Noise-Induced Hearing Loss

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Noise-induced hearing loss (NIHL) is the second most common cause of sensorineural hearing loss, after age-related hearing loss, and affects approximately 5% of the world's population. NIHL is associated with substantial physical, mental, social, and economic impacts at the patient and societal levels. Stress and social isolation in patients' workplace and personal lives contribute to quality-of-life decrements which may often go undetected.

noise-induced hearing loss | sensorineural hearing loss | cochlear hair cell | diagnosis

1. Introduction

Noise-induced hearing loss (NIHL) is a consequence of multifactorial damage to auditory structures following exposure to occupational, environmental, or recreational sources of loud sound. Noise has been recognized as a factor contributing to hearing loss long before rigorous data collection, sophisticated analyses, and careful experimental design became the norm. Although earplugs were patented in 1864, hearing protection devices are mentioned in ancient Greek mythology [1]. NIHL was formally acknowledged as a medical condition in the United States (US) during the Industrial Revolution, first named 'boilermaker's disease' as a reference to the hearing loss suffered by workers building engines that powered transportation and production [2]. Historical data on US women who worked in the factories during World War I and II reveal devastating health effects, including hearing loss, although disorders caused by exposure to chemicals received more attention than those attributable to noise [3]. Noted physician and Nobel Prize winner Robert Koch predicted in 1910 that "one day man will have to fight noise as fiercely as cholera and pest" [4]. Despite this prediction and the long-standing knowledge of the adverse effects of noise on hearing and extensive research in the modern era, hearing loss continues to rank among the most common work-related illnesses both in the US and the world [5].

NIHL may be unilateral (affecting one ear) or bilateral (affecting both ears), and the hearing deficits may be transient or permanent [6]. The duration and severity of NIHL depends on the extent and location of cellular damage, which correlates with intensity and duration of the sound stimulus. Because the mammalian auditory sensory epithelium—the organ of Corti—does not spontaneously regenerate when sensory cells are lost, noise-induced hair cell or neural degeneration can result in permanent hearing loss particularly in the setting of repeated exposure [6][7]. Furthermore, NIHL is frequently irreversible and can have a profoundly negative impact on an individual's quality of life and on the economy and society at large. However, NIHL is largely a preventable condition when appropriate precautions, such as the use of hearing protection, can be taken. Therefore, implementing measures to detect and attenuate causative factors, raising awareness of the condition and

implementing protective strategies, and developing therapies that protect against or mitigate damage from noise exposure can aid in the prevention of this common condition.

2. Prevention and Management of NIHL

2.1. Prevention

NIHL is mostly preventable, and tangible steps to reduce the burden of the disorder can be taken via the implementation of educational programs, regulation, and legislation to raise awareness and pre-emptively mitigate the damage caused by noise. In the US, the 1972 Noise Control Act established federal noise emission standards for commercial products and required that the public be provided information about noise emission levels and ways of reducing them [8]. Two US governmental departments—OSHA and the National Institute for Occupational Safety & Health (NIOSH)—have made recommendations for the permissible noise limit (PEL) of workplace noise exposure based on the average time a worker is exposed [9][10]. Daily noise dose is expressed as a percentage, per occupational standards, taking duration, sound exposure level, and course of exposure into account. For example, reaching 100% of a worker's daily noise dose could be expressed as 85 dBA per NIOSH and 90 dBA per OSHA over a shift of 8 h. The course of exposure is cut when there is an increase in noise levels [11] (**Table 1**). Additionally, OSHA regulates that employers must provide hearing protection if employees are exposed to noise over the permissible exposure limit of 90 dB over an eight-hour time-weighted average [12]. Arenas et al. compared the occupational noise exposure levels in Latin America, the US, and Canada and found that 81% of the countries have a PEL of 85 dBA and that the majority of the countries limit impulsive noise exposure to a peak unweighted sound pressure level of 140 dB [13]. However, there were no established regulations in 27% of the countries, potentially exposing millions of people to NIHL.

Table 1. Occupational noise exposure limits recommended by NIOSH and OSHA.

Sound Pressure Level (dB)	Permissible Exposure Time	
	NIOSH	OSHA
120	9 seconds	7 minutes 30 second
115	28 seconds	15 minutes
112	56 seconds	22 minutes 48 seconds
110	1 minute 29 seconds	30 minutes
109	1 minute 53 seconds	34 minutes 12 seconds
106	3 minutes 45 seconds	52 minutes 12 seconds
105	4 minutes 43 seconds	1 hour
103	7 minutes 30 seconds	1 hour 18 minutes

Sound Pressure Level (dB)	Permissible Exposure Time	
	NIOSH	OSHA
100	15 minutes	2 hours
97	30 minutes	3 hours
95	47 minutes 37 seconds	4 hours
94	1 hour	4 hours 36 minutes
91	2 hours	7 hours
90	2 hours 31 minutes	8 hours
88	4 hours	10 hours 36 minutes
85	8 hours	16 hours
82	16 hours	24 hours 18 minutes
81	20 hours 10 minutes	27 hours 54 minutes
80	25 hours 24 minutes	32 hours

The NIOSH limits represent clinically safe levels, and the OSHA limits are more liberal to account for practical issues in industry [9][10]. Units of time are standardized for ease of comparison. Abbreviations: dB, decibel; OSHA, Occupational Safety and Health Administration; NIOSH, National Institute for Occupational Safety and Health.

ensive for small businesses and require maintenance and calibration, thereby limiting their widespread implementation. However, smartphone applications for this purpose are now available and provide inexpensive alternatives to specialist calibrated sound meters. An evaluation of the reliability of nine applications found the NIOSH Sound Level Meter to be the most accurate [14]. A free, accessible, and reliable app may help increase compliance with legislation and easy monitoring of environmental noise levels [15]. Additionally, in 2009, the European Commission mandated that output levels in new personal audio devices should be set to a standard of 85 dB, allowing users to increase the volume to a maximum of 100 dB. When users raise the volume to maximum level, a message was required to pop up that warns of the potential for hearing loss.

Hearing protective devices (HPDs) such as earmuffs and earplugs play an important role in protection against noise exposure. Plugs need to be inserted to ensure coverage of the entire ear canal's circumference to provide protection and minimize irritation. Noise Reduction Ratings (NRRs) are calibrations to assess the protection range of HPDs in a single attenuation value (in dB). Because NRRs are derived via laboratory-based testing, they may overestimate the actual protection provided in non-experimental environments. Therefore, the NRR is derated by 50% on a dB scale before estimating exposure protection [16]. A Cochrane systematic review (2017) of interventions to prevent occupational NIHL found evidence that training on the proper insertion of ear plugs significantly reduced short-term noise exposure but called for more studies on the effectiveness of stricter legislation or better use of hearing protection devices [17]. Additionally, a randomized controlled trial showed that effective training of earplug usage led to significant improvement in the efficacy of HPDs in comparison to the usage of a device with higher NRR [18]. HPD fit-testing systems provide a customized fit for increased attenuation; however, they often require special facilities for testing such as a quiet room or audiometric booth or specialized equipment. Compliance in wearing HPDs is a barrier, especially in the military, as they are thought to decrease auditory situational awareness (e.g., sound detection, sound localization, and speech perception) [16][19]. However,

novel fit test techniques (i.e., via a smartphone application) may enable better training and monitoring compliance [16].

Finally, clinicians can actively counsel patients at risk of NIHL on hearing protection strategies and the hazards of noise exposure in the workplace or recreationally (i.e., concerts, sports events, gun ranges, etc.). Simple strategies outlined by the US Centers for Disease Control and Prevention include avoiding exposure to excessive noise, turning down the volume on music, moving away from sources of noise, and using HPDs to reduce exposure to safe levels [20].

2.2. Clinical Management

There is no cure for NIHL and, to date, no approved pharmacological treatment indicated for its treatment. Although there are currently no clinical practice guidelines specifically for NIHL management, such guidelines exist for sensorineural hearing loss in adults (i.e., from the American Academy of Otolaryngology-Head and Neck Surgery (AAOHNS) [21], American Academy of Audiology [22], and the UK National Institute for Health and Care Excellence [23]) and are applicable. Relevant recommendations include exclusion of conductive hearing loss, audiometric confirmation of sensorineural hearing loss (SNHL) characteristic of noise trauma, and exclusion of retrocochlear pathology in case of asymmetric SNHL based on contrast-enhanced brain MRI or ABR testing. NIHL is clinically managed with hearing aids and/or use of hearing protection during exposure, although if hearing loss worsens, patients may be eligible for cochlear implants [24]. In some cases of acute noise-induced TTS, clinicians may consider the use of intratympanic steroids such as dexamethasone [25][26], although high-quality, long-term efficacy evidence in humans is lacking, and it is not considered for chronic occupational noise exposure. Additionally, the WHO classifies hearing loss into mild, moderate, severe, and profound, listing the typical signs and various recommendations for each level of disability (Box 1). Clinicians can use this classification to educate patients regarding the natural history of NIHL while counseling them on protective measures and the benefits of auditory rehabilitation (i.e., hearing aids or other assistive devices). However, the WHO severity levels are arbitrarily defined, and the system does not address patients with <25 dB hearing level and unilateral hearing loss [27]. Additionally, the speech-in-noise test, which is an effective test for measuring noise interference on speech perception skills, is not considered by the WHO system [28].

Box 1. WHO grades of hearing loss. WHO grades from the 1991 working group on prevention of deafness and hearing impairment [29]. Additional comments on the classifications from Olusanya et al. [27]. Abbreviations: dB, decibel; ISO, International Organization for Standardization; WHO, World Health Organization.

Grade of impairment	Audiometric ISO value	Performance	Recommendation	Comments added to the prior classification
0-None	≥25 dB	No or very slight hearing problem. Can hear whispers.	None	20 dB also recommended. People with 15–20 dB levels may have hearing problems. People with

				unilateral hearing loss may have problems even if the better ear is normal.
1-Slight	26–40 dB	Can hear and repeat words spoken in a normal voice at 1 m	Counseling. Hearing aids may be needed	Some difficulty in hearing but can usually hear normal level of conversation
2-Moderate	41–60 dB	Can hear and repeat words spoken in raised voice at 1 m	Hearing aids are usually recommended	None
3-Severe	61–80 dB	Can hear some words when shouted into better ear	Hearing aids needed. Otherwise lip-reading and signing should be taught	Discrepancies between pure-tone thresholds and speech discrimination score should be noted
4-Profound	≥81 dB	Unable to hear and understand even a shouted voice	Hearing aids may help understanding words. Additional rehabilitation needed. Lip-reading and sometimes signing are essential.	Speech is distorted, the degree depending on the age at which hearing was lost

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