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Major Article

Contamination of reusable electroencephalography electrodes: A multicenter study

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Key Words:
Electroencephalography (EEG) cup electrodes
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Cross-contamination

Background: Reusable electroencephalography cup electrodes and lead wires (rEEGs-CELWs) could be a source of microorganisms capable of causing hospital-acquired infections. The purpose of this study was to investigate for bacterial species of cleaned rEEGs-CELWs.

Methods: This microbiologic evaluation involved 4 epilepsy monitoring units where rEEGs-CELWs were swabbed for bacteria using standard techniques. Analyses involved descriptive statistics and logistic regression (across sites).

Results: Of 124 swabs, 31 (25.0%; range, 13.3%-43.3%) showed positive bacterial cultures, without between-site differences ($P = .17$). Bacteria were labeled by risk for hospital-acquired infection: no risk, potential risk (primarily in immunocompromised patients), and at risk (associated with infections and antibiotic resistance). At-risk bacteria species were *Staphylococcus epidermidis* (38.7%), *Staphylococcus capitis* subsp *ureolyticus* (3.2%), and *Staphylococcus haemolyticus* (9.6%). Potential-risk species were *Micrococcus* spp (22.6%), *Acinetobacter lwoffii* (6.5%), *Staphylococcus hominis* subsp *hominis* (6.5%), and *Staphylococcus warneri* (6.5%). *Bacillus* (9.6%) was the only no-risk species. Of 18 antibiotics tested on positive cultures, resistant bacteria were found in a median of 1 (range, 0-11) positive culture, equating to a 6.7% (range, 0%-61.1%) resistant antibiotic rate; no microorganisms were resistant to all antibiotics tested.

Conclusions: Bacteria that were potential risk or at risk for infection were found on 22.6% of cleaned rEEGs-CELWs. Use of single-use electrodes and research on scalp infection and infection reduction interventions are warranted.

Reusable equipment, such as electroencephalography (EEG) cup electrodes, may harbor bacteria that can lead to hospital-acquired infection (HAI) (including antibiotic-resistant HAI) because cleaned, ready-to-use EEG electrodes may be placed in critically ill or immunocompromised patients. The EEG procedure, which starts with abrasion of the skin to allow placement of EEG cup electrodes, may be a source of HAI. Insufficient cleaning of reusable EEG electrode surfaces, especially around the cup area that comes into contact with the abraded scalp skin surface, could expose patients to bacteria and microscopic epithelial cells or blood. Therefore, EEG electrodes are categorized as a semi-critical device that requires comprehensive reprocessing to prevent HAIs.[1-3] Other investigators found bacterial growth on inanimate objects used in hospital and health care

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environments, such as electrocardiographic lead wires,[4] ultrasound probes,[5] bath basins,[6] and blood pressure cuffs.[7] Further, cleaning of EEG electrodes may not be simple because an EEG electrode set encompasses multiple lead wires and cup electrodes that may become entangled, and microscopic debris, including blood, may be hard to remove from EEG electrodes.

Cleaning technique policies are not always standardized, and health care providers who complete disinfection procedures may not adhere to recommended policy expectations.[8,9] In a consensus statement on continuous EEG monitoring in critically ill adults and children, authors created many recommendations specific to training personnel for monitoring of infection control. Themes included EEG electrode equipment monitoring, disinfecting equipment, applying scalp electrodes, monitoring of a patient's scalp for evidence of skin breakdown or infection (during monitoring and after electrode removal), removing electrodes from nonintact skin, and high-level disinfection and steam sterilization.[10] However, consensus statement recommendations did not provide specific semi-critical (moderate-level) disinfection recommendations after removing EEG electrodes from noncritical patients.[10]

Bacterial HAIs are costly for the health care sector and Medicare[11] and are burdensome for patients. Heightened quality of care and patient safety expectations have led to an increased interest in the role of cleaning surfaces and hands to manage HAI.[12] Strict cleaning procedures and proper cleaning and disinfecting techniques are part of a multibarrier strategy to prevent HAIs.[13,14]

It is important to learn if bacteria, epithelial cells, and blood remain on cleaned reusable EEG electrodes. The primary purposes of this study were to examine if cleaned, ready-to-use EEG electrodes harbored bacteria and, if bacteria were present, to identify the bacterial species, risk for human infection, and prevalence of antibiotic resistance. Secondary purposes were (1) to examine the prevalence and load of epithelial cells and blood on cleaned, ready-to-use EEG electrodes and (2) to determine if the presence of EEG electrode microbial growth was variable across 4 data collection sites.

METHODS

A prospective, multihospital microbiologic evaluation was initiated to assess cleaned, reusable EEG electrodes. The institutional review board of the principal investigator's site deemed the methodology to be nonhuman research that did not require ethical oversight and review.

Setting and sample

Four U.S. hospital sites were selected because of their diversity in location (East, Midwest [North], South, and West), diversity in size (from 500 to >1,400 beds), and ability to coordinate nursing research with an external site. Other inclusion criteria were leadership in neuroscience care, presence of an epilepsy monitoring unit, and use of reusable EEG electrodes as part of usual care assessment and monitoring in an epilepsy monitoring unit. Further, sites were willing to participate, able to assign a neurology, epilepsy, or research nurse to coordinate one-time data collection, able to assist the laboratory and coordinating center research nurse to navigate to the area where EEG electrodes were stored after cleaning and before use, and able to provide verbal assurance that on most days there were a minimum of 3 reusable EEG electrode sets that had been cleaned, stored, and ready for use and could be included in specimen collection. For all 4 sites, the number of electrode sets and individual electrodes available varied from bundled electrodes in groups of 10-24 and individually hung electrodes after cleaning on a wall or in a cabinet. There were no exclusion criteria.

The minimum number of swab samples to be collected, cultured for bacteria, and analyzed was 120 (30 per hospital). Power calculations assumed 80% power and used 2-sided tests. In the calculation, a reference proportion of 40% was assumed, which allowed for a conservative estimate of power because variability is greatest around 50%. Using a 95% confidence interval (CI) for estimation and a Bonferroni-corrected significance level of $0.05/6 = 0.008$ to allow for comparisons of the 4 sites, with 30 samples per site, it would be possible to estimate the percentage of positive cases (across all sites) with 95% confidence to within ±14% and detect differences of ≥43% between individual sites. Power calculations were performed using SAS software (version 9.4; SAS Institute, Cary, NC).

Data collection: Swabbing procedure

The coordinating center arranged sample collection with each site investigator. To minimize site bias, site investigators were asked not to communicate the date of specimen collection. A coordinating center research nurse travelled to and oversaw specimen collection at all 4 sites. A trained laboratory technician/microbiologist from the certified clinical laboratory responsible for analyzing specimens traveled to all 4 sites to complete the procedures of specimen preparation, collection, storage, and shipment of samples. The coordinating center nurse and microbiologist wore a protective face shield, barrier gown, and gloves during preparation, collection, storage, and shipping of swabs obtained from reusable EEG electrodes.

The microbiologist followed the same procedure for collection of each specimen. The bacterial swab was removed from its packaging, and the tip was moistened with a drop of sterile saline. The microbiologist swabbed EEG electrodes from multiple wires, ensuring that the EEG cup and lower third of the electrode lead wire were targeted. After swabbing was complete, it was inserted into its transport tube and a biohazard bag. The coordinating center nurse labeled each specimen and completed laboratory requisitions, which were placed in the open-ended pouch of the biohazard bag. To assess presence of epithelial cells and blood, the coordinating center nurse and microbiologist observed visually for the presence of dried blood, and a gram stain slide was prepared. The slide was air-dried and shipped with the culture swab. All samples were shipped using overnight delivery. Once at the clinical laboratory, culture swabs were plated to both aerobic and anaerobic media and inoculated into thioglycollate broth. Gram stain slides were stained and visualized under a microscope before results were categorized and quantified.

During each specimen collection, the coordinating center nurse completed a case report form that provided details of the number of cup electrode sets that were used in specimen collection, the number of EEG electrodes swabbed from each lead wire set, and the storage location of electrodes (eg, if they were bundled with others in a set, if they were hanging as individual electrodes). Observation of blood or other debris was also recorded. All swab specimens were collected during a 10-week period (February-April 2017).

Analysis plan

Bacterial species were categorized based on their risk and virulence of causing human infection,[15-29] as assigned in a previous publication[4]: no risk (no pathogenic potential because the bacteria was not previously associated with human disease), potential risk (low risk of pathogenesis in healthy adults with normal immune system function but a risk of infection in immunocompromised patients), and at risk (risk of infection when skin was punctured, or with presence of catheters, implants, or wounds).

Categorical variables were summarized using frequencies and percentages, and continuous variables were summarized using medians and ranges. To compare clinical sites on rates of positive cultures and positive results for epithelial cells, mixed effect logistic regression models were fit with site as a fixed effect and storage area within site as a random effect, to adjust for any potential correlation caused by storing wires in the same location. Odds ratios and 95% CIs for all comparisons were calculated. Per comparison significance levels of 0.05/6 = 0.008 were assumed for each comparison. Summaries were calculated using SAS Software (version 9.4; SAS Institute, Cary, NC).

RESULTS

Of the 4 sites that provided specimen samples from cleaned, reusable EEG electrodes, cleaning procedures were somewhat similar. All 4 sites used a 2-step cleaning process. First, using a reusable brush to clean EEG cup electrodes, sites soaked and washed electrodes with a dishwashing detergent and water (2 sites), mild pH enzyme-based, presoak-plus-cleaner (1 site), or a germicidal bleach cleaner (1 site). Then, all sites used a bleach-based product as a wipe, spray, or liquid to disinfect EEG electrodes.

In total, 124 specimens were obtained, including 30 each from sites A, B, and C and 34 from site D. The number of EEG electrodes available for specimen sampling varied by site, from 4 sets at site D to 7 sets at sites A and B. The number of individual EEG cup electrodes swabbed per specimen, per site ranged from 3 to 12 (median, 5), to all swabbing of all available clean, ready-to-use EEG electrodes.

Overall, 31 of 124 EEG electrodes (25%; 95% CI, 17.4%-32.6%) had a positive culture. Of the 31 positive cultures, 30 EEG electrodes had growth of just 1 bacterial species, and 1 EEG electrode had growth of 2 bacterial species (Table 1). Epithelial cells were found on 60.5% (95% CI, 51.9%-69.1%) of EEG electrodes, but no EEG electrodes were positive for white blood cells.

In total, 8 bacterial species were identified. All but one (*Acinetobacter lwoffii*) can be considered skin or scalp flora. Three bacterial species were at risk for causing human infection (Table 1) and accounted for 16 of the 31 positive cultures (51.6%), equaling 12.9% of all samples (16/124). Four bacteria species were potential risk for human infection and accounted for 13 of the 31 positive cultures (41.9%). Only 1 bacterial species identified was considered no risk for human infection (*Bacillus*) and was observed in 3 of 31 specimens (9.7%). Overall, 28 of 124 specimens (22.6%; 95% CI, 15.8%-31.1%) had potential risk or at risk bacterial growth.

For EEG electrodes with positive cultures, antibiotic resistance was assessed. Between 12 and 18 antibiotics were tested on each positive culture. The median percentage of antibiotics that was resistant within a positive-culture EEG electrode swabbing was 7.5% (range, 0%-61.1%). Within positive cultures, 12 (38.7%) involved 4 bacterial isolates with antibiotic resistance in ≥38% of samples: *Bacillus* spp (1 of 3 positive cultures had a 47% antibiotic resistance rate), *Staphylococcus epidermidis* (5 of 10 positive cultures had a 38.8%-61.1% antibiotic resistance rate), *Micrococcus* spp (5 of 7 positive cultures had a 38.8% antibiotic resistance rate), and *Staphylococcus haemolyticus* (1 of 3 positive cultures had a 50% antibiotic resistance rate). Within positive cultures, bacterial isolates of the following microorganisms had an antibiotic resistance rate of ≤13%: *Acinetobacter lwoffii*, *Staphylococcus capitis* subsp *ureolyticus*, *Staphylococcus hominis* subsp *hominis*, and *Staphylococcus warneri*. None of the electrodes with a positive culture were resistant to all antibiotics (Table 2).

By site, the percentage of positive cultures varied from 13.3%-43.3%. However, there were no statistically significant differences in the rate of positive cultures between any 2 sites assessed after applying Bonferroni correction or by all sites (Table 3). Epithelial cell presence varied by hospital site ($P = .002$) and when comparing sites (site A had fewer epithelial cells on clean, reusable EEG

Table 1
Positive cultures, epithelial cells, and white blood cells (N = 124)

Factor		n	n (%)
Positive culture		124	31 (25.0)
Isolate of first microorganism identified	Risk for infection*	31	
Acinetobacter lwoffii	Potential risk		2 (6.5)
Bacillus spp	No risk		3 (9.7)
Micrococcus spp	Potential risk		6 (19.4)
Staphylococcus capitis subsp *ureolyticus*	At risk		1 (3.2)
Staphylococcus epidermidis	At risk		12 (38.7)
Staphylococcus haemolyticus	At risk		3 (9.7)
Staphylococcus hominis subsp *hominis*	Potential risk		2 (6.5)
Staphylococcus warneri	Potential risk		2 (6.5)
Isolate of second microorganism identified	Risk for infection	1	
Micrococcus spp	Potential risk		1 (100.0)
Epithelial cells		124	
None seen			49 (39.5)
0-2 per LPF			41 (33.1)
3-5 per LPF			34 (27.4)
White blood cells		124	
None seen			124 (100.0)

LPF, low-power field magnification.
*No risk (no pathogenic potential; bacteria was not previously associated with human disease), potential risk (low risk of pathogenesis in healthy adults with normal immune system function but a risk of infection in immunocompromised patients), and at risk (risk of infection when skin is punctured, or with presence of catheters, implants, or wounds).

Table 2
Antibiotic resistance in positive cultures

Factor	n	Value
Antibiotics tested, n (%)	32	
12		2 (6.3)
15		4 (12.5)
16		4 (12.5)
17		7 (21.9)
18		15 (46.9)
No. of resistant antibiotics, median (minimum-maximum)	32	1.00 (0.00-11.0)
Percent of resistant antibiotics, median (minimum-maximum)	32	7.5 (0.00-61.1)
All tested antibiotics resistant, yes, n (%)	32	0 (0.0)

Table 3
Site comparisons of positive culture and epithelial cell prevalence in electroencephalography electrodes

Outcome	Site comparison*	Odds ratio (95% CI)	*P* value	Overall *P* value
Positive culture	A vs B	2.01 (0.43-9.33)	.36	.17
	A vs C	0.39 (0.09-1.60)	.17	
	A vs D	1.19 (0.26-5.47)	.81	
	B vs C	0.19 (0.04-0.89)	.037	
	B vs D	0.59 (0.12-3.02)	.51	
	C vs D	3.08 (0.64-14.70)	.14	
Epithelial cells	A vs B	0.06 (0.01-0.25)	<.001	.002
	A vs C	0.08 (0.02-0.35)	.001	
	A vs D	0.06 (0.01-0.26)	<.001	
	B vs C	1.38 (0.35-5.42)	.63	
	B vs D	1.01 (0.24-4.16)	.99	
	C vs D	0.73 (0.17-3.10)	.64	

CI, confidence interval.
*Positive culture rates of 4 hospital sites: A (23.3%), B (13.3%), C (43.3%), and D (20.6%).

electrodes [16.7%] than sites B [76.7%], C [70.0%], and D [76.5%]) (Table 3).

DISCUSSION

Bacteria were found on 25% of clean, reusable EEG electrodes in 4 epilepsy monitoring units. Of 8 bacterial species, 7 (88%) were potential risk or at risk for causing human infection. No white blood cells were found on clean, reusable EEG cup electrodes, but epithelial cell prevalence varied significantly, with lower rates at site A compared with the other 3 sites.

Presence of bacteria and epithelial cells but no white blood cells provided evidence that cleaning procedures at the 4 sites were sufficient to remove evidence of blood, but inadequate in ensuring optimally clean electrodes. Because, to our knowledge, this is the first examination of the presence of epithelial and blood cells on clean EEG electrodes, replication of this research at different sites would provide definitive evidence that cleaning procedures could lead to varying epithelial cell prevalence.

The prevalence of bacterial growth on clean, reusable EEG electrodes was not surprising because other investigators have found bacterial growth on inanimate objects used in hospital and health care environments.[4-7] However, EEG electrodes are semi-critical devices that are placed on abraded skin and should not harbor bacteria that can lead to infection and, worse, be antibiotic resistant.

There is evidence that cleaning procedures can be performed adequately. In the study of ultrasound probes, all bacteria were normal flora.[5] In a cardiac catheterization laboratory, where head coverings and face masks were not required, cultures from the tips of catheters and sterile saline flush bowls did not produce clinically significant bacterial growth.[30] Because potential risk and at risk bacteria were present on reusable EEG cup electrodes after cleaning, hospitals should consider reevaluating cleaning schedules, practices, and policies[12] and also whether assessment and monitoring for scalp infection are warranted. Alternately, single-use EEG electrodes could be considered to eliminate the potential risk of patient-to-patient cross-contamination.

It is unknown if bacterial growth leads to scalp infections during or after EEG procedures are completed. Patients may be discharged to home from the epilepsy unit and think that new onset pain, redness, or warmth on a section of their scalp was merely because of the EEG procedure, when in fact it could be because of an infection. In the current research, scalp infection was not assessed and EEG cleaning practices were not observed. Future research may enhance understanding of gaps and disparities in cleaning that could affect the prevalence of bacterial growth and presence of clinically significant scalp infection, even if isolated to a small area.

There were some limitations of this study. Although there were many specimens obtained, there were only 4 sites involved, which may limit generalizability of findings, especially to hospital sites with <500 beds, hospitals that use EEG electrodes in settings other than an epilepsy unit, and those that routinely have few or many clean, ready-to-use EEG electrodes available when needed. Because the number of available EEG electrode sets and individual electrodes varied by site, sites with fewer electrodes available had more swabs obtained from different locations on the same electrode. It is possible that the presence of bacteria could have been transferred from one electrode to others via handling, therefore increasing the rate of positive cultures. Further, technical personnel from our sites were sensitized to the arrival of the data collection team and may have altered their cleaning methods or the diligence in which they carried out the cleaning procedure. It is possible that the underlying bacterial contamination rate may actually be higher than the reported findings from this study.

CONCLUSIONS

In this study, 7 of 8 bacterial species found on clean, ready-to-use EEG cup electrodes were considered to be normal flora. Of bacterial species identified, 22.6% were categorized as posing potential risk or higher risk of infection that could lead to an HAI. Additionally, epithelial cells were present, and prevalence varied by site. Presence of bacteria and epithelial cells could be influenced by cleaning practices. Infection prevention strategies are needed in relation to EEG electrode equipment used in EEG procedures, and cleaning policies and procedures should be assessed and monitored routinely.

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