

Different faces of the stethoscope: history, usefulness, evolution, contamination, and disinfection practices

Różne oblicza stetoskopu: historia, zastosowanie, ewolucja, zanieczyszczenie i sposoby dezynfekcji

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Słowa kluczowe: historia stetoskopu, higiena stetoskopu, zanieczyszczenie stetoskopu, zakażenia związane z opieką zdrowotną (HAI), przydatność stetoskopu.

Abstract

A stethoscope is a tool mainly used by physicians of various specialties in their daily work. Over the centuries, newer designs of this diagnostic tool have been improved and developed. A stethoscope in medical practice, which comes into contact with many patients, poses a high risk of infection transmission and thus may increase the incidence of infection in healthcare facilities. Research data indicate that a stethoscope can be contaminated by 21–100% with clinically relevant bacterial pathogens, including multidrug-resistant strains. A stethoscope is considered non-critical equipment, and the recommendations for cleaning the stethoscope are after each patient, once a day, or once a week. However, there are still no clear-cut algorithms for its handling. The use of disinfectants requires the selection of a suitable agent that, with frequent disinfection of stethoscopes, will not damage sensitive parts and at the same time effectively remove pathogens.

Streszczenie

Stetoskop to narzędzie używane głównie przez lekarzy różnych specjalności w ich codziennej pracy. Na przestrzeni wieków udoskonalano i rozwijano coraz to nowsze konstrukcje tego narzędzia diagnostycznego. Stetoskop w praktyce medycznej ma kontakt z wieloma pacjentami, co stwarza wysokie ryzyko przenoszenia infekcji, a także może zwiększać częstość występowania infekcji w placówkach opieki zdrowotnej. Dane z badań wskazują, że stetoskop może być zanieczyszczony w 21–100% klinicznie istotnymi patogenami bakteryjnymi, w tym szczepami wielolekoopornymi. Stetoskop jest uważany za sprzęt niekrytyczny, a zalecenia dotyczące dezynfekcji stetoskopu dotyczą czyszczenia po każdym pacjencie, raz dziennie lub raz w tygodniu. Nadal jednak nie ma jednoznacznych, szczegółowych algorytmów dotyczących postępowania. Stosowanie środków dezynfekujących wymaga doboru odpowiedniego środka, który przy częstej dezynfekcji stetoskopów nie uszkodzi wrażliwych części, a jednocześnie skutecznie usunie patogeny.

Introduction

The stethoscope is one of the most important symbols of medicine [1]. The name stethoscope is derived from the Greek words ‘stethos’ meaning chest and ‘skopos’ meaning observer [2]. This instrument is the most well-known, basic, and non-invasive diagnostic tool in medicine. In their daily work, it is used by doctors of various specialties, mainly internists, anaesthesiologists, cardiologists, general practitioners, and paediatricians. In addition to physicians, patient examinations using stethoscopes are also performed by nurses, paramedics, medical students, and staff in care homes for the elderly [3]. Based on

the speciality for which the stethoscope is used, a distinction is made between an anaesthetic stethoscope, an internal medicine stethoscope, a cardiology stethoscope, a paediatric/neonatology stethoscope, and a nursing stethoscope [4]. Originally, stethoscopes were designed to auscultate the lungs and heart, helping to assess the respiratory and cardiovascular systems. Other uses of stethoscopes include auscultation of bowel murmurs and assessment of vascular murmurs [4]. In our study, we attempted to determine whether the stethoscope is still an essential tool used in medicine or whether it can be successfully replaced by other diagnostic equipment. In addition, we dis-

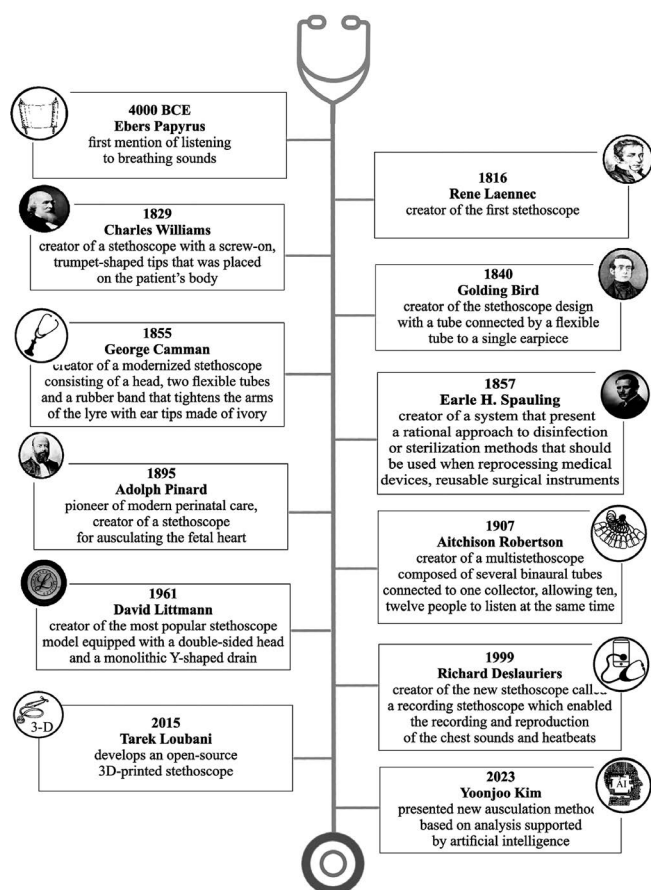


Figure 1. A timeline presenting breakthrough moments in the history of the stethoscope. Own elaboration inspired by an illustration named Evolution of stethoscope from <https://www.theweek.in/webworld/features/lifestyle/evolution-of-stethoscope.html>

cussed the phenomenon of stethoscope contamination, stethoscope hygiene guidelines, how to perform hygiene, and how to evaluate its effectiveness.

The history of the stethoscope

The first mention of listening to breath sounds dates back to ancient Egypt in 1500 BC and was included in the Ancient Egyptian Ebers Papyrus preserved as one of the most valuable and oldest documents on medicine (Figure 1). Other records have been found in the Hindu Vedas from around 1400 to 1200 BC and in the Hippocratic Writings from around 440 to 360 BC [5].

The invention of the stethoscope in 1816 is attributed to a Frenchman, Rene Théophile Hycanith Laennec [2]. This doctor reported extraordinary acoustic sensitivity acquired through the practice of auscultation, thanks to which he replaced direct auscultation with an ear applied to the patient's body, with an attempt at auscultation using a sheet of paper rolled into a cylinder [2]. After 3 years of experiments with refining the shape, testing different materials, and practical exercises, he finally developed an instrument in the shape of a 25 cm long wooden

cylinder. Originally, it was an earpiece in the form of a wooden, funnel-shaped tube with a flat end on the ear side. Laennec then carved a new tool with ivory tips at both ends so that it would conduct heat [5]. In addition to the discovery of the stethoscope, Laennec's great merit was the work he did to bring the invention into everyday use. The inventor died in 1826 at the age of 45, having previously diagnosed tuberculosis with the stethoscope he had invented [5].

The golden age of the stethoscope has been referred to as the period of the first 100 years since its invention. During this time, many stethoscope designs based on Laennec's idea were being developed [4, 5]. By the 1820s, the stethoscope was widely available throughout Europe. Doctors experimented with different sizes, shapes, and materials to create the most effective tool. The first concepts of the bin-aural stethoscope appeared in the early 1830s. A number of stethoscope designs named after their creators, such as Davies, Fergusson, Fox, Piorry, Stokes, and Walshe represented modifications not significantly different from the original [6].

The first significant development in the design of the stethoscope was presented in 1829 by Charles Williams [6]. This stethoscope consisted of a trumpet-shaped main part made of mahogany applied to the body and screwed to a connector provided with 2 bent tubes [6]. In 1840, British physician Golding Bird published a design for a stethoscope with a tube connected via a flexible tube to a single earpiece [7]. An interesting solution for an upgraded stethoscope consisting of a head, 2 flexible tubes and a rubber band tensioning the lyre arms with ivory ear tips was published in 1855 by George Camman [2]. James Murray in 1889 described the use of a rubber ring on the rim of the stethoscope's funnel, which improved the sealing of the head's contact with the patient's body and listening comfort [6]. The profile of the stethoscope funnel also changed over time, initially being cone-shaped, then bell-shaped, and over time resembling the shape of a trumpet tip. In 1894, engineer Robert Bowles proposed the first head design using a diaphragm [6]. In 1895, paediatrician Adolph Pinard – a pioneer of modern perinatal care – invented a stethoscope for auscultation of the foetal heart [8].

Further stethoscope designs followed in the early 20th century. In 1907, Aitchison Robertson connected several wires to a single manifold, allowing 10 or 12 people to auscultate a patient at the same time for educational purposes [6].

The most popular model of stethoscope was described in 1961 by American cardiologist David Littmann [5]. This instrument used a single Y-shaped tube together with a double-sided head, one side shaped like an open funnel designed to listen to low-frequency tones and the other side closed with a rigid plastic membrane to filter out these tones. In 1964, Littmann obtained a patent for an improved stethoscope

equipped with an acoustic diaphragm that amplifies the tones, called the diaphragm stethoscope, which is used in medical practice today [5].

Thanks to the development of electronics, the era of the first electronic stethoscopes with head-mounted microphones and electrical amplification of the acoustic signal began in the 1970s. Subsequently, piezoelectric diaphragms made of brass were used for the same purpose. Further development of these devices was based on the technology of digital processing of the received signals, which created the possibility of computerised analysis and software processing of the data [9]. In 1999, thanks to the work of Richard Deslauriers, a stethoscope was invented to record and reproduce chest sounds and heartbeats [5]. In 2015, physician Tarek Loubani and his team developed an *open source* stethoscope using 3D printing [10]. One of the more recent developments is the development of digital stethoscopes with machine learning (ML) algorithms aided by artificial intelligence (AI) [11].

Stethoscopes – legal framework

As a medical device, a stethoscope must meet quality and safety standards for the protection of patient and user health. In the countries of the European Union, for medical devices, Regulation (EU) 2017/745 of the European Parliament and of the Council (Medical Device Regulation – MDR) has been in force since 26 May 2021. It replaced the previously applicable Directives and Regulations 93/42/EEC (Medical Device Directive – MDD) [12]. To improve human safety, the MDR document clarifies and extends the legal regulations concerning, *inter alia*, the classification, labelling, and placing on the market, of medical devices to increase the degree of control of the competent authorities (EU and national) over the route that a product of the relevant category must take from the manufacturer to the user. Every medical device must have an EU Declaration of Conformity as well as CE marking. In addition to the MDR, the medical device manufacturer must have a quality management system following ISO 13485 and a risk management system following ISO 14971 [13]. In addition, the manufacturer can register its product in the European Database on Medical Devices (EUDAMED) effective from 26 May 2022 [14].

Stethoscope innovations

Recent proposed stethoscope innovations include an electronic stethoscope designed for deaf or hard-of-hearing healthcare professionals. This stethoscope is connected wirelessly to a hearing aid amplifier [15]. Another innovation dedicated to screening in the primary care setting is the use of a stethoscope to detect peripheral arterial disease (PAD) [16]. In contrast, Frauenrath *et al.* proposed the MR stethoscope as a promising alternative to currently available magnet-

ic resonance imaging (MRI) cardiac gating techniques [17]. Makaryus *et al.* presented a novel digital electronic stethoscope, the cardiac sonospectrographic analyser (CSA) adapted for the diagnosis of coronary artery disease (CAD) [18].

As new models and applications of stethoscopes keep pace with medical advances, a simulation stethoscope (SS) has also been developed that can be a useful addition to simulation-based emergency medicine training for students. The SS is a wireless, remotely programmable stethoscope that allows any sound to be transmitted wirelessly to a receiver, improving the value of the physical examination [19]. As an alternative to disposable plastic stethoscopes, a study by Kelmenson *et al.* (2014) evaluated a prototype electronic stethoscope for auscultation of heart tones. Examination with this stethoscope does not require direct physician-patient contact. In addition, this type of device has more accurate acoustics by reducing background noise [20].

In telemedicine, the stethoscope, together with an otoscope and a high-resolution camera, is the equipment of a remote presence solution (RPS) used in real-time in the telemedicine process [21]. Other studies have tested a digital stethoscope using artificial intelligence (StethoMe AI) specifically trained to detect pathological respiratory murmurs in children [22]. In 2021, a digital auscultatory stethoscope (DAS) used to determine the frequency of subclinical rheumatic heart diseases (RHDs) and train a deep learning (DL) algorithm using waveform data from a digital signal was described [23]. In contrast, Yang *et al.* (2021) developed a prototype of the Auscul Pi non-contact electronic stethoscope. This device enables real-time capture of auscultatory sounds using a micro-speaker. In addition, the Auscul Pi can store data files for later quantitative analysis [24]. Newly designed electronic and digital stethoscopes for use in both clinical and educational settings allow for improvements in traditional auscultation techniques [4].

In addition to modifications to the device itself, innovations are also taking place in various applications of stethoscopes. For example, in Poland, there was an E-stethoscope programme, which involved the use of simple electronic stethoscopes with which the lungs could be easily examined at home as part of tele-assistance by primary care physicians. This programme was run as a pilot involving post-SARS-CoV-2 patients with coexisting respiratory diseases (<http://gov.pl/web/estetoskop>) [25]. The substitution of stethoscopes for other diagnostic devices is not always due to reluctance to use a stethoscope, but is dictated by safety concerns, as was the case during the COVID-19 disease pandemic.

Stethoscope's alternative diagnostic tools

Stethoscopes are still the mainstay of clinical diagnosis; however, several new diagnostic methods have

been proposed as alternatives to these devices. Among the technologies replacing the stethoscope are hand-held mobile ultrasounds (HHU ultrasounds), also known as visual stethoscope. HHUs exploit the wave phenomena occurring for ultrasound propagating in tissues, particularly the reflection of the wave at the boundary of media, and are thus used in the diagnosis of peripheral lung diseases [26]. On the other hand, hand-held echocardiograms are used as screening tools to detect cardiac abnormalities [27]. Another alternative is bedside ultrasound machines (point-of-care ultrasound – POCUS) called stethoscopes of the 21st century ('stethoscope of the 21st century') [28–33]. POCUS machines are ultrasound devices that are prevalent in cardiology and cardiac surgery, neonatology, orthopaedics, gastroenterology, and urology, among others [28–33]. They have also been used for COVID-19 patients for whose care the use of the stethoscope has been limited, and bedside lung point-of-care ultrasound (Lu-POCUS) has been recognised as a safe alternative to imaging [34].

Empirical mode decomposition (EMD) is a device designed to correctly diagnose both normal and abnormal heart tones by dividing them into different phases of the cardiac cycle and comparing them with a standard set of sounds [35].

The HeartBuds device is another alternative to the stethoscope. It is a handheld mobile auscultation device that connects to an app on a smartphone and then plays the sound heard through the phone's speakers [36]. In addition to the HeartBuds device, there are also devices on the market that work on slightly different principles such as CardioSleeve, SensiCardiac, Eko Core, and Thinklabs [37].

The stethoscope as a vector of multidrug-resistant pathogens

In medical practice, the use of the stethoscope as an instrument that comes into contact with multiple patients poses a high risk of transmission of infection and may therefore increase the incidence of infection in healthcare settings [38].

Contamination of stethoscope surfaces was first reported in 1972, when Gerken *et al.* and independently Mangi *et al.* (1972) investigated contamination of stethoscopes mainly with staphylococci, among which many strains were multidrug-resistant [39, 40].

Recent publications also report stethoscopes being contaminated with microorganisms. For example, the results of our study showed that among the 66 student stethoscopes examined, all devices were contaminated by bacteria. The most frequently isolated bacterial species belonged to the genera *Staphylococcus* (50.5%), *Bacillus* (25.2%), and *Micrococcus* (17.3%), as well as other bacteria representing the skin microbiota [41]. A long-term study by the team of Boulee *et al.* showed that 83% of stethoscopes can harbour bacteria

[38]. In this study, the most common bacteria isolated from stethoscope surfaces included coagulase-negative staphylococci (CoNS), *P. aeruginosa*, *Vancomycin-resistant Enterococci* (VRE), *Clostridioides difficile*, *Respiratory syncytial virus* (RSV), and methicillin-resistant *Staphylococcus aureus* (MRSA) [38]. A study involving 47 stethoscopes showed bacterial growth from 78.7% of stethoscope surfaces [42]. In a study conducted by Adhikari *et al.* on 87 stethoscopes, bacterial colonisation with at least one bacterium was seen in 28.74% of stethoscopes. All 52.94% of isolates belonged to the genus *Staphylococcus*, the majority (83.33%) being *S. aureus*. Of the Gram-negative bacilli, bacteria from the genus *Acinetobacter* (43.75%) and *Pseudomonas* spp. (31.25%) were the most numerous groups contaminating the stethoscopes examined. About half of the Gram-negative isolates (47%) were multidrug-resistant (MDR) [1]. In yet another study by Ehondor *et al.* (2023) on 106 stethoscopes it was found that 35.8% of these samples were culture-positive, including *S. aureus* (33.3%), where MRSA (26.3%), CoNS (33.3%), and methicillin-resistant coagulase-negative staphylococci (MRCoNS) accounted for 9.6%. In contrast, Gram-negative bacilli were dominated by *Acinetobacter* spp. (5.3%), *Klebsiella* spp. (3.5%), and *E. coli* species (1.8%) [43]. In conclusion, stethoscopes are contaminated primarily with bacteria from the skin, but also with dangerous multidrug-resistant pathogens from the hospital environment with high pathogenic and hyperepidemic potential.

According to current reports, stethoscope surfaces are much less frequently contaminated by fungi, among which *Candida albicans*, *C. tropicalis*, *C. parapsilosis*, and *C. auris* are mainly detected [44, 45].

Stethoscopes as source of clonal transmission of microorganisms

The stethoscope as a reservoir of microorganisms can be a potential source of healthcare-associated infections (HAIs) [46]. HAIs are a serious medical problem worldwide [47]. These infections are inevitable, being due in part to medical advances and usually caused by multidrug-resistant bacteria with a high potential for epidemic spread [47].

The clonal spread of multidrug-resistant strains representing different bacterial species isolated from the surface of stethoscopes has been demonstrated in numerous research papers, including our own [41, 48, 49]. Among others, in a previous in-house study, the authors demonstrated the clonal structure of MRSA and methicillin-resistant *Staphylococcus epidermidis* (MRSE) isolated from the surfaces of fifth-year medical students' stethoscopes, which spread among students assigned to different exercise groups [41]. A study by the Korean scientific team of Lee *et al.* (2021) showed a 95% similarity obtained by pulsed field gel electrophoresis (PFGE) between *Klebsiella*

pneumoniae strains producing carbapenemase type KPC-2 isolated from 3 patients and from a stethoscope used in the ward [48]. In contrast, the Spanish scientific team of Millán-Lou *et al.* (2021) conducted a study whose aim was to describe the molecular epidemiology of a *Serratia marcescens* outbreak in the neonatal unit. They detected one clone of *S. marcescens* bacteria represented by 18 different samples from the ward environment, including 1 sample from a stethoscope used to examine hospitalised neonates [49].

SARS-CoV-2 pandemic impact on stethoscope use

During the COVID-19 pandemic, medicine became an area of special challenges, and medical personnel were subjected to unique risks and responsibilities. A key task conditioning the efficiency of the entire healthcare system became the creation of safe working conditions [50]. The stethoscope, which is in direct, close contact with an infected person, became the subject of various assessments, with the medical community divided over its role in the situation. Disagreements have arisen about the stethoscope as a tool that transmits the SARS-CoV-2 virus [50–52]. For example, a study by Vasudevan *et al.* (2023) cited a case report of a cardiology resident who developed a SARS-CoV-2 virus infection, which she probably transmitted via her stethoscope [51]. In contrast, a study conducted by a team from Spain on 100 stethoscopes showed that, after contact with patients confirmed positive for SARS-CoV-2, these stethoscopes were not the source of the virus infection [50]. At the beginning of the COVID-19 pandemic, a review paper analysing 22 studies was published, showing the ability of other coronaviruses (Severe Acute Respiratory Syndrome (SARS)-causing coronavirus, Middle East Respiratory Syndrome (MERS) coronavirus, and endemic human coronaviruses (HCoV) to survive on inanimate surfaces (metals, glass, various plastics) [53]. This work shows that these viruses are capable of surviving on non-living surfaces for up to 9 days. At the same time, it was found that these viruses could be effectively inactivated using 62–71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite for surface disinfection. As a result of the above and the initially scant information characterising the new coronavirus, these reports raised concerns among healthcare professionals caring for SARS-CoV-2-infected patients about the existing risk of transmission [52]. Given the potential for coronaviruses to survive on a variety of surfaces, it is important to emphasise that a contaminated stethoscope can realistically compromise the safety of patients, doctors, and all other healthcare personnel.

On the other hand, the occurrence of the COVID-19 disease pandemic has changed the healthcare model. There has been an increased demand for remote care

and face-to-face treatment for diseases that require isolation, such as SARS-CoV-2 infection, and stethoscopes are being developed to address these issues using advances in technology [11]. It is also important to mention that before the pandemic, some hospitals were using disposable plastic stethoscopes in patient rooms to reduce the spread of healthcare-associated infections [23].

Another common practice during the COVID-19 pandemic was the use of the Auscul Pi non-contact stethoscope, as it allowed accurate auscultation by medical workers wearing protective suits and having difficulty examining patients infected with the SARS-CoV-2 virus [24]. During the COVID-19 pandemic, there was also a practice of limiting the use of stethoscopes, and diagnostic imaging became an essential part of the initial examination of patients. Due to the high infectivity of the SARS-CoV-2 virus, bedside POCUS lung ultrasonography became a safe alternative for examination [34].

The occurrence of the COVID-19 pandemic has changed the healthcare model. During this time, scientists focused on developing newer stethoscope solutions that minimised close contact with patients, thereby increasing workplace safety. Similarly to the development of imaging techniques, there was also advancement in wireless and digital stethoscopes, as well as sophisticated algorithms using computer analysis of complex data. All devices previously considered technological novelties found practical application during the COVID-19 pandemic due to the circumstances. An example of an innovative stethoscope solution during the COVID-19 pandemic was wireless stethoscopes for examining patients in makeshift hospitals. These stethoscopes could prevent cross-infections and detect valuable symptoms, aiding healthcare workers in making accurate decisions and alleviating patients' symptoms more quickly. Moreover, the study emphasised that doctor-patient communication based on stethoscope use could reduce the psychological effects of the epidemic on isolated patients [54]. In a prospective observational study by Kaimakamis *et al.* (2024), critically ill COVID-19 patients in ICUs were examined using novel digital auscultation techniques. For patients with severe acute respiratory distress syndrome (ARDS) caused by COVID-19, the study aimed to investigate the associations between lung sound characteristics and lung mechanics, length of stay, and survival. Digital stethoscopes captured and recorded lung sounds in an online database for further analysis with advanced AI techniques. This annotated lung sound database is publicly available [55]. In turn, in a study conducted by the research team of Lella *et al.* (2024), based on artificial intelligence (AI), abnormalities in COVID-19 and other common respiratory diseases were identified using data from a digital stethoscope with a deep convolutional neural network (CNN) [56].

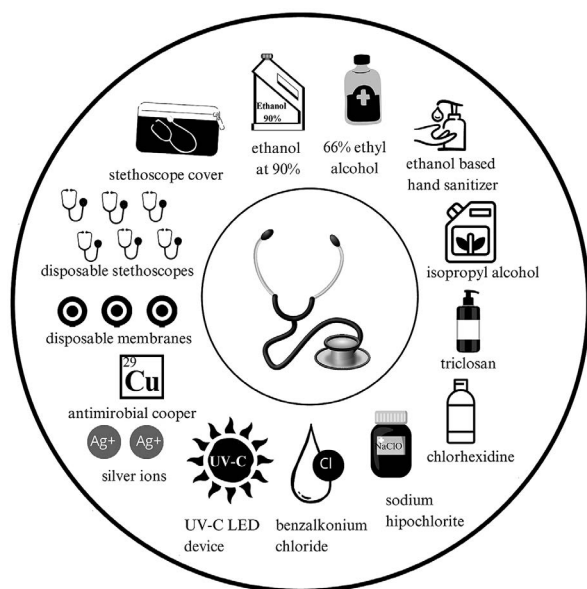


Figure 2. Disinfection methods intended for stethoscopes. Authors' elaboration based on [61, 72]

The stethoscope as non-critical medical equipment

The frequent contamination of stethoscopes, the transmission of HAI pathogens and the experience of healthcare professionals in relation to the COVID-19 disease pandemic mandate the question of how to decontaminate the stethoscope and whether the person handling this equipment has such an obligation at all. In 1857, a system was proposed by E. Spaulding presenting a rational approach to the methods of disinfection and sterilisation of medical devices, reusable surgical instruments, and equipment used for patient care [57]. The system takes into account methods of decontamination, which is the removal of contaminants of biological origin, including pathogenic microorganisms, from instrument surfaces. The Spaulding classification is widely accepted by regulatory bodies such as the European Centre for Disease Prevention and Control (ECDC), the US Food and Drug Administration (FDA), and the US Centers for Disease Control and Prevention (CDC) [57].

According to the Spaulding classification system, as well as the Healthcare Infection Control Practices Advisory Committee (HICPAC) and CDC guidelines, the stethoscope is classified as non-critical medical equipment, i.e. in contact with intact skin. It is therefore recommended to disinfect the stethoscope at a frequency of once a day or weekly [58]. Also in Regulation (EU) 2017/745 of the European Parliament and of the Council (Medical Device Regulation – MDR), stethoscopes are classified as Class I low-risk medical devices with a measuring function (so-called Class Im) [12].

Stethoscope disinfection practices

To decontaminate the stethoscope, use disinfectants that meet standards, have a wide range of action, and are designed for use on stethoscope materials.

According to current guidelines, low-level disinfection is recommended for the stethoscope, as for other non-critical devices [57]. Low-level disinfection involves the reduction of vegetative forms of bacteria (with the exception of mycobacteria), yeast-like fungi, and enveloped viruses [57]. In the countries of the European Union, including Poland, the methodology for testing the effectiveness of disinfectant preparations is recommended by the regulations contained in EN 14885 [59]. Accordingly, disinfectants that meet the licensing requirements must provide adequate ranges of bactericidal, fungicidal, mycobactericidal, virucidal, and sporicidal efficacy. EN 14885 addresses disinfection of equipment in various areas such as medicine, veterinary medicine, the food industry, and others [59].

In contrast, in the United States, the responsibility for the review and oversight of chemical disinfectants and sterilisers comprises 2 agencies: the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) [60].

Among the most effective disinfectants dedicated to stethoscopes, ethanol 90%, ethanol-based hand sanitiser (EBHS), triclosan, chlorhexidine (CHX), isopropyl alcohol (ISP), 66% ethyl alcohol, sodium hypochlorite (NaClO), and benzalkonium chloride (BKC) have been proven to lower the presence of bacteria on stethoscopes (Figure 2) [61].

A randomised trial by Johnson *et al.* (2023) showed that the use of alcohol-based hand disinfectants (ABHR, alcohol-based hand rub) significantly reduced stethoscope contamination during routine use [62]. Mehta *et al.* (2010) evaluated the effectiveness of ABHR containing 62% ethanol compared to wipes soaked in 70% isopropyl alcohol in disinfecting stethoscopes using 84 devices as examples. One-time cleaning of stethoscopes with ABHR reduced bacterial contamination by approximately 90% [63]. In contrast, the aim of the study by Lecat *et al.* (2009) was to determine the effectiveness of an ethanol-based cleanser (EBC) compared with isopropyl alcohol-soaked swabs in reducing bacterial contamination of stethoscope membranes. As a result, cleaning with EBC and isopropyl alcohol-soaked swabs significantly reduced bacterial counts by 92.8% and 92.5%, respectively, but none of the agents tested was statistically superior [64].

In contrast, a prospective, randomised, double-blind study by Parmar *et al.* compared the effectiveness of immediate and daily stethoscope cleaning using 66% ethanol [65]. The study included 100 stethoscopes whose contamination was assessed at 4 time points. The results showed that immediate cleaning and daily decontamination were associated with a significant reduction in the incidence of con-

tamination, to 28% and 25%, respectively. While, after 4 days without disinfection and 4 days with a single disinfection each day, respectively, the effectiveness of this process was lower [65].

Another method used to disinfect stethoscopes is ultraviolet C (UVC) light, which has a proven disinfecting capacity for stethoscope membranes [66–68]. For example, in a study by Rudhart *et al.* (2022), stethoscopes were treated with UVC light, and it was concluded that this decontamination method could provide an alternative means of decontaminating medical equipment, including stethoscopes [66]. A study by Messina *et al.* (2015) found a high efficacy of using ultraviolet (UV) light-emitting diodes (LEDs) to decontaminate stethoscope membranes against ($p < 0.01$) *E. faecalis*, *S. aureus*, *E. coli*, and *P. aeruginosa* bacteria. The method was equally effective against all bacterial species tested ($p > 0.01$) [68].

According to the literature, several antimicrobial stethoscope covers have been developed to prevent surface contamination and cross-transmission of clinically relevant pathogens. As early as 1997, the US Patent Office granted a patent for a removable, disposable stethoscope cover of any geometric shape having a self-adhesive pad for removable attachment of the cover to the entire surface of the stethoscope diaphragm [69]. Overlays can have many modifications, including silver ion sputtering. A study by Wood *et al.* (2007) evaluated the utility of antimicrobial stethoscope covers infused with silver ions on a group of 74 stethoscopes. The study did not yield the expected results; on the contrary, the presence of a stethoscope cover was associated with higher colony counts ($p < 0.001$) [70]. A study by Milamet *et al.* (2001) tested the antimicrobial efficacy of textile stethoscope covers [71]. Twenty-two overlays collected over a 3-week period were evaluated. The study showed that these overlays are a potential problem in controlling stethoscope contamination due to improper use [71]. In contrast, a study by Nazari-Shafti *et al.* (2023) showed that disposable Stethoglove caps (SC, Stethoglove GmbH, Hamburg, Germany) can be safely and effectively used as a stethoscope cover while allowing the acoustic quality of auscultation to be maintained [72]. Sarih *et al.* (2022) evaluated the antimicrobial activity of natural rubber (NR) latex films modified with different types of antimicrobial agents such as mangosteen peel powder (MPP), zinc oxide nanoparticles (ZnO NP), and povidone-iodine (PVP-I). The highest antimicrobial activity was obtained when ZnO NP was added [73].

Another strategy tested was to manufacture the stethoscope components most commonly subject to contamination from antimicrobial copper. According to a study by Schmidt *et al.* (2017), stethoscopes whose diaphragm, binaural tube, and the 2 ear tubes were made of antimicrobial copper alloys (AMCus) were less contaminated than their control counterparts [74]. In

another study, doctors and resident physicians and paediatric nurses alternated using a control stethoscope and a copper stethoscope for 1 week. Based on the results, significantly lower bacterial concentrations were found on the copper stethoscopes than on the control stethoscopes [75].

A 1 : 100 hypochlorite solution (500–600 ppm free chlorine) should be used to disinfect a stethoscope visibly contaminated with blood (e.g. in a haemodialysis centre) [76]. According to the EPA, medical devices must be treated for the appropriate minimum contact time, which is 10 minutes for most registered disinfectants [77]. On the other hand, the efficacy of these agents against vegetative forms of microorganisms (e.g. *Acinetobacter* spp., *E. coli*, *K. pneumoniae*, MRSA, *P. aeruginosa*, and vancomycin-resistant enterococci) has been experimentally proven against exposure times of 1 min [68, 78, 79].

For stethoscope disinfection processes to be effective, users should rigorously follow the recommendations in the available documents as well as the instructions on product labels. The possible side effects on the stethoscope of the disinfection process itself as well as of the disinfectant with prolonged use should be taken into account [57].

Stethoscope pathogens' "tolerance" to disinfectants used in health care

The widespread use of biocides over the years has been closely linked to the development of resistance to these chemicals among bacteria [80]. Classed as biocides, disinfectants are considered to be non-selective in their action on microbial cells, due to the multiplicity of mechanisms causing the toxic effect and the multiple points of entry. In addition, a characteristic feature of disinfectants is their generally broad spectrum of action on many types of microorganisms [81, 82]. However, not all biocides used for disinfection of stethoscopes show sufficient efficacy. For some disinfectants, the phenomenon of disinfectant resistance, referred to as 'reduced sensitivity' or 'increased tolerance', is not new, as the first reports on this subject date back to the 1960s [83].

A biocide-resistant microbial population is defined when the concentration of the biocide recommended for use by the manufacturers (*in-use concentration*), or the concentration that exhibits a lethal or static effect, does not eliminate the microorganism in question. Reduced bacterial susceptibility to biocides can be determined by either innate (*intrinsic resistance*) or acquired (*acquired resistance*) resistance mechanisms of the bacterial cell [80].

In practice, acquired resistance is most common and is the result of selection or adaptation of microorganisms to environmental conditions that are unfavourable to them. Acquired resistance can be produced by mutation or acquisition together with mobile

genetic elements such as plasmids, transposons, and phages [84–86]. The reason for reduced sensitivity to antimicrobial compounds is due to modifications in cell surface envelopes associated with selective permeability of the cytoplasmic membrane. Bacteria occurring as biofilms compared to bacteria occurring as single cells are more resistant [85]. Induced changes occur in response to bacterial exposure to subinhibitory concentrations of biocides, the action of which induces 2 primary mechanisms of resistance: overexpression of membrane proteins that form so-called *efflux* pumps (particularly in Gram-negative bacteria) and the production by bacteria of enzymes that directly inactivate biocide molecules [85].

Gram-negative bacteria have a lower sensitivity to the antimicrobial effect of biocides compared to Gram-positive bacteria [87]. In Gram-negative bacteria, the penetration of biocides (e.g. *quaternary ammonium* salts [QACs]) is hindered by an impermeable barrier formed by an outer membrane rich in LPS and numerous outer membrane proteins (OMPs). In contrast, the cell wall of Gram-positive bacteria is readily permeable to biocides [87]. Bacteria of the genus *Mycobacterium* show a natural reduced sensitivity to a wide range of disinfectants due to the high lipid content of the cell wall [85]. It is also important to bear in mind the natural resistance of bacterial spores (spores) to the physical and chemical effects of disinfectants [85]. The few compounds with sporicidal activity include aldehydes, ethylene oxide, and oxidising compounds. Bacterial spores remain insensitive to a number of biocides including alcohols, phenol, QACs, and organic mercury compounds toxic to vegetative forms of bacterial cells [85].

Acquisition of resistance to biocides as a result of cross-resistance is also a very dangerous phenomenon [88]. Cross-resistance is characterised by the total or partial insensitivity of microorganisms to groups of preparations belonging to the same or related chemical class, whose active substance is a compound with the same or similar chemical structure [89–92]. For example, in a study by Morante *et al.* (2021) the phenomenon of cross-resistance was demonstrated in *K. pneumoniae* isolates that showed reduced sensitivity to these biocides after exposure to chlorhexidine (CHG) and isopropanol (ISP), and at the same time, these isolates showed reduced sensitivity to trimethoprim with sulfamethoxazole (TMP/SMX) [89]. CHG and ISP are the 2 main disinfectants used in healthcare facilities, whose use increased significantly during the COVID-19 pandemic [89]. Wu *et al.* (2016) observed the phenomenon of cross-resistance in clinical isolates of *S. aureus*, which showed reduced sensitivity to various antibiotics and chlorhexidine (CHX) after exposure to tetracycline [90]. In contrast, a study by Mc Cay *et al.* (2010) showed that the mechanisms that determine *P. aeruginosa* resistance to benzalkoni-

um chloride resulted in the tested strain also proving insensitive to ciprofloxacin and novobiocin [91].

Summary

Despite advancements in civilisation, science, and technology, using a stethoscope for examination remains the most accessible, quickest, and cheapest method for initially diagnosing many diseases and their symptoms [1, 6, 93]. In many situations (e.g. war), the stethoscope may be the only support available to the physician in making a diagnosis [93, 94]. An additional advantage of stethoscopes is that they are a mainstay in the training of medical students and other health professions. Technological advances have contributed to the improvement of existing stethoscopes and the development of ever newer designs of these diagnostic tools. For example, in Poland alone, the number of stethoscopes filed with the Polish Patent Office between 1931 and 2023 was 141 (www.uprp.pl) [95].

The stethoscope is acknowledged as a medical device, and consequently its use and decontamination are subject to regulation. In light of the globally increasing threat of newly emerging infectious diseases and multidrug-resistant microorganisms, a properly performed stethoscope disinfection process is essential to guarantee the safety of both healthcare professionals and patients [57]. The user of a stethoscope should be aware of the obligation to clean this device regularly with appropriate disinfectants, but there are no clear algorithms for doing so. Furthermore, the user should be aware of the risks associated with improper or negligent disinfection of the stethoscope.

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References

- Adhikari S, Adhikaree N, Paudel KP, Nepal R, Poudel B, Giri S, Khadka S, Khawas S, Sapkota S, Regmi RS, Rijal KR. Bacterial assessment of stethoscopes used by healthcare workers at a Tertiary Care Government Hospital in Bharatpur, Nepal. *Diseases*. 2023; 11: 55.
- Donoso FA, Arriagada SD, René Théophile Hyacinthe La-ënnec (1781-1826). Two hundred years of the stethoscope. A brief overview. *Arch Argent Pediatr*. 2020; 118: e444-e448.
- Alali SA, Shrestha E, Kansakar AR, Parekh A, Dadkhah S, Peacock WF. Community hospital stethoscope cleaning practices and contamination rates. *Am J Infect Control*. 2020; 48: 1365-1369.
- Seah JJ, Zhao J, Wang DY, Lee HP. Review on the advancements of stethoscope types in chest auscultation. *Diagnos-tics*. 2023; 13: 1545.
- Choudry M, Stead TS, Mangal RK. The history and evolution of the stethoscope. *Cureus*. 2022; 14: e28171.
- Bishop PJ. Evolution of the stethoscope! *J R Soc Med*. 1980; 73: 448-456.
- Swarup S, Makaryus AN. Digital stethoscope: technology update. *Medical devices: evidence and research. Med De-vices (Auckl)*. 2018; 11: 29-36.
- Dunn PM. Adolphe Pinard (1844–1934) of Paris and intrauterine paediatric care. *Arch Dis Child Fetal Neonatal Ed*. 2006; 91: F231-F232.
- Leng S, San Tan R, Chuan Chai KT, Wang C, Ghista D, Zhong L. The electronic stethoscope. *Biomed Eng On-line*. 2015; 14: 66.
- Pavlosky A, Glauche J, Chambers S, Al-Alawi M, Yaney K, Loubani T. Validation of an effective, low cost, Free/open access 3D-printed stethoscope. *PLoS One*. 2018; 13: e0193087.
- Kim Y, Hyon YK, Woo SD, Lee S, Lee SI, Ha T, Chung C. Evolution of the stethoscope: advances with the adoption of machine learning and development of wearable devices. *Tuberc Respir Dis (Seoul)*. 2023; 86: 251-263.
- Regulation (EU) 2017/745 of the European parliament and of the council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC, Melvin 2022, Nüssler 2023.
- The ISO 13485/14971/14969 – Medical Devices Package provides regulatory requirements for quality management medical device systems and incorporating and maintaining a risk management system associated with the use of medical devices.
- EUDAMED (European Database on Medical Devices) operating since 26 May 2022, [https://ec.europa.eu/tools/eudamed].
- Aumann HM, Emanetoglu NW. Stethoscope with digital frequency translation for improved audibility. *Healthc Technol Lett*. 2019; 6: 143-146.
- Carmo GAL, Mandil A, Nascimento BR, Arantes BD, Bit-tencourt JC, Falqueto EB, Ribeiro AL. Can we measure the ankle-brachial index using only a stethoscope? A pilot study. *Fam Pract*. 2009; 26: 22-26.
- Frauenrath T, Hezel F, Heinrichs U, Kozerke S, Utting JF, Kob M, Butenweg Ch, Boesiger P, Niendorf T. Feasibility of cardiac gating free of interference with electro-magnetic fields at 1.5 Tesla, 3.0 Tesla and 7.0 Tesla using an MR-stethoscope. *Invest Radiol*. 2009; 44: 539-547.
- Makaryus AN, Makaryus JN, Figgatt A, Mulholland D, Kushner H, Semmlow JL, Mieres J, Taylor AJ. Utility of an advanced digital electronic stethoscope in the diagnosis of coronary artery disease compared with coronary computed tomographic angiography. *Am J Cardiol*. 2013; 111: 786-792.
- Warrington SJ, Beeson MS, Fire FL. Are simulation stethoscopes a useful adjunct for emergency residents' training on high-fidelity mannequins? *West J Emerg Med*. 2013; 14: 275-277.
- Kelmenson DA, Heath JK, Ball SA, Kaafarani HMA, Baker EM, Yeh DD, Bittner EA, Eikermann M, Lee J. Prototype electronic stethoscope vs. conventional stethoscope for auscultation of heart sounds. *J Med Eng Technol*. 2014; 38: 307-310.
- Portnoy JM, Waller M, De Lurgio S, Dinakar C. Telemedicine is as effective as in-person visits for patients with asthma. *Ann Allergy Asthma Immunol*. 2016; 117: 241-245.
- Kevat A, Kalirajah A, Roseby R. Artificial intelligence accuracy in detecting pathological breath sounds in children using digital stethoscopes. *Respir Res*. 2020; 21: 253.
- Ali F, Hasan B, Ahmad H, Zahra Hoodbhoy Z, Zainab Bhuriwala Z, Hanif M, Ansari SU, Chowdhury D. Detection of subclinical rheumatic heart disease in children using a deep learning algorithm on digital stethoscope: a study protocol. *BMJ Open*. 2021; 11: e044070.
- Yang C, Zhang W, Pang Z, Zhang J, Zou D, Zhang X, Guo S, Wan J, Wang K, Pang W. A low-cost, ear-contactless electronic stethoscope powered by raspberry Pi for Auscultation of patients with COVID-19: prototype development and feasibility study. *JMIR Med Inform*. 2021; 9: e22753.
- E-stethoscope. The program regarding the use of e-stethoscopes in telemedicine was introduced on the basis of the regulation of the Minister of Health of January 31, 2022 on the pilot program for the use of electronic stethoscopes in primary health care by beneficiaries infected with the SARS-CoV-2 virus. The program will be implemented in three stages (qualification of primary health care facilities for the program, provision of services using electronic stethoscopes and evaluation of the pilot program), [http://gov.pl/web/estetoskop].
- Malik AN, Rowland J, Haber BD, Thom S, Jackson B, Volk B, Ehrman RR. The use of handheld ultrasound devices in emergency medicine. *Curr Emerg Hosp Med Rep*. 2021; 9: 73-81.
- Vignon P. Portable echocardiographs: useful or futile? *Arch Mal Coeur Vaiss*. 2003; 96: 1202-1209.
- Kalagara H, Coker B, Gerstein NS, Kukreja P, Deriy L, Pierce A, Townsley MM. Point-of-care ultrasound (POCUS) for the cardiothoracic anesthesiologist. *J Cardiothorac Vasc Anesth*. 2022; 36: 1132-1147.
- McLeod P, Beck S. Update on echocardiography: do we still need a stethoscope? *Intern Med J*. 2022; 52: 30-36.
- Shepherd J, Mukthapuram S, Kim JH. Neonatal POCUS: embracing our modern day "stethoscope". *Semin Fetal Neonatal Med*. 2022; 27: 101394.
- Oluku J, Stag A, Cheema KS, El-Raheb K, Beese R. The role of point of care ultrasound (PoCUS) in orthopaedic emergency diagnostics. *Cureus*. 2021; 13: e13046.
- Allocca M, Furfaro F, Fiorino G, Peyrin-Biroulet L, Danese S. Point-of-care ultrasound in inflammatory bowel disease. *J Crohns Colitis*. 2021; 15: 143-151.
- Lavi A, Tzemah S, Hussein A, Bishara I, Shcherbakov N, Zelichenko G, Mashiah A, Gross M, Cherbinski L, Neman Z, Cohen. M. A urologic stethoscope? Urologist performed sonography using a pocket-size ultrasound device in the point-of-care setting. *Int Urol Nephrol*. 2017; 49: 1513-1518.

34. Osterwalder J. COVID-19 - more lung pocus and sparing use of stethoscope, chest X-ray and lung CT. *Praxis* (Bern 1994). 2020; 109: 583-591.
35. Stallone A, Ciccone A, Materassi M. New insights and best practices for the successful use of empirical mode decomposition, iterative filtering and derived algorithms. *Sci Rep*. 2020; 10: 15161.
36. Patel RS, Schwarz J, Danesh V, Einhorn A, Bello D. Clinical Performance of the heartbuds, an electronic smartphone listening device, compared to FDA approved class I and class II stethoscopes. *J Mob Technol Med*. 2016; 5: 45-51.
37. Thiagarajaa SR, Dantua R, Shresthaa PL, Chitnis A, Thompsona MA, Anumandlaa PT, Sarmac T, Dantu S. A novel heart-mobile interface for detection and classification of heart sounds. *Biomed Signal Process Control*. 2018; 45: 313-324.
38. Boulee D, Kalra S, Alison Haddock A, Johnson TD, Peacock WF. Contemporary stethoscope cleaning practices: what we haven't learned in 150 years. *Am J Infect Control*. 2019; 47: 238-242.
39. Gerken A, Cavanagh S, Winner HI. Infection hazard from stethoscopes in hospital. *Lancet*. 1972; 299: 1214-1215.
40. Mangi RJ, Andriole VT. Contaminated stethoscopes: a potential source of nosocomial infections. *Yale J Biol Med*. 1972; 45: 600-604.
41. Talaga-Ćwiertnia K, Ochońska D, Gajda M, Kowalczyk M, Palczewska M, Brzychczy-Włoch M. Stethoscopes or maybe "bacterioscopes" – is hand hygiene solely capable of preventing hospital-associated infections? *Pol J Microbiol*. 2023; 72: 79-91.
42. Jovanovic A, Paunovic K, Ercegovac M, Popovic D, Davidovic D. Personal stethoscope disinfection practices and bacterial contamination: a cross-sectional study at the University Hospital Emergency Department in Belgrade, Serbia. *Am J Infect Control*. 2024; 52: 176-182.
43. Ehondor OT, Ibadin EE. A microbiological assessment of stethoscopes used by clinicians in a tertiary hospital in Benin City, Nigeria. *Malays J Med Sci*. 2023; 30: 94-101.
44. Kamath N, Swaminathan R, Prabhu A. Bacterial and fungal flora on stethoscopes of healthcare workers in Navi Mumbai and effective use of 70% isopropyl alcohol as a disinfectant. *JMSCR (J Med Sci Clin Research)*. 2017; 05: 17672-17676.
45. Keri VC, Kumar A, Singh G, Xess I, Khan MA, Rastogi N, Sahu M, Wig N. Fungal carriage on healthcare workers' hands, clothing, stethoscopes and electronic devices during routine patient care: a study from a tertiary care center. *J Prev Med Hyg*. 2021; 62: E170-E173.
46. Peacock WF, Torriani F, Elliott LA, Killeen J, Kipper SB, Marinella M, Nunez D, Neath SX, Dadwal S. Stethoscope hygiene, workflow, and patient safety: the crux of healthcare associated infections. *Int J Health Policy Plann*. 2023; 2: 30-35.
47. Rafa E, Wałaszczek MZ, Wałaszczek MJ, Domański A, Różańska A. The incidence of healthcare-associated infections, their clinical forms, and microbiological agents in intensive care units in southern Poland in a multicentre study from 2016 to 2019. *Int J Environ Res Public Health*. 2021; 18: 2238.
48. Lee R, Choi SM, Jo SJ, Han S, Park YJ, Choi MA, Kong BK. A quasi-experimental study on stethoscopes contamination with multidrug-resistant bacteria: Its role as a vehicle of transmission. *PLoS One*. 2021; 16: e0250455.
49. Millán-Lou M, López C, Bueno J, Pérez-Laguna V, Laprestac C, Fuertes ME, Rite S, Santiago M, Romoa M, Samper S, Cebollada A, Oteo-Iglesias J, Rezusta A. Successful control of *Serratia marcescens* outbreak in a neonatal unit of a tertiary-care hospital in Spain. *Enferm Infecc Microbiol Clin (Engl Ed)*. 2021; S0213-005X(21)00186-5.
50. Baeza-Trinidad R, Brito-Diaz AY, Mosquera-Lozano JD, Azcona-Gutierrez JM. Could the stethoscope be a SARS-CoV-2 vector? *Enferm Infecc Microbiol Clin (Engl Ed)*. 2022; 40: 522-523.
51. Vasudevan RS, Thani KB, Aljawder D, Maisel S, Maisel AS. The stethoscope: a potential vector for COVID-19? *Eur Heart J*. 2020; 41: 3393-3395.
52. Patel L, Gandhi D, Beddow D. Controversies on the stethoscope during COVID-19: a necessary tool or an unnecessary evil? *Am J Med Sci*. 2021; 361: 278-280.
53. Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *J Hosp Infect*. 2020; 104: 246-251.
54. Zhuge Y, Rong L, Ye L, Liu J, Su L, Zhang Z, Wang J, Zhang Z. The value of the wireless stethoscope in patients with COVID-19 infection in a makeshift hospital. *BioMedical Engineering OnLine*. 2023; 22: 71.
55. Kaimakamis E, Kotoulas S, Tzimou M, Karachristos C, Giannaki C, Kilintzis V, Stefanopoulos L, Chatzis E, Beredimas N, Rocha B, Pessoa D, Paiva RP, Maglaveras N, Bitzani M. Back to the future: the novel art of digital auscultation applied in a prospective observational study of critically ill COVID-19 patients. *Pneumonia (Nathan)*. 2024; 16: 9.
56. Lella KK, Jagadeesh MS, Alphonse PJA. Artificial intelligence-based framework to identify the abnormalities in the COVID-19 disease and other common respiratory diseases from digital stethoscope data using deep CNN. *Health Inf Sci Syst*. 2024; 12: 22.
57. Rowan NJ, Kremer T, McDonnell G. A review of Spaulding's classification system for effective cleaning, disinfection and sterilization of reusable medical devices: viewed through a modern-day lens that will inform and enable future sustainability. *Sci Total Environ*. 2023; 878: 162976.
58. Rutala WA, Weber DJ, and the Healthcare Infection Control Practices Advisory Committee (HICPAC). Guideline for disinfection and sterilization in healthcare facilities, 2008. Centers for Disease Control and Prevention website. <https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf>. Updated May 2019. Accessed March 22, 2021.
59. N 14885:2022/AC:2023 – Chemical disinfectants and antiseptics – Application of European Standards for chemical disinfectants and antiseptics [<https://standards.iteh.ai/>].
60. Anonymous. Memorandum of understanding between the Food and Drug Administration, Public Health Service, and the Environmental Protection Agency, 1993.
61. Napolitani M, Bezzini D, Moirano F, Bedogni C, Messina G. Methods of disinfecting stethoscopes: systematic review. *Int J Environ Res Public Health*. 2020; 17: 1856.
62. Johnson AA, Warren BG, Anderson DJ, Johnson MD, Gamez I, Smith BA. Impact of alcohol-based hand-rub disinfection on bacterial bioburden on stethoscopes in a real-world clinical setting. *Infect Control Hosp Epidemiol*. 2023; 44: 1029-1031.
63. Mehta AK, MD, Halvosa JS, Gould CV, Steinberg JP. Efficacy of alcohol-based hand rubs in the disinfection of stethoscopes. *Infect Control Hosp Epidemiol*. 2010; 31: 870-872.
64. Lecat P, Cropp E, BS, McCord G, Haller NA. Ethanol-based cleanser versus isopropyl alcohol to decontaminate stethoscopes. *Am J Infect Control*. 2009; 37: 241-243.
65. Parmar RC, Valvi CC, Sira P, Kamat JR. A prospective, randomised, double-blind study of comparative efficacy of immediate versus daily cleaning of stethoscope using 66% ethyl alcohol. *Indian J Med Sci*. 2004; 58: 423-430.

66. Rudhart SA, Gunther F, Dapper LI, Gehrt F, Stuck BA, Hoch S. Analysis of bacterial contamination and the effectiveness of UV light-based reprocessing of everyday medical devices. *PLoS One*. 2022; 17: e0268863.
67. Messina G, Fattorini M, Nante N, Rosadini D, Serafini A, Tani M, Cevenini G. Time effectiveness of ultraviolet C light (UVC) emitted by light emitting diodes (LEDs) in reducing stethoscope contamination. *Int J Environ Res Public Health*. 2016; 13: 940.
68. Messina G, Burgassi S, Messina D, Montagnani V, Cevenini G. A new UV-LED device for automatic disinfection of stethoscope membranes. *Am J Infect Control*. 2015; 43: e61-e66.
69. United States Patent, Wurzbarger Isaac, Patent Number: 45, Date of Patent: 5,686,706 Nov. 11, 1997, Assignee: M&W Medical Supplies LLC. Monsey, NY.
70. Wood MW, Lund RC, Stevenson KB. Bacterial contamination of stethoscopes with antimicrobial diaphragm covers. *Am J Infect Control*. 2007; 35: 263-266.
71. Milam MW, Hall M, Pringle T, Buchanan K. Bacterial contamination of fabric stethoscope covers: the velvet-eaten rabbit of health care? *Infect Control Hosp Epidemiol*. 2001; 22: 653-655.
72. Nazari-Shafti TZ, Meyborg H, Iske J, Schloss M, Seeber F, Friedrich A, Exarchos V, Richter A, Falk V, Emmert MY. A clinical study to evaluate the safe and effective use of a new, single use stethoscope cover to enable reduction in pathogen transmission during auscultation. *Front Med*. 2023; 10: 1179145.
73. Sarih NM, Gwee K, Maher S, Rashid AA. Natural rubber (NR) latex films with antimicrobial properties for stethoscope diaphragm covers. *Materials*. 2022; 15: 3433.
74. Schmidt MG, Tuuri RE, Dharsee A, Attaway HH, Fairey SE, Borg KT, Salgado CD, Hirsch BE. Antimicrobial copper alloys decreased bacteria on stethoscope surfaces. *Am J Infect Control*. 2017; 45: 642-647.
75. Arendsen LP, Thakar R, Sultana AH. The use of copper as an antimicrobial agent in health care, including obstetrics and gynecology. *Clin Microbiol Rev*. 2019; 32: e00125-18.
76. Centers for Disease Control (CDC). Recommendations for preventing transmission of infections among chronic hemodialysis patients. *Morb Mortal Wkly Rep Recomm Rep*. 2001; 50: 1-43.
77. Centers for Infection Control and Prevention. CDC 24/7. Factors Affecting the Efficacy of Disinfection and Sterilization. Guideline for Disinfection and Sterilization in Healthcare Facilities 2008.
78. Agam B, Sarath RS, Bhavna DB, Kajal G, Shashank P. To assess the stethoscope cleaning practices, microbial load and efficacy of cleaning stethoscopes with alcohol-based disinfectant in a tertiary care hospital. *J Infect Prevent*. 2019; 20: 46-50.
79. Zachary KC, Bayne PS, Morrison VJ, Ford DS, Silver LCh, Hooper DC. Contamination of gowns, gloves, and stethoscopes with vancomycin-resistant enterococci. *Infect Control Hosp Epidemiol*. 2001; 22: 560-564.
80. Russell AD. Biocide use and antibiotic resistance: the relevance of laboratory findings to clinical and environmental situations. *Lancet Infect Dis*. 2003; 3: 794-803.
81. Gerba CP, Rusin P. Relationship between the use of anti-septics/disinfectants and the development of antimicrobial resistance. In: Rutala WA, ed. *Disinfection, sterilization and antisepsis: principles and practices in healthcare facilities*. Washington, DC: Associat Prof Infect Control Epidemiol 2001: 187-194.
82. Russell AD. Bacterial resistance to disinfectants: present knowledge and future problems. *J Hosp Infect*. 1998; 43: S57-S68.
83. Krzywicka H, Janowska J. Oporność bakterii na działanie niektórych środków dezynfekcyjnych. *Roczn. PZH* 1981; XXXII: 371-377.
84. McDonnell G, Russell AD. Antiseptics and disinfectants: activity, action, and resistance. *Clin Microbiol Rev*. 1999; 12: 147-179.
85. Russell AD. Mechanisms of bacterial resistance to biocides. *Int Biodeterior Biodegrad*. 1995; 36: 247-265.
86. Maillard JY, Pascoe M. Disinfectants and antiseptics: mechanisms of action and resistance. *Nat Rev Microbiol*. 2024; 22: 4-17.
87. Stickler DJ. Bacterial resistance. In: Russell, Hugo and Ayliffe's Principles and Practice of Disinfection, Preservation and Sterilization. 4th Edition. Fraise AP, Lambert PA, Maillard JY. Blackwell Publishing, Oxford 2004; 154-216.
88. Abbood HM, Hijazi K, Gould IM. Chlorhexidine resistance or cross-resistance, that is the question. *Antibiotics (Basel)*. 2023; 12: 798.
89. Morante J, Quispe AM, Ymaña B, Moya-Salazar J, Luque N, Soza G, Chirinos MR, Pons MJ. Tolerance to disinfectants (chlorhexidine and isopropanol) and its association with antibiotic resistance in clinically-related *Klebsiella pneumoniae* isolates. *Pathog Glob Health*. 2021, 115: 53-60.
90. Wu D, Lu R, Chen Y, Qiu J, Deng C, Qiang Tan Q. Study of cross-resistance mediated by antibiotics, chlorhexidine and *Rhizoma coptidis* in *Staphylococcus aureus*. *J Glob Antimicrob Resist*. 2016; 7: 61-66.
91. Mc Cay PH, Alain A. Ocampo-Sosa AA, Fleming GTA. Effect of subinhibitory concentrations of benzalkonium chloride on the competitiveness of *Pseudomonas aeruginosa* grown in continuous culture. *Microbiology*. 2010; 156: 30-38.
92. Braoudaki M, Hilton AC. Low level of cross-resistance between triclosan and antibiotics in *Escherichia coli* K-12 and *E. coli* O55 compared to *E. coli* O157. *FEMS Microbiol Lett*. 2004; 235: 305-309.
93. Blaufox MD. An ear to the chest: an illustrated history of the evolution of the stethoscope. *J R Soc Med*. 2002; 95: 626-627.
94. Fuster V. The stethoscope's prognosis very much alive and very necessary. *J Am Coll Cardiol*. 2016; 67: 1118-1119.
95. The Polish Patent Office (PPO) (access 2019-10-20) [www. uprp.pl].

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