubiquitous problem for patients admitted to the ICU, irrespective of geography, supportive therapies or illness severity. However, sound levels did vary between hospitals and the difference remained significant when time of recording and bed occupancy were taken into account.

In our study, the use of a unit sleep policy or protocol was infrequent but associated with statistically higher, although clinically similar, sound levels. Patel et al introduced a multicomponent nocturnal sleep bundle in a single ICU and found a significant increase in sleep and decrease in delirium. In contrast, Tainter et al (3) found the use of a formal quiet time was associated with a clinically irrelevant reduction in sound levels at night, largely attributable to excessive environmental noise. These findings are consistent with several studies in which implementation of a sleep protocol based on alteration in staff behavior has shown minimal decrease in sound or improvement in sleep duration (12–14). Whether the differences in findings relate to environmental factors, implementation strategy or are a result of 'implementation decay' was not assessed in our study (15). Future studies should consider addressing this issue and may assist in updating delirium guidelines (16).

The extent to which noise is a major contributor to sleep disruption in the ICU has been questioned. Freedman et al (17) performed sound level recordings and PSG in 22 patients in a single medical ICU and found that noise accounted for only 17% of awakenings. In our study, performed in a large number of patients and ICUs, the mean maximum sound levels of 78 dB, recorded within a meter of the patient's head, were similar in volume to an alarm clock (18). We believe that, for the majority of patients in the ICU, in whom light sedation or no sedation is the goal, it is implausible that sound levels in this range do not cause sleep disruption. Furthermore, the results align with the evidence of reported patient perception of noise as a substantial contributor to sleep disruption (19, 20).

Earplugs are a cheap and easily administered noise abatement strategy that may reduce delirium in patients admitted to the ICU (21). Despite this, our study found that earplugs were

TABLE 2. Factors Associated With Sound Levels

Maximum Sound Level, dB	Result[a] (*n* = 539)	Difference, Mean (95% CI)	*p*
Time of day			
Day—08:00 to 22:00 (*n* = 474)	79 (78–80)	5 (3–8)	< 0.001
Night—22:00 to 08:00 (*n* = 65)	74 (71–76)		
Single room			
Yes (*n* = 301)	78 (77–80)	0 (–2 to –2)	0.93
No (*n* = 234)	78 (77–79)		
Unit sleep policy			
Yes (*n* = 119)	81 (79–83)	4 (2–6)	< 0.001
No (*n* = 420)	77 (77–78)		
Illness severity			
SOFA > 7 (254)[b]	78 (77–80)	0 (–1 to 2)	0.527
SOFA ≤ 7 (284)[b]	78 (77–79)		
Positive pressure ventilation			
Yes (*n* = 211)	78 (76–79)	1 (–1 to 2)	0.313
No (*n* = 328)	79 (78–80)		
Antipsychotic medication			
Yes (*n* = 49)	78 (75–80)	1 (–2 to 3)	0.615
No (*n* = 490)	78 (78–79)		

SOFA = Sequential Organ Failure Assessment.
[a]Mean and SD unless otherwise specified.
[b]SOFA scored without neurologic component.

TABLE 3. Factors Associated With Time Awake Overnight

Variable (*n* = 539)	Median Hours Awake (IQR)	Median Difference (95% CI)	*p*
Single room			
Yes (*n* = 191)	3 (1–4)	0 (–0.4 to –0.9)	0.35
No (*n* = 182)	3 (1–4)		
Unit sleep policy			
Yes (*n* = 77)	3 (2–4)	0 (–1 to 1)	0.40
No (*n* = 299)	3 (1–4)		
Illness severity			
SOFA > 7 (*n* = 181)	3 (1–4)	0 (–1 to –1)	0.80
SOFA ≤ 7 (*n* = 195)	3 (1–4)		
Positive pressure ventilation			
Yes (*n* = 146)	2 (0–4)	1 (0–2)	<0.001
No (*n* = 230)	3 (2–4)		
Antipsychotic medication[a]			
Yes (*n* = 38)	4 (2–6)	1 (0–2)	0.01
No (*n* = 338)	3 (1–4)		

IQR = interquartile range, SOFA = Sequential organ failure assessment.
[a]Difference remains significant when excluding patients receiving positive pressure ventilation ($p = 0.01$)

used in less than 1% of patients, suggesting that the quality of the evidence is currently insufficient to lead to widespread implementation. Given the difficulties in achieving a clinically meaningful reduction in sound levels in the ICU, further studies should assess the feasibility and efficacy of earplugs as a unit-level strategy to abate sound, improve sleep, reduce delirium, and, potentially, improve patient-centered outcomes (20, 21).

Our study also found that overnight sleep disruption is substantial and ubiquitous, and independent of ICU location or illness severity. Compared with non-intubated patients, the number of hours awake overnight was significantly less in patients receiving mechanical ventilation, possibly due to the difficulty in differentiating sedation from sleep. However, a median observed duration of 2 hours awake overnight in ventilated patients is still high and likely to underestimate the true time awake, and, particularly if cumulative over the ICU stay, of potential clinical significance (22).

Several limitations to this study are recognized. Prevalent patients may be systematically different to incident patients with overrepresentation of long-stay patients. Sound levels and documentation of wakefulness may have been recorded at separate time points precluding analysis of association. Timing was not controlled between or within sites. These issues could easily be addressed in future studies using this recording methodology. Although sound levels were only recorded for a minute and only a minority of measurements occurred overnight, the findings are consistent with other studies and this still represents one of the largest cohort of ICU patients to have sound measurements recorded overnight (5, 23). Sleep disruption was measured using a validated observational tool that may underestimate wakefulness (total time and number of disruptions) compared with the gold standard of PSG (24). However, Edwards et al (9) found that nursing assessment of sleep was correct 82% of the time compared with PSG, standardized PSG staging criteria may not reliably determine the presence or absence of sleep in critical illness, and revised sleep scoring criteria proposed for critically ill patients proposed (pathologic wakefulness and atypical sleep), also rely first on a bedside behavioral assessment of sleep (25). Sound levels were assessed using an app downloaded to a personal mobile device rather than a gold standard measurement device. However, the sound levels reported in our pragmatic study were consistent with other studies, and it is unlikely that the large, representative, sample size of our study could have been achieved with conventional sound measuring equipment (23, 26, 27). Sedation

scores were not collected and future studies should examine the interplay between the measurement of sedation and sleep.

CONCLUSIONS

Across a large number of ICUs, patients were exposed to high sound levels and substantial sleep disruption irrespective of previous implementation of a sleep policy or protocol, single room occupancy, mechanical ventilation status, or illness severity. Sound and sleep measurement using simple, accessible tools can facilitate future studies and could feasibly be implemented into clinical practice.

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