Improving Detection of Adolescent Hearing Loss

Deepa L. Sekhar, MD; Julie A. Rhoades, AuD; Amy L. Longenecker, LPN; Jessica S. Beiler, MPH; Tonya S. King, PhD; Mark D. Widome, MD, MPH; Ian M. Paul, MD, MSc

Objectives: To compare a protocol for pure-tone threshold testing, capable of detecting high-frequency hearing loss as indicated by notched audiometric configurations, with the current school rapid hearing screen and to determine typical adolescent noise exposures associated with notched audiometric configurations.

Design: In conjunction with required school rapid hearing screening, a pure-tone threshold testing protocol was administered, specifically to test hearing at high frequencies. A single audiologist reviewed the results. Students completed a survey assessing their noise exposures.

Setting: A public high school in Pennsylvania.

Participants: Eleventh-grade students.

Main Outcome Measure: Notched audiometric configurations on the pure-tone threshold test.

Results: Among 296 participants, 78 (26.4%) failed pure-tone threshold testing compared with 15 (5.1%) failing rapid hearing screening. Among those failing the pure-tone threshold testing, 67 (85.9%) failed due to notched audiometric configurations. Self-reported headphone use with an MP3 player was significantly associated with notched audiometric configurations compared with use of earbuds or stereo connection/docking systems.

Conclusions: Pure-tone threshold testing incorporating high frequencies detects adolescent hearing loss more often than rapid hearing screens. Most state hearing screens omit high-frequency testing, potentially missing high-frequency losses, such as noise-induced hearing loss. Because noise-induced hearing loss in particular is preventable and hazardous noise exposures have increased, a reliable school hearing screen to detect high-frequency hearing loss in adolescents is warranted.

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School-based hearing screening was implemented in the late 1920s to identify hearing losses severe enough to affect educational achievement.1-3 This focus has persisted: school hearing screens generally focus on a limited subset of test frequencies involved in speech perception (typically <3000 Hz).1,2 Although recommendations were made to include high-frequency (≥3000 Hz) screening more than 30 years ago, school hearing screens in most states are not designed to detect high-frequency hearing loss (HFHL), as occurs with noise-induced hearing loss (NIHL).1,4 A recent cross-sectional analysis of data from the National Health and Nutrition Examination Survey (NHANES), however, demonstrated that the prevalence of HFHL has increased among US adolescents from 12.8% in 1988-1994 to 16.4% in 2005-2006.5 Adolescent low-frequency hearing loss is less common but increased from 6.1% to 9.0% during the same period.6

The increase in HFHL may be partially attributed to the popularity of personal listening devices for adolescents, who may be unaware of the potential harm caused by loud noise exposure.1,5-11 Studies show adolescents are at increased risk of exposure to loud music, and audiometric testing of adolescents demonstrates results suggestive of NIHL. However, data directly linking the degree and duration of exposure to sound-hazardous listening environments and subsequent hearing loss are more difficult to identify.6-11

Pennsylvania’s school-based hearing screening program mandates testing in kindergarten through third grade and in the 7th and 11th grades.12 Like school-based programs in most other states, testing is not designed to detect the notched audiometric configurations, or noise notches, that may indicate NIHL.1,12 Our hypothesis was that Pennsylvania’s current school-based rapid hearing screen, by omitting

See also pages 1135 and 1141
high-frequency testing among 11th-grade adolescents, fails to detect prevalent and preventable HFHL, such as NIHL. Providing objective data to support this hypothesis could inform policy changes for both school hearing screening and public health interventions. Eleventh graders were selected to test this hypothesis because NIHL is cumulative, with the highest prevalence of findings likely in older compared with younger children.1

**METHODS**

**PARTICIPANTS AND STUDY DESIGN**

Rapid hearing screens are administered annually to all 11th graders at Hershey High School (Hershey, Pennsylvania), as mandated by the Pennsylvania Department of Health.12 Letters were sent to parents of all students entering the 11th grade at this public school in August 2009 regarding the study hearing screen, a pure-tone threshold test incorporating high frequencies, affording the option for parents to decline participation for their children. This study was approved by Penn State College of Medicine's Human Subjects Protection Office with a waiver of informed consent. The study was also approved by the principal of Hershey High School.

Students were provided with passes at 5- to 10-minute intervals to come to a school conference room dedicated to testing. The single conference room was separated into 2 sections by an accordion partition. All participants entered the conference room and completed a 16-item survey on noise exposure, the rapid hearing screen, and lastly the pure-tone threshold test.

The survey addressed typical adolescent hazardous noise exposures, such as MP3 players, cell phones, lawn mowers, band instruments, and shop class. Participants were asked to estimate the amount of time exposed to these potentially damaging noise sources. Along with demographic characteristics, several items addressed medical and family history pertinent to hearing (Table 1 and Table 2). Participants reported past use of hearing protection and future interest in hearing conservation. The survey was completed with paper and pencil on a scannable form to eliminate errors in data transfer. The study coordinator (A.L.L.) addressed issues regarding the survey questions. Each participant was assigned a number tagged to his or her survey and screening results.

Rapid hearing screening and pure-tone threshold testing were conducted in September-October 2009 during 7 days with American National Standards Institute Maico MA27 audiometers (calibrated annually, ANSI S3.6-2004; most recent, May 19, 2009; MAICO Diagnostics, Eden Prairie, Minnesota), which can measure frequencies from 250 to 8000 Hz. A standard TDH-39 headphone assembly (Telephonics, Farmingdale, New York) was used. Students were not excluded for current middle ear problems or upper respiratory symptoms because this is not part of the school protocol.12 Note was made if participants wore hearing aids. The school nurse conducted all rapid hearing screening. The research coordinator (A.L.L.) was a licensed practical nurse trained to conduct all pure-tone threshold testing by a certified audiologist (J.A.R.).

Per the Pennsylvania school hearing screening guidelines, the rapid hearing screen determines the ability to hear 25-dB hearing level (HL) pure tones at 250, 500, 1000, 2000, and 4000 Hz (Table 3).12 The 1000-Hz tone was initially presented at 55-dB HL, 40-dB HL, and 25-dB HL. Following a positive response to these 3 tones, only 25-dB HL pure tones were presented once at each tested frequency.12

After the rapid hearing screen, students crossed the partition and completed the pure-tone threshold test. The pure-tone threshold test omitted the 250-Hz frequency but added 3000-, 6000-, and 8000-Hz frequencies (Table 3).13 Threshold testing identified the lowest dB HL at which the participant could positively respond to a tone in 2 of 3 trials. This level identified the hearing “threshold” that was marked on the audiogram at each tested frequency.12,14,15

**PASS/FAIL CRITERIA**

The school nurse determined failure of the rapid hearing screen using established criteria.14 Students failed for inability to hear 2 or more 25-dB HL tones in 1 or both ears at any frequency.12 Results were recorded as either “pass” or “fail.”

Similar to the protocol for the rapid hearing screen, students with 2 or more thresholds in 1 or both ears above 25-dB HL on the pure-tone threshold test were categorized as test failures by a single certified audiologist. The audiologist also reviewed the pure-tone threshold tests applying criteria for a notched audiometric configuration as described by Niskar et al13 (Figure). The first sign of a notched audiometric configuration is usually a threshold loss at 3000, 4000, or 6000 Hz. The location of the notch may vary depending on several factors.13,14 A notched audiometric configuration was defined as thresholds less than or equal to 15-dB HL at 500 and 1000 Hz; notchings at 3000, 4000, or 6000 Hz at least 15-dB HL poorer than the poorest threshold at 500 or 1000 Hz; and recovery of at least 10-dB HL at 8000 Hz compared with the poorest threshold at 3000, 4000, or 6000 Hz.13

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**Table 1. Participant Demographic Characteristics and Pure-Tone Threshold Test Resultsa**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study Cohort (N=296)</th>
<th>Pass (n=218)</th>
<th>Fail–Noise Notch (n=67)</th>
<th>Fail–Other (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>16.6 (0.4)</td>
<td>16.6 (0.4)</td>
<td>16.6 (0.4)</td>
<td>16.6 (0.5)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>154 (52.0)</td>
<td>117 (53.7)</td>
<td>33 (49.3)</td>
<td>4 (36.4)</td>
</tr>
<tr>
<td>Female</td>
<td>142 (48.0)</td>
<td>101 (46.3)</td>
<td>34 (50.7)</td>
<td>7 (63.6)</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>228 (77.0)</td>
<td>169 (77.5)</td>
<td>49 (73.1)</td>
<td>10 (90.9)</td>
</tr>
<tr>
<td>Black/African American</td>
<td>7 (2.4)</td>
<td>5 (2.3)</td>
<td>2 (3.0)</td>
<td>0</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>6 (2.0)</td>
<td>5 (2.3)</td>
<td>1 (1.5)</td>
<td>0</td>
</tr>
<tr>
<td>Asian</td>
<td>23 (7.8)</td>
<td>19 (8.7)</td>
<td>4 (6.0)</td>
<td>0</td>
</tr>
<tr>
<td>Multiple</td>
<td>16 (5.4)</td>
<td>10 (4.6)</td>
<td>6 (9.0)</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>3 (1.0)</td>
<td>2 (0.9)</td>
<td>1 (1.5)</td>
<td>0</td>
</tr>
<tr>
<td>No response</td>
<td>13 (4.4)</td>
<td>8 (3.7)</td>
<td>4 (6.0)</td>
<td>1 (9.1)</td>
</tr>
</tbody>
</table>

*a* Data are given as number (percentage) unless otherwise indicated.
Because testing was performed in the school setting where ambient noise was a factor and background noise specifically affects test performance at lower frequencies (500 and 1000 Hz), our definition of a noise notch, similar to that of Meinke and Dice,1 allowed for thresholds at 15-dB HL or less at 500 and/or 1000 Hz, with notching at least 15-dB HL poorer than the better threshold at 500 or 1000 Hz.17 Results were marked as “pass,” “fail–noise notch,” or “fail–other.”

STATISTICAL ANALYSIS

Descriptive statistics were calculated for all participants. Students were categorized into pass and fail categories for the rapid hearing screen and pass, fail–noise notch, or fail–other for the pure-tone threshold test. The χ2 and Cochran-Mantel-Haenszel tests were used to evaluate bivariate associations between test results and risk factors raised in the survey questions. Subsequently, risk factors significantly associated with pure-tone threshold test results (pass vs fail–noise notch) were investigated in a multivariate logistic regression model. This model also allowed for the results to be adjusted by sex and for the evaluation of sex as an effect modifier of the various risk factors. Results are reported in odds ratios and 95% CIs. An α of .05 was used to determine statistical significance. All statistical measures were calculated using SAS, version 9.2 (SAS Institute, Cary, North Carolina).

RESULTS

PARTICIPANTS AND HEARING SCREENING RESULTS

Of the 300 eligible 11th graders, 296 (98.7%) completed the state-mandated rapid hearing screen, the pure-tone threshold test, or both.
tone threshold test, and the survey. Of the 296 participating students, 15 (5.1%) failed the rapid hearing screen and 78 (26.4%) failed the pure-tone threshold test. Nine students (3.0%) failed both tests, 6 (2.0%) failed only the rapid hearing screen, but 69 (23.3%) failed only the pure-tone threshold test (Table 4).

Of the 78 students failing the pure-tone threshold test, 67 (85.9%) failed with results consistent with a notched audiometric configuration. The other 11 failed because of the inability to hear 2 or more 25-dB HL tones at any of the tested frequencies in 1 or both ears. Of those students who met criteria for a noise notch, 59 (88.1%) had unilateral hearing loss, with the left ear involved in 42 of these 59 cases (71.2%). The frequency most commonly involved with hearing loss was 6000 Hz in 65 of 67 cases (97.0%).

### Table 3. Comparison of Rapid Hearing Screen vs Pure-Tone Threshold Test

<table>
<thead>
<tr>
<th>Hearing Screen</th>
<th>Frequencies Tested, Hz</th>
<th>Fail Criteria</th>
<th>Time to Complete, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid hearing screen</td>
<td>250, 500, 1000, 2000, 4000</td>
<td>Inability to hear 2 or more 25-dB tones in 1 or both ears at any frequency</td>
<td>2</td>
</tr>
<tr>
<td>Pure-tone threshold test</td>
<td>500, 1000, 2000, 3000, 4000, 6000</td>
<td>Inability to hear 2 or more 25-dB tones in 1 or both ears at any frequency OR Notched audiometric configuration a) thresholds ≤15-dB HL at 500 and/or 1000 Hz b) notching at 3000, 4000, or 6000 Hz &gt;15 dB poorer than the better threshold at 500 or 1000 Hz c) recovery of ≥10 dB at 8000 Hz compared with the poorest threshold at 3000, 4000, or 6000 Hz</td>
<td>5</td>
</tr>
</tbody>
</table>

Abbreviation: HL, hearing level.

### Table 4. Pass and Fail Totals for the Rapid Hearing Screen and Pure-Tone Threshold Test

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pure-Tone Threshold Test Pass</th>
<th>Pure-Tone Threshold Test Fail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid hearing screen pass</td>
<td>212 (71.6)</td>
<td>69 (23.3)</td>
<td>281 (94.9)</td>
</tr>
<tr>
<td>Rapid hearing screen fail</td>
<td>6 (2.0)</td>
<td>9 (3.0)</td>
<td>15 (5.1)</td>
</tr>
<tr>
<td>Total</td>
<td>218 (73.6)</td>
<td>78 (26.4)</td>
<td>296 (100.0)</td>
</tr>
</tbody>
</table>

### Figure

Sample of a normal audiogram (A) vs notched audiometric configuration (B). The noise notch is visualized by the dip in audiogram B at 4000 Hz.

### Bivariate Analysis of Risk Factors Associated with a Notched Audiometric Configuration

An initial analysis of associations between the risk factors in the survey questions and failure of the pure-tone threshold test due to a notched audiometric configuration demonstrated that the method by which students listened to their MP3 players was significant ($P = .005$; Table 2). Specifically, headphone use with an MP3 player was associated with failing the pure-tone threshold test for a noise notch. No other sources of noise exposure questioned in the survey were significantly associated with failing the pure-tone threshold test for a noise notch. With the exception of tinnitus ($P = .02$), no medical conditions or symptoms were significantly associated with a notched audiometric configuration. Reported time exposed to hazardous noise sources was not significantly associated with a noise notch.

### Multivariate Analysis of Risk Factors for a Notched Audiometric Configuration

Results from the bivariate analysis were subsequently investigated for modification by sex and incorporated into a multivariate logistic regression (Table 5). Use of headphones with an MP3 player increased the odds of failing the pure-tone threshold test for a noise notch by more than...
Table 5. Multivariate Logistic Regression of Risk Factors for Failure for a Notched Audiometric Configuration (Noise Notch) 

<table>
<thead>
<tr>
<th>Risk Factor for Noise Notch</th>
<th>OR (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of listening to MP3 player</td>
<td>. . .</td>
<td>.002</td>
</tr>
<tr>
<td>Headphones vs earbuds</td>
<td>4.28 (2.01-9.14)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Headphones vs stereo connection/docking system</td>
<td>3.34 (1.33-8.39)</td>
<td>.01</td>
</tr>
<tr>
<td>Isolation/noise-canceling attachment vs earbuds</td>
<td>1.99 (0.55-7.17)</td>
<td>.29</td>
</tr>
<tr>
<td>Stereo connection/docking system vs earbuds</td>
<td>1.28 (0.56-2.92)</td>
<td>.55</td>
</tr>
<tr>
<td>Headphones vs isolation/noise-canceling attachment</td>
<td>2.15 (0.58-7.94)</td>
<td>.25</td>
</tr>
<tr>
<td>Isolation/noise-canceling attachment vs stereo connection/docking system</td>
<td>1.55 (0.39-6.14)</td>
<td>.53</td>
</tr>
<tr>
<td>Ever had ringing in the ears (no vs yes)</td>
<td>2.36 (1.24-4.50)</td>
<td>.009</td>
</tr>
<tr>
<td>Ever played a musical instrument–males</td>
<td>0.60 (0.24-1.54)</td>
<td>.29</td>
</tr>
<tr>
<td>Ever played a musical instrument–females</td>
<td>2.68 (1.07-6.70)</td>
<td>.04</td>
</tr>
</tbody>
</table>

Abbreviation: OR, odds ratio. 
*These results are adjusted for sex, and sex is also included as an effect modifier for instrument exposure. The sex by instrument interaction term was significant with P = .03. The effect of sex is not reported in the table because of inclusion in the nested effect for instrument.

The survey revealed that among those failing testing due to a noise notch, 89.6% reported willingness to turn down the volume on electronic devices, 79.1% reported they would limit time using electronic devices, and 73.1% reported that they would be willing to consider use of a volume-limiting device. However, only 59.7% reported willingness to consider use of earplugs/ear muffs.

**BEHAVIOR MODIFICATION**

To our knowledge, this study is the first to apply criteria for a notched audiometric configuration for the detection of hearing loss in the public school system. The results suggest that by omitting high-frequency testing, Pennsylvania’s current school-based hearing screen fails to detect substantial numbers of adolescents with noise notches and potentially misses the opportunity to identify and to prevent further NIHL. The findings provide objective data by which to consider a policy change on school-based hearing screening in Pennsylvania and most other states. In short, changes in the sources of hearing loss require changes in the tests to detect it.

Our results may be compared with those of 3 previous studies using NHANES data. Niskar et al applied the noise notch criteria to data from NHANES III conducted from 1988 to 1994. They reported 12.5% of children aged 6 to 19 years in the United States were estimated to have a noise notch in 1 or both ears. Those in the northeast had the lowest prevalence of noise notches (8.7%) when children were grouped by geographic region. Shargorodsky et al recently reported an increase in the prevalence of HFHL among adolescents aged 12 to 19 years from NHANES III 1988-1994 to NHANES 2005-2006, although the 16.4% prevalence of a noise-induced threshold shift—the development of a noise notch measured over 2 time points—did not appreciably change in this age group during the same period. Both studies performed testing in a soundproof booth and used exclusion criteria, which was not part of our protocol.

Because both studies considered a wider age range of participants and HFHL related to NIHL is cumulative, it is not surprising that the prevalence in the current report is higher. It is unclear why Shargorodsky et al found an increasing prevalence of HFHL without an increase in the prevalence of noise-induced threshold shifts, unless adolescents are unknowingly exposed to factors inducing HFHL besides noise.

Henderson et al compared NHANES data from 1988-1994 with such data from 2005-2006 for noise-induced threshold shifts and HFHL and found a significant increase in the prevalence of noise-induced threshold shifts among female adolescents that eliminated the previous sex differences found in noise-induced threshold shifts. Our results similarly did not demonstrate sex as a significant risk factor for a notched audiometric configuration.

Similar to our study, Niskar et al found most participants had unilateral noise notches. Niskar et al also found that 6000 Hz was the most commonly involved frequency among US children who met noise notch criteria, with 97% of noise notches at 6000-Hz. There is debate as to the validity of the 6000-Hz noise notch to indicate NIHL. Some have suggested that a 6000 Hz noise notch may be an early sign of NIHL. Others contend improper equipment calibration may lead to a high false-positive rate of notches at 6000 Hz, especially with telephonic dynamic headphone-style earphones. However, one would not expect a calibration error to affect only 1 ear. Also, with a calibration error, one might not expect survey results to correlate with test findings.

Screening for hearing loss in speech-related frequencies is logical for younger children (eg, kindergarten to third grade), whose education could be affected by poor hearing in this range due to middle ear dysfunction. However, the incidence of otitis media decreases as children grow older, reducing the potential for undiagnosed hearing loss in the speech-related frequencies. The greater risk to adolescents is NIHL involving higher frequencies not currently included in typical school hearing screenings across the United States. Noise-induced hearing loss is a result of cumulative exposure to sound-hazardous environments, and eventually, NIHL can progress to have a negative effect on speech and communication. Audiologic damage caused by noise is irreversible, although further hearing loss is preventable by the identification and avoidance of sound-hazardous environments.
Improving the breadth and quality of hearing screening would seem to be extremely valuable because our participants reported a willingness to change their listening behaviors similar to other studies.23,24 Although self-reported willingness to change behavior must be followed by implementation of an action plan for modifications, early detection of NIHL could prove a catalyst in this effort.

Most adolescents are unaware of their hearing loss, and they may further worsen their hearing through continued exposure to hazardous sound levels.1,2 Long-term benefits of screening may include hearing preservation, which may improve personal and professional success and lead to decreased costs for the medical system. Future studies are needed to specifically address the functional limitations of HFHL for adolescents and the burdens on society.

Students failing the extended screen for a noise notch were significantly more likely to report headphone use with an MP3 player. It is possible that students reporting headphone use as opposed to earbud use need to further increase the volume to overcome ambient noise. Perhaps students using headphones wear them longer than those using earbuds. Also, in comparison with reported headphone users, those students reporting use of a stereo connection/docking system may be using the device for background music and thus have the volume set lower. It is also possible that reported headphone users have other high-risk hearing behaviors not elucidated by the survey.

The finding that participants without a history of tinnitus had increased odds of failing the pure-tone threshold test is of unclear significance. Nor is it clear why females playing a musical instrument were more likely to demonstrate a noise notch.

This analysis was limited by several factors. First, testing conditions were the same as those for standard school hearing screening. Background noise (eg, talking, the ventilation system, and school bells) may have affected the results. Another major limitation was that students did not complete gold standard testing with an audiologist in a soundproof booth to calculate the sensitivity and specificity of our pure-tone threshold test. This next step is the focus of a current investigation at our institution. It may be argued that recent exposure to loud noise could have caused transient noise notches and skewed the results.26 The lack of baseline and follow-up audiograms, the standard used by the Occupational Safety and Health Association, is also a limitation.14,20,27

Student fatigue and attention span may have affected the results because the pure-tone threshold test was always conducted after the survey and rapid hearing screen were completed. The order was not randomly assigned or changed. For students failing the rapid hearing screen but passing the pure-tone threshold test, it is suspected their failure occurred at 250 Hz because this frequency was not included in the pure-tone threshold test. However, rapid hearing screen results are reported only as pass or fail, so this cannot be verified. The research coordinator was not masked to rapid hearing screen results. Survey completion was subject to recall bias; students may incorrectly estimate their levels of noise exposure. Some substantial sources of noise may not have been detected by our survey questions. Also, our results may have been affected by the limited racial and ethnic diversity of the study population.

This study provides objective evidence that Pennsylvania's current rapid hearing screen, by omitting high frequencies, fails to detect a significant number of high school students with noise notches, potentially missing NIHL. If school-based pure-tone threshold testing is validated in a soundproof booth by an audiologist, routine school-based HFHL screening may be a viable option to improve hearing loss detection in the high school setting.

Because NIHL is progressive, preventable, and associated with common sources of excessive sound exposures experienced by adolescents, policy changes regarding school-based hearing screening may be warranted because most state hearing screens are similar to the Pennsylvania screen.

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Correspondence: Deepa L. Sekhar, MD, Penn State College of Medicine, 500 University Dr, Mail Code HS83, Hershey, PA 17036 (dsekhar@hmc.psu.edu)

Author Contributions: Dr Sekhar had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Sekhar, Beiler, Widome, and Paul. Acquisition of data: Longenecker and Beiler. Analysis and interpretation of data: Sekhar, Rhoades, King, Widome, and Paul. Drafting of the manuscript: Sekhar. Critical revision of the manuscript for important intellectual content: Sekhar, Rhoades, Beiler, King, Widome, and Paul. Statistical analysis: King. Obtained funding: Sekhar and Paul. Administrative, technical, and material support: Sekhar, Longenecker, and Beiler. Study supervision: Widome and Paul.

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REFERENCES


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