



Hearing Screening and Risk Factors of Hearing Loss: A Systematic Review

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Abstract

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BACKGROUND: According to the World Health Organization (WHO), it is predicted that hearing loss will increase to 2.5 billion people by 2050. Risk factors associated with hearing loss can occur in the uterus, at birth, or acquired.

AIM: This study aims to determine the most common risk factors and their relationship with the severity of hearing loss.

METHODS: Seven databases (NELITI, PubMed, SpringerLink, ScienceDirect, ProQuest, Emerald Insight and Wiley Online Library) were searched in January and February 2022. The keyword terms used were related to hearing assessment, hearing loss, and risk factor(s).

RESULTS: The initial search resulted in 7608 articles. A total of 1234 underwent title and abstract screening. Of these, 1223 were excluded due to various criteria. A total of 11 articles were assessed for eligibility, all of which met the inclusion criteria. In the 11 analyzed articles, the risk factors were categorized as prenatal and postnatal. The most common prenatal risk factors included genetic factor(s), family history, consanguineous marriage, and maternal infection during pregnancy. Meanwhile, the most common postnatal risk factors included prolonged mechanical ventilation, hyperbilirubinemia, asphyxia, premature birth, low birth weight, congenital anomalies, and consumption of ototoxic drugs. In one study, individuals with one risk factor had a hearing threshold of 76.47 ± 28.27 decibels (dB) nHL, whereas individuals with four risk factors had a hearing threshold of 85 ± 40.41 dB nHL.

CONCLUSION: The most common risk factors for hearing loss are genetic factor(s), prolonged use of mechanical ventilation, hyperbilirubinemia, birth defects, and consumption of ototoxic drugs. In addition, the more risk factors an individual has, the likelihood of hearing loss is greater and the degree of hearing loss is more severe.

Introduction

Hearing loss is defined as a decrease in the ability to hear from the right ear, left ear, or both ears in the frequency range of 20–20,000 Hertz (Hz) either suddenly or gradually [1], [2], [3]. In 2014, the World Health Organization (WHO) stated that 360 million people or 5.3% of the total world population had hearing loss. It is predicted that this will increase to 2.5 billion people by 2050 [1], [4]. Among the 360 million people, the prevalence is dominated by male population aged >15 years (183 million people) compared to adult women (145 million people). Hearing loss can occur in both adults and children. However, its incidence is increasing in the adolescent and young adult population due to daily exposure of high-frequency sounds from music [1].

In adults, hearing loss is defined as a hearing threshold of ≥ 41 decibels (dB) without a hearing aid. While in children, the threshold is ≥ 31 dB. Hearing loss can occur because of problems in the auditory organs causing individuals to have difficulty processing sound waves. According to the WHO, the severity of hearing loss is divided into five grades. The lowest grade is 0 and the highest is 4. Grade 0 is defined as a hearing

threshold of 25 dB HL where individuals can still hear whispering sounds. Grade 1 or mild is defined as a hearing threshold of 26–40 dB HL where individuals can still repeat someone's words with a distance of 1 meter. Grade 2 or moderate is defined as a hearing threshold of 41–60 dB HL where individuals can repeat someone's words with a higher sound frequency and a distance of 1 meter. Grade 3 or severe is defined as a hearing threshold is 61–80 dB HL where individuals can only hear loud sounds or screams. Grade 4 or very severe is defined as a hearing threshold of >81 dB HL where individuals cannot hear and understand the sound at all [1], [5], [6], [7].

Hearing loss risk factors that occur in the womb or during birth is referred to as congenital factors. Those factors include genetic factor(s) from parents that are related to the X chromosome such as Down syndrome, Usher syndrome; rubella, cytomegalovirus, or herpes simplex virus infections during pregnancy; the consumption of ototoxic drugs or alcohol during pregnancy; premature birth; low birth weight; abnormalities in the structure of the head and/or face; trauma during childbirth; and diabetes in the mother. Aside from that, hearing loss can also occur due to acquired risk factors such as age, exposure to high-frequency and intense noise,

chronic suppurative otitis media, iodine deficiency, localized physical trauma to the auditory organs, and consumption of ototoxic drugs such as loop diuretics, quinine, and salicylates for heart disease, cisplatin and carboplatin for cancer, and aminoglycoside antibiotics for infections [5], [6], [7], [8], [9].

Hearing screening, which assesses the ability of the ear to hear the softest sound or also called as hearing threshold, can be examined by an audiometer by pairing headphones on the right and left ears and playing sounds with various frequencies and intensities. The results of the screening will be documented in graphic form as an audiogram. In the audiogram sheet, the sound frequency in Hz is shown on the horizontal line and the sound intensity in dB is shown on the vertical line. Hearing threshold values for the right and left ears are distinguished by a symbol and a letter, namely, the small circle symbol for the right ear and the letter "X" for the left ear. [1], [5]. Aside from audiometer, hearing loss can be assessed using a bone conduction test by placing a bone conductor against the mastoid process to assess the difference in the duration of air conduction and bone conduction of sound waves traveling toward the cochlea in the inner ear. This can detect hearing loss caused by a problem in the auditory canal that conducts sound waves or a problem in the nerves that generate action potentials to perceive sound to the brain [1], [10], [11].

Hearing loss may cause disturbances in communication and affect the psychological condition of the patients which causes anxiety and depression, especially in patients with severe or profound hearing loss [12]. This indicates the importance of evaluating the most common risk factors of hearing loss in an effort to prevent hearing loss. Thus, this study aims to identify and evaluate scientific articles using a systematic review method regarding risk factors of hearing loss that were found in hearing screening and the relationship between risk factors and the severity of hearing loss.

Methods

This study used a systematic review method to identify, evaluate, and synthesize previously published scientific articles. The first data collection step was to search for articles on topics related to hearing screening and hearing loss in databases including NELITI, PubMed, SpringerLink, ScienceDirect, ProQuest, Emerald Insight, and Wiley Online Library using the keywords "(“Hearing screening” OR “Hearing test” OR “Hearing evaluation” OR “Hearing assessment”) AND (“Hearing impairment” OR “Hearing loss”) AND “risk factors.” The articles were further selected based on inclusion and exclusion criteria. The inclusion criteria included research articles published in the past

10 years (January 2012–January 2022) in international journals, fully accessible articles, and Indonesian or English articles.

Inaccessible articles, duplicated articles between libraries, non-research articles, titles, and abstracts that were not in accordance with PICOS (Population: individuals of various ages who had hearing screening; Intervention: risk factor for hearing loss; Comparison: absence of risk factor; Outcome: the severity of hearing loss) were excluded from our study. Articles that met the inclusion criteria and did not include the exclusion criteria were then critically reviewed using a checklist from the Joanna Briggs Institution Critical Appraisal. The stages of searching and selecting articles are summarized in the PRISMA diagram (Figure 1).

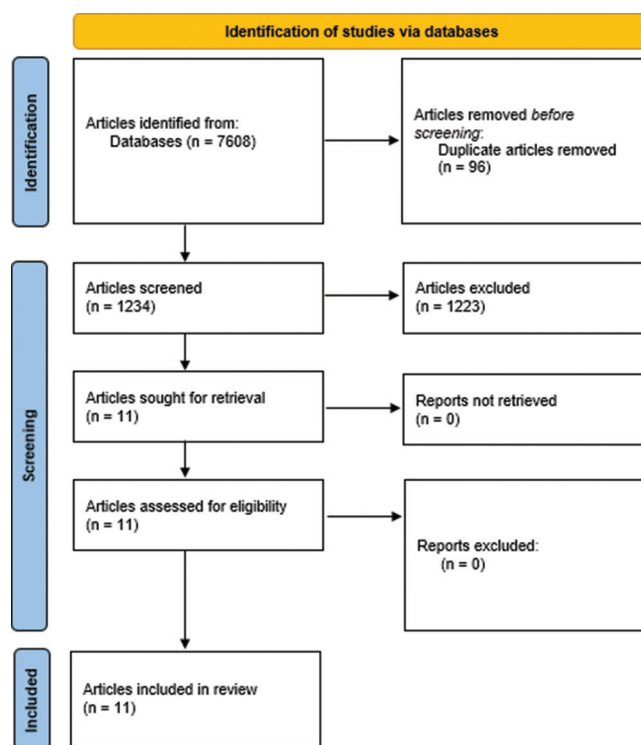


Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Results

The initial search resulted in 7608 articles. A total of 1234 articles underwent title and abstract screening. Of these, 1223 articles were excluded due to various criteria. A total of 11 articles were assessed for eligibility, all of which met the inclusion criteria. The articles featured data from various countries, which are Italy (n = 2), India (n = 2), China (n = 1), England (n = 1), Poland (n = 1), North America (n = 1), Nigeria (n = 1), Singapore (n = 1), and Uganda (n = 1). The study designs were retrospective study (n = 4), cross-sectional study (n = 3), case–control (n = 2), and cohort

($n = 2$). Sample size varied from 93 to 165416 samples. All of the studies enrolled infants and/or children, ranging from newborn to children aged 14 years old. However, the majority of the studies ($n = 10$) enrolled infants who were admitted to Neonatal Intensive Care Unit (NICU) or well-baby nursery [13], [14], [15], [16], [17], [18], [19], [20], [21], [22]. Only one study enrolled children aged 5–14 years old [23].

The hearing screening modalities varied, with the majority of the studies performing more than one diagnostic assessment. Auditory brainstem response was used in 8 studies, followed by transient-evoked otoacoustic emission that was used in 4 studies and distortion product otoacoustic emission that was used in 3 studies. Aside from that, otoacoustic emission, brain-evoked response audiometry, automated otoacoustic emission, tympanometry, brainstem auditory-evoked potential, free-field audiometry, otoscopy, tuning fork examination, and diagnostic audiometry were also used in assessing hearing loss (Table 1).

Due to various hearing screening modalities used in the studies, the definition of hearing loss varied as well. The WHO classification for hearing loss was used in one study [23]. Another study used the Bureau International for Audiophonology (BIAP) classification, in which the classification included normal (<20 dB HL), mild hearing loss (21–40 dB HL), moderate hearing loss (41–70 dB HL), severe hearing loss (71–90 dB HL), and profound hearing loss (>90 dB HL) [17]. A study in the UK, with ABR as the hearing screening tool, defined permanent childhood hearing impairment as permanent hearing loss equal to or >40 dBnHL across 0.5–4 kHz [15].

The risk of bias assessment has been carried out based on study eligibility, study selection, data collection, also synthesis and findings. Each paper is evaluated with Cochrane review criteria and judged as low, high, and unclear risk. Nine studies were found to be at low risk. Only one study appeared to be high risk, and one study with unclear risk (Table 2).

Discussion

The population in the analyzed studies ranged from newborns to children. The most common risk factors for hearing loss in the analyzed studies varied from different countries. The risk factors were categorized into prenatal and postnatal. The most common prenatal risk factors included genetic factor(s), family history, consanguineous marriage, and maternal infection during pregnancy due to rubella virus or cytomegalovirus. The most common postnatal risk factors included prolonged use of mechanical ventilation, hyperbilirubinemia, asphyxia, premature

birth, low birth weight, congenital anomalies, and consumption of ototoxic drugs. These risk factors could be interconnected and mutually supportive in causing hearing loss [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23].

Before the availability of clinical analysis of a gene that may cause hearing loss, the occurrence of hereditary hearing loss is common in individuals with a family history of hearing loss and blood-related parents. Technically, it is difficult to identify genetic mutations and deafness phenotypes. Thus, the use of hearing aids or cochlear implants are the only options for hearing loss management [13]. However, other articles mentioned that the most common gene mutations associated with hearing loss are GJB2, SLC26A4, and mitochondrial 12S Rrna [24], [25].

The prolonged use of mechanical ventilation could cause noise exposure that damage hearing. Hyperbilirubinemia damages the outer hair cells in the cochlea, in which bilirubin >35 mg/dL is statistically significant with an increased risk of sensorineural hearing loss. Ototoxic drugs, such as aminoglycosides and furosemide, will inhibit the action of cholinergic nerves in the central auditory system and trigger apoptosis in hair cells. Therefore, hearing loss is more common in infants treated in the NICU with conditions requiring respiratory management and blood transfusion. In addition to those drugs, ventilator is also the most frequently used device in the NICU for infants with asphyxia, premature birth, and low birth weight. Volpe's research stated that several risk factors had synergistic effects, such as hypoxia, bilirubin, and aminoglycosides, which would not cause hearing loss alone but were associated with other factors. Meanwhile, premature birth and low birth weight have additive effects and cause significant hearing loss [14], [15], [20]. The mechanisms of several other risk factors were not stated in details in the studies.

Consanguineous marriage has occurred frequently in several countries, especially in the Middle East. Social practices involving the practice of planned marriage within families and public ignorance of the negative repercussions of the practice are implicated for the high prevalence of consanguineous marriage. One study found that consanguineous marriage could increase the risk of giving birth to children with sensorineural hearing loss for up to 3.5 times greater than non-consanguineous marriage. Thus, it is essential to educate parents about the adverse effect of consanguineous marriage as a preventive measure of sensorineural hearing loss [26].

Maternal infection due to virus has known to cause congenital acquired hearing loss, especially sensorineural hearing loss. Rubella virus and cytomegalovirus are the most common viruses that can cause hearing loss. The mechanism of viral infection resulting in hearing loss is still not fully understood.

Table 1: Hearing screening and risk factors of hearing loss

City/Country	Study design	Sample size (n)	Diagnostic assessment	Details of screening protocol	Results and Conclusions
Guangzhou, China [13]	Retrospective	720	OAE and AABR	Newborns without complications were screened for hearing at 3 days of age, or after being discharged from the NICU. Then re-screened at 42 days of age.	The most common risk factors for hearing loss in this study were genetic factor (s) (20.14%), followed by unexplained SNHL, inner ear structural malformations, maternal rubella infection during pregnancy, and others. After re-screening, among children with confirmed permanent sensorineural hearing loss, 41.34% had a moderate hearing loss, 31.86% had a profound hearing loss, and 26.8% had a severe hearing loss.
Maharashtra, India [14]	Cross-sectional, comparative	127	BERA	Infants aged 6 months–1 year from low socioeconomic backgrounds who had multiple risk factors at birth or delayed onset hearing loss were screened using BERA.	The most common prenatal risk factors was consanguineous marriage compared to history of deafness in family and maternal infection during pregnancy. Meanwhile, the most common neonatal and late-onset risk factors were developmental delay (32.18%) and asphyxia at birth (22.99%). In 87 infants who had one or more risk factors; 10.34% of infants had a severe-profound bilateral hearing loss, 17.24% of infants had bilateral mild-moderate hearing loss, and 12.64% had an unilateral hearing loss.
The United Kingdom [15]	Case control	2242	AOAE and AABR	Infants who were admitted to the NICU for more than 48 hours were screened using the AOAE and AABR.	The most common risk factor for hearing loss were prolonged use of ventilator (53%), followed by congenital anomalies including Wolf-Hirschorn syndrome, Treacher Collins syndrome, CHARGE syndrome (29%), and seizures (17.7%). Of the 62 babies diagnosed with permanent hearing loss, 4 infants had a mild hearing loss, 29 infants had a moderate hearing loss, 4 infants had a severe hearing loss, 8 infants had a profound hearing loss, while 11 late-onset infants and 6 infants had an auditory neuropathy.
Western Sicily, Italy [16]	Cohort	412	TEOAE, ABR and tympanometry	Infants aged 4–20 weeks underwent an audiological examination to determine risk factors for congenital, delayed-onset, and progressive sensorineural hearing loss. Parents of infants with suspected hearing loss were recommended to have their children re-screened after 3 weeks.	Two hundred thirty nine infants were specifically associated with one risk factor for hearing loss, whereas 173 infants were associated with various risk factors for hearing loss. Among them, 121 infants had 2 risk factors, 40 infants had 3 risk factors, 11 infants had 4 risk factors, and 1 infant had 5 risk factors. The three most common risk factors were premature births (36.65%), infants requiring intensive care for more than 5 days (26.70%), and infants experiencing respiratory distress syndrome (27.43%). There were 84 infants diagnosed with hearing loss, 37 infants had conductive hearing loss and 47 infants had sensorineural hearing loss. Regarding the degree of hearing loss, 44.68% of infants had a moderate hearing loss, 10.64% of infants had a severe hearing loss, and 44.68% of infants had a profound hearing loss.
Campania, Italy [17]	Retrospective	165416	TEOAE and AABR	Newborns were screened for hearing using TEOAE and AABR in 2 stages, Stage 1: 2–3 weeks of age Stage 2: 3–4 weeks of age Infants who failed both screenings were referred to the nearest audiology service for a comprehensive audiological evaluation.	The most common risk factors for hearing loss were family history (35%), premature infants (25.5%), low birth weight (19.2%), severe hyperbilirubinemia (19%), prolonged use of ventilators (15%), and congenital infections (12.5%). The types of hearing loss found were bilateral sensorineural (48.5%), unilateral sensorineural (42.5%), permanent conductive (4.5%), and audiological neuropathy (4.5%). Regarding the degree of hearing loss, 39% had a mild hearing loss, 37% had a profound hearing loss, 15% had a moderate hearing loss, 9% had a severe hearing loss.
Poland [18]	Retrospective	351	TEOAE, DPOAE and ABR	Infants who failed to undergo a NHS in the first stage using TEOAE were then subjected to hearing screening using otoacoustic emission and ABR in the second stage.	The most common risk factors for hearing loss were hyperbilirubinemia (71.51%), followed by premature birth (63.25%), and consumption of ototoxic drugs (62.11%). Other less common risk factors were low birth weight (31.62%), intensive therapy for at least 7 days (27.07%), and the use of mechanical ventilation for at least 5 days (22.22%). Among the 59 infants diagnosed with hearing loss, 46 had a moderate hearing loss and 13 had a severe hearing loss.
Mexico, North America [19]	Case-control	93	BAEP, FFA, TEOAE, and DPOAE	Children born weighing < 750 grams were screened for hearing using BAEP at 3–6 months of age, then FFA at 6–24 months of age, and TEOAE and DPOAE in samples with abnormal BAEP results.	Regarding sensorineural hearing loss, 2 children had a severe hearing loss and 4 children had a profound hearing loss. Then, 3 of them had ventricular leukomalacia, 2 children had hydrocephalus, and 1 child had cerebral palsy as a risk factor. Apart from neurological comorbidities, the use of endotracheal mechanical ventilation was statistically significant in children with sensorineural hearing loss.
Nigeria, West Africa [20]	Longitudinal cohort	201	AABR	Hearing screening was performed on all infants at admission, discharge, and 6 weeks after discharge.	Neonatal sepsis was the most common risk factor for hearing loss (94%), followed by hyperbilirubinemia (44.3%), and severe perinatal asphyxia (40.8%). In addition, premature infants of < 34 weeks, consumption of amikacin > 5 days, very low birth weight were also risk factors for hearing loss. In this study, family history was the least common risk factor at 0.5%.
Singapore [21]	Retrospective	2661	AABR	Infants born and treated in the NICU were subjected to UNHS using the 2-stage AABR protocol. The first stage was during or after 34 weeks of age. If it failed, the second stage was carried out 3–6 weeks after that.	The most common risk factors for hearing loss were the use of mechanical ventilation > 48 hours (75.50%), premature birth (56.70%), low birth weight of < 1500 grams (51%) and consumption of ototoxic drugs (51%). Regarding the degree of conductive hearing loss, 16 infants had a mild-moderate hearing loss, 5 infants had a severe-profound hearing loss. Meanwhile, for sensorineural disorders, 5 infants had a mild-moderate hearing loss and 6 infants had a severe-profound hearing loss.
Karnataka, India [22]	Prospective cross sectional	402	DPOAE and ABR	Hearing screening protocol was carried out in 2 stages. The first one was DPOAE. If it failed, ABR was performed.	Consanguineous marriage was statistically significant with hearing loss in infants admitted to the NICU ($p = 0.003$) and not admitted to the NICU ($p = 0.452$). In addition, family history was significantly associated with hearing loss ($p = 0.003$ in infants admitted to the NICU and $p = 0.013$ in infants not admitted to the NICU) In addition, congenital infection and hyperbilirubinemia were also found to be significantly associated. In infants admitted to the NICU and diagnosed with hearing loss, 6 of them had a moderate hearing loss and the remaining 5 had a profound hearing loss. Meanwhile, in infants who were not admitted to the NICU, 1 infant had a moderate-severe hearing loss and the remaining 2 had a profound hearing loss.
Uganda, East Africa [23]	Cross sectional	639	Otoscopy, tuning fork examination, and diagnostic audiometry	All hearing screenings were performed by a PI to assess the hearing threshold in dB. If the hearing threshold was > 30 dB, otoscopy and tuning fork test were performed. If those failed, diagnostic audiometry was performed.	In this study, 20 children had hearing loss; 8 children with conductive type, 11 children with sensorineural type, and 1 child with mixed type. The most common cause of conductive hearing loss was chronic suppurative otitis media (50%), whereas in sensorineural hearing loss, 90.9% had no known cause. Based on the grading, 8 children had a mild hearing loss, 4 children had a moderate hearing loss, and 8 children had a profound hearing loss.

OAE: Otoacoustic emissions, AABR: Automated auditory brainstem response, BERA: Brainstem evoked response audiometry, AOAE: Automated otoacoustic emission, TEOAE: Transient evoked otoacoustic emission, DPOAE: Distortion product otoacoustic emission, BAEP: Brainstem auditory-evoked potentials, FFA: Free-field audiometry, NICU: Neonatal intensive care unit, NHS: Newborn hearing screening, UNHS: Universal newborn hearing screening, PI: Principal investigator, dB: Decibels

Table 2: Risk of bias

Study	Study eligibility	Study selection	Data collection	Synthesis and findings	Review risk of bias
Fang <i>et al.</i> , 2020 [13]	Low	Low	Low	Low	Low
Mukherjee <i>et al.</i> , 2012 [14]	Low	Low	High	Low	High
Nair <i>et al.</i> , 2020 [15]	Low	Low	Low	Low	Low
Martines <i>et al.</i> , 2012 [16]	Low	Low	Low	Low	Low
Malesci <i>et al.</i> , 2020 [17]	Low	Unclear	Low	Unclear	Unclear
Lachowska <i>et al.</i> , 2014 [18]	Low	Low	Low	Low	Low
Martinez-Cruz <i>et al.</i> , 2012 [19]	Low	Low	Low	Unclear	Low
Labaeka <i>et al.</i> , 2018 [20]	Low	Low	Low	Low	Low
Jayagobi <i>et al.</i> , 2020 [21]	Low	Low	Low	Low	Low
Hajare <i>et al.</i> , 2018 [22]	Low	Low	Low	Low	Low
Basañez <i>et al.</i> , 2015 [23]	Low	Low	High	Low	Low

However, some studies mentioned that the proteins expressed from cytomegalovirus would trigger an immune response that resulted in inflammation and edema in the cochlea. Meanwhile, some studies found that rubella virus acted directly to damage the cochlea and cause the necrosis of organ of corti and stria vascularis. The damage of stria would also make alterations to the composition of endolymph [27].

Prolonged environmental noise from mechanical ventilation will increase the risk of hearing loss in preterm neonates because this condition will damage hair cell in the cochlea. These hair cells have no ability to regenerate. Thus, prolonged exposure of noise will cause permanent damage and preterm neonates will lose the ability to hear completely. However, Rastogi *et al.* found that nasal continuous positive airway pressure (NCPAP) did not increase the prevalence of hearing loss compared to mechanical ventilation, despite the higher noise generated from NCPAP [28].

The Majority of the studies did not explain the association between the degree of hearing loss in certain populations and the risk factors. However, Martines *et al.* found that the population with only one risk factor had a hearing threshold of 76.47 ± 28.27 dB nHL, whereas the population that with four risk factors had a hearing threshold of 85 ± 40.41 dB nHL. The percentages of individuals with 1, 2, 3, and 4 risk factors who had sensorineural hearing loss were 13.3%, 6.6%, 10%, 18.18%, and 100%, respectively. As mentioned by the Joint Committee on Infant Hearing, the occurrence of hearing loss increased with the more risk factors the individuals had [16].

Conclusion

The risk factors analyzed in our study were not much different from those that were previously stated in prior studies. The most common risk factors included genetic factor(s), prolonged use of mechanical ventilation, hyperbilirubinemia, birth defects, and consumption of ototoxic drugs, which were more common in infants admitted to the NICU. In addition, the more risk factors an individual has, the likelihood of hearing loss is greater and the degree of hearing loss is more severe.

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