Comparative Performance of High-End and Economical Stethoscopes in Automated Auscultation

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Comparative Performance of High-End and Economical Stethoscopes in Automated Auscultation

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Abstract: Blood pressure measurement is a vital procedure in assessing cardiovascular health. Automated auscultation is being developed to detect Korotkoff sounds that determine systolic and diastolic blood pressure. The quality of the stethoscopes influences the accuracy of this development. This study aims to evaluate and compare the performance of a high-end (Littmann) and an economical (ABN) stethoscope in detecting Korotkoff sounds for blood pressure measurements using the automatic auscultation method. The study used a mixed design, combining between-subject and within-subject approaches. This comparative experimental study involved 85 respondents with three repetitions of measurements, resulting in a total of 255 data for each stethoscope. The suitability of the measurements was evaluated based on the international accuracy standards AAMI/ANSI/ISO and BHS and analyzed using non-parametric statistical test. The results showed that ABN had an average systolic measurement error of 4.4 ± 4.8 mmHg with a percentage of agreement of 75%, 91%, and 95% at thresholds 5, 10, and 15 mmHg. Meanwhile, Littmann showed a lower average systolic error of 3.4 ± 3.5 mmHg with an agreement of 80%, 96%, and 98%. For diastolic measurements, both stethoscopes showed similar mean errors of 4.1 ± 4.1 mmHg. Paired analysis revealed a significant difference in manual systolic pressure, while diastolic measurements showed no significant difference between ABN and Littmann. Overall, although both stethoscopes met the established accuracy standards, Littmann was superior in consistency and accuracy of systolic measurements, which are important in evaluating Korotkoff sounds in blood pressure measurements using automatic auscultation. However, ABN can still be considered a reliable alternative, particularly for diastolic pressure measurement.

Keywords: automatic auscultation; blood pressure measurement; Korotkoff sound; stethoscope

1. Introduction

Blood pressure is an essential indicator used to assess cardiovascular function and monitor numerous medical problems, such as hypertension, heart disease, and vascular disorders[1)]. Hypertension is one of the primary causes of worldwide death, accounting for around 9.4 million fatalities per year, with 1.7 million deaths due to cardiovascular disease[2)]. In Indonesia, the prevalence of hypertension reached 34.5 percent in 2018, emphasizing the importance of good management and early detection[3)]. Accurate blood pressure measurement is an important step in ensuring proper diagnosis and optimal clinical management. Blood pressure measurement is one of the most popular and necessary medical procedures for evaluating the condition of the heart. Proper health measurement also helps to prevent disease in the pandemic period[4)].

The history of the development of blood pressure measurement techniques has evolved rapidly since the invasive methods[5)]. Beginning with Riva-Rocci's introduction of the cuff-based sphygmomanometer in 1896, and further supported by Nicolai Korotkoff's auscultation technique in 1905, this method has established itself as the gold standard in manual blood pressure measurement[6)]. Manual auscultation has historically been the gold standard for blood pressure measurement due to its ability

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to detect systolic and diastolic pressure through Korotkoff sound directly[7,8]. However, this method has limitations, such as dependence on operator skills, which can cause variations in results. Therefore, automation technology has begun to be developed to improve the objectivity, efficiency, and reliability of blood pressure measurements[9].

Automatic auscultation-based measuring is a contemporary method that uses sensor technology and algorithms to identify Korotkoff sounds more consistently[10]. This system's accuracy is heavily dependent on the stethoscope's ability to catch Korotkoff sounds without distortion or ambient interference[11].

The stethoscope plays an important role in the automated system, as a link between Korotkoff sounds and the measurement process[12]. Several studies mentioned in the reviewed papers discuss automatic auscultation tools but have not focused on the type of stethoscope[13]. As a result, this study attempts to review numerous journals that use commercial stethoscopes in studies on automatic auscultation. A literature review was conducted using the Web of Knowledge database, focusing on publications containing specific keyword combinations: (automated OR automatic) AND (blood pressure OR Korotkoff sound OR auscultation blood pressure OR auscultatory blood pressure) AND (measurement OR detection). There were 29 studies, shown in Figure 1, that mentioned the type of stethoscope on the automatic auscultation device.

Based on existing research data that shown in Table 1, there are 25 studies that use stethoscope in process of automatic blood pressure measurement based on Korotkoff sound, while 4 other studies use non stethoscope devices. Of the 25 studies the commercial stethoscopes used are Littmann, ABN, Not-stated stethoscopes, and built-in system stethoscopes (TeleMedCare[36] and digital sphygmocorder-II (DS-II)[37]). Non stethoscope studies use technologies such as PVDF-Film[38,39], piezoelectric kind microphone (TSD 108, BIOPAC Co. Ltd., USA)[40], and narrowband microphones[41].

The majority of the highest presentations use Littmann stethoscopes, indicating the dominance in various automatic auscultation studies. Littmann is also widely recognized as a global leader in the stethoscope market[42],

Table 1: Summary of sensing devices used in Korotkoff sound-based automatic blood pressure measurement studies

Reference	Analysis Technique	Sound Acquisition System
Sullivan, 2002[14]	Recording	Littmann
Allen, 2004[15]	Short-time Fourier Transform	Littmann
Hamidon, 2014[16]	time-frequency	Littmann
Lee, 2015[17]	audio and visual	Littmann
Wang, 2009[18]	visual analysis	Littmann
Macaulay, 2020[19]	Adjustable Blood Pressure System	Littmann
Menti, 2024[20]	KOROT P3 Accurate	Littmann
Fania, 2024[21]	KOROT P3 Accurate	Littmann
Ntineri, 2023[22]	proprietary algorithm	Littmann
Pratiwi, 2020[23]	Amplitude Parameter and Oscillation Beat	ABN
Naufal, 2020[24]	thresholding and frequency	ABN
Naufal, 2019[25]	sound pressure level	ABN
Pan, 2019[26]	Convolutional Neural Network (CNN)	Not-stated stethoscopes
Pan, 2017[27]	Convolutional Neural Network (CNN)	Not-stated stethoscopes
Pan, 2021[28]	Convolutional Neural Network (CNN)	Not-stated stethoscopes
Fan, 2019[12]	Convolutional Neural Network (CNN)	Not-stated stethoscopes
Goh, 2016[29]	thresholding of amplitude	Not-stated stethoscopes
Gomez, 1998[30]	power spectral density and energy	Not-stated stethoscopes
Saggio, 2015[31]	thresholding based on hearing ability	Not-stated stethoscopes
Chen, 2017[32]	visual analysis	Not-stated stethoscopes
Wolff, 2007[33]	HMM (Hidden Markov Model)	Not-stated stethoscopes
Wu, 2016[34]	Accutension	Not-stated stethoscopes
Celler, 2020[35]	GMM-HMM (Gaussian Mixture Model–Hidden Markov Model)	Not-stated stethoscopes
Sukor, 2012[36]	noise classification	built-in system
Hong, 2017[37]	sound pressure level and equal loudness contour	built-in system
Li, 2019[38]	thresholding the amplitude	PVDF-film
Li, 2016[39]	thresholding the amplitude	PVDF-film
Park, 2008[40]	PSD changes in each beat epoch (30-40 epochs)	piezoelectric type microphone
Sebald, 2002[41]	envelope detection and thresholding from amplitude	Direct to microphone

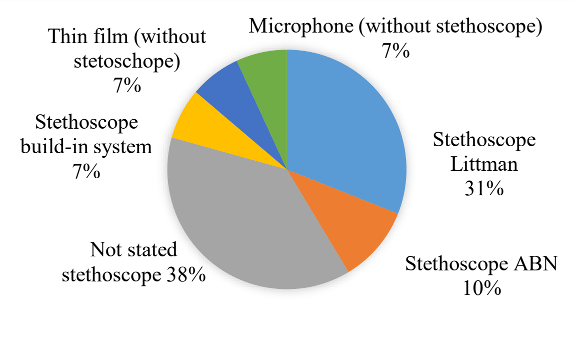


Fig. 1: Distribution of stethoscopes used for automatic blood pressure measurement

known for its superior acoustic sensitivity, ergonomic build, and advanced diaphragm technology[43]. However, their relatively high cost can be challenging, particularly for integration into low-cost automated auscultation systems[44]. For these reasons, the Littmann model is categorized as a high-end stethoscope, referring to devices with advanced acoustic features and premium pricing.

In comparison, ABN stethoscope has a limited presence in research and is locally market available at a more economical price[45]. Price comparison based on the Indonesian government procurement catalog shows that ABN stethoscopes are significantly more affordable than Littmann models—often by a factor of three to five[44,45]. However, their performance in automated blood pressure measurement systems has not been thoroughly evaluated. Accordingly, the ABN stethoscope is considered an economical stethoscope, representing devices with basic functionality and lower cost. This contrast makes Littmann and ABN ideal representatives of high-end and economical stethoscope categories, respectively.

Therefore, the main focus of this study is to compare two commercial stethoscopes (Littmann and ABN) using applicable standards and statistics to give recommendations for usage of automated auscultation equipment. Comparing these two stethoscopes addresses both technological diversity and real-world applicability. The inclusion of these two stethoscope models in this study aims to provide practical recommendations for future design of automated auscultation systems that balance performance and affordability, especially in developing healthcare environments.

2. Methods

As designed in previous research conducted[23], the hardware of this devices includes a microcomputer, pressure sensor, ADC, stethoscope, microphone, and driver, pumping system, LCD, and push button. This device captures and processes sound and pressure signals. The pressure sensor was calibrated with a calibrated aneroid sphygmomanometer. Sound signals are recorded using an earphone microphone connected to stethoscope tubing and linked via USB driver to Raspberry Pi. The illustration of system integration shows in Figure 2a.

The software system on the Raspberry Pi 3 Model B uses Python 3.9.2 and Thonny IDE to manage the recording and processing of data. The sound recorded with PyAudio and Wave at a 16 bit resolution and a sampling rate of 44.1 kHz. Recording lasts for 40-60 seconds, covering inflation up to 160 mmHg and deflation to 0 mmHg[2].

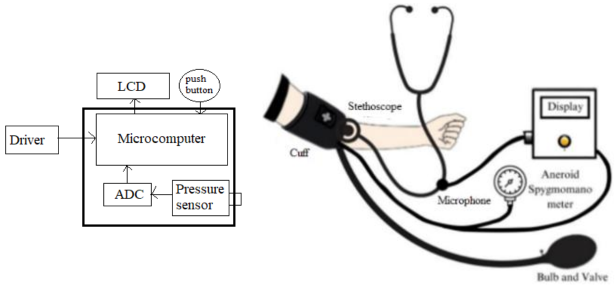
During deflation, the recorded sound signal is denoised and reduced in size. The sound signal is then thresholded, and the Korotkoff sound's peak is identified using the pressure oscillation beat. Furthermore, the timing of the first and last Korotkoff sounds is calculated and transformed into systolic and diastolic pressure readings.

This study used a quantitative method with a between-subject comparative design to compare the effectiveness of two commercial stethoscopes. The study population was individuals in the Research Center for Testing and Standard Technology Research (PRTPS) of the National Research and Innovation Agency (BRIN). The inclusion criteria were healthy male and female volunteers, with no history of stroke, metabolic disorders, or any other condition known to cause unstable blood pressure. The exclusion criteria included the presence of any acute or chronic illness, stroke or history of stroke, or metabolic disease.

To compare a high-end and an economical stethoscope model, the Littmann and ABN devices were selected based on their respective classifications described in the Introduction. The study sample consisted of 85 subjects for each stethoscope, selected using a purposive sampling technique. The total measurements obtained were 255 data per group after repeating the measurements at least three times. Although the study primarily used a between-subject design, some participants were assessed using both stethoscopes, making partial within-subject comparisons possible.

The data collection was process was carried out in two main stages. The first stage was preparation and providing information to participants regarding ethical clearance, purpose, procedures, benefits, and risks of the study. Participants who were willing to participate signed an informed consent and provided demographic data and health parameters, such as age, body mass index (BMI), and arm circumference. Participants were also informed that the confidentiality of the data in this study would be guaranteed and used in related research.

The second stage was blood pressure measurement, which was carried out according to standard protocols. The illustration is shown in Figure 2b. Participants were asked to sit in relaxed position with the arm supported at heart level. The cuff was wrapped around the upper arm, with the lower edge positioned approximately 2.5 cm above the antecubital fossa and the diaphragm of the stethoscope was placed directly over the brachial artery. The examiner conducted all measurement to listen to the Korotkoff



(a) (b)

Fig. 2: Automatic blood pressure device (a) and measurement setup (b) based on Korotkoff sound

sounds in parallel (no inter-tester variability). Each stethoscope was measured three times with a 30-60 second repetition interval to assess intra-tester consistency.

Validation of each stethoscope is done individually by comparing the estimated value of the tool with manual method using a calibrated aneroid sphygmomanometer. In accordance with AAMI/ANSI/ISO (American Association for the Advancement of Medical Instrumentation / American National Standards Institute / International Organization for Standardization) and BHS (British Society of Hypertension) guidelines, the validation of all non-invasive blood pressure measurement devices must be obtained against the manual auscultatory method, which is recognized as the clinical reference standard. The difference in error between the Littmann and ABN stethoscope is then compared.

The evaluation analysis was carried out referring to the standard protocols of AAMI/ANSI/ISO and BHS. The AAMI/ANSI/ISO protocol calculates the mean and standard deviation of the difference in blood pressure measurements, while BHS classifies the results based on percentage of measurements differences that meet the criteria of ≤ 5 mmHg, ≤ 10 mmHg, ≤ 15 mmHg[46]. The recommended results are those that can meet AAMI/ANSI/ISO requirements, with mean error and standard deviation at ≤ 5 mmHg and ≤ 8 mmHg, respectively, as well as BHS criteria of 50%, 75%, and 90%.

The analysis was also considered statistically to determine whether there was a significant difference between performance of the two stethoscopes in blood pressure measurement based on automated auscultation. In this study, non-parametric statistical tests were applied. The Mann-Whitney U test was used to compare independent groups (respondent characteristics and unpaired comparison between the ABN and Littmann stethoscope groups). Meanwhile, for paired comparisons (manual versus automatic and ABN versus Littmann within-subjects group), the Wilcoxon Signed-Rank test was employed. All tests were performed at a 95% confidence level, with p-values < 0.05 were considered statistically significant.

3. Results

3.1. Respondent data evaluation

An overview of the analysis of data collected from respondents is shown in Table 2. The number of respondents and experimental data meet the minimum criteria of AAMI/ANSI/ISO and BHS standard.

Respondents using the ABN stethoscope had a greater average age, BMI, and arm circumference than those using the Littmann stethoscope. Deflation rates in both groups are in the range of 6-7 mmHg/s. Littman showed a tendency for better consistency than ABN, especially in certain parameters such as age, Height, BMI, and deflation rate. It can be seen from the standard deviations of participant data.

The distribution of participant data in Figure 3 is presented through boxplots to visualize differences in blood pressure values and other characteristic. Comparison of data from respondents who used ABN and Littmann stethoscope shows differences in data distribution and variation in several categories. Stethoscope ABN had a wider range of data on age, weight, height, and arm circumference, with a slightly higher median, reflecting greater variation. Meanwhile, Littmann showed a more central data distribution with smaller variations in the categories of weight, BMI, arm circumference, and deflation rate, indicating better consistency. Overall, ABN data is more volatile than Littmann data, which is more steady and evenly distributed. This suggests that Littmann tends to produce more uniform measurements on certain parameters.

Table 2: Characteristics of ABN and Littmann respondent data.

Information	Description	Stethoscope	
		ABN	Littmann
Measurements	Participants	85	85
	Data	255	255
Gender	Woman	30	45
	Man	55	40
Age	Average	30.8±10.1	28.1±10.0
	Range	18–63	19-57
Weight (kg)	Average	66.0±12.8	61.8±13.5
	Range	46 – 100	40 - 100
Height (cm)	Average	164.8 ± 9.8	163.7±6.9
	Range	110 – 182	149 - 180
BMI (kg/m^2)	Average	24.32 ± 4.7	22.9 ± 4.2
	Range	17.6-52.1	13.9-33.4
Upper arms (cm)	Average	26.9 ± 3.2	25.7 ± 4.4
	Range	19.5 – 35	17 - 48
Arm (%)	Right	67	72
	Left	18	13
Def-Rate (mmHg/s)	Average	6.2 ± 1.5	6.9 ± 1.2
	Range	2.9 - 11.8	3.7 - 11.1

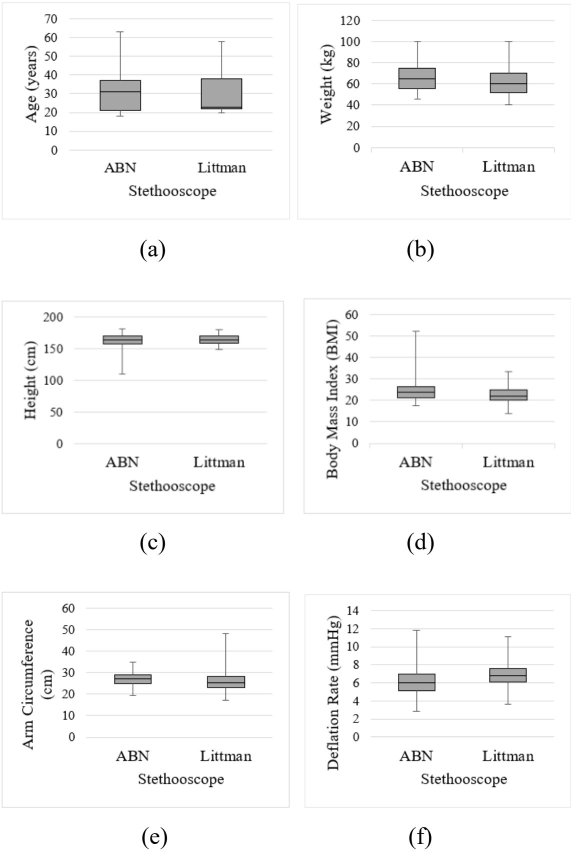


Fig. 3: Boxplot graph of ABN and Littmann respondent data characteristics (a) age (b) weight (c) height (d) body mass index (BMI) (e) arm circumference (f) deflation rate

Table 3: Results of the Mann–Whitney U test on the characteristics of respondent data

Age	Weight	Height	BMI	Arm	Def-Rate
0.195	0.020	0.232	0.036	0.026	0.000

The results of the independent comparison Mann-Whitney U test in Table 3 show significant differences between ABN and Littmann user data in the categories of weight, BMI, arm circumference, and deflation rate (p-value < 0.05). Meanwhile, in the categories of age and height, there are no significant differences (p-value > 0.05) indicating similarity in data distribution on these characteristics.

3.2. Comparison of Stethoscopes Performance for Automated Auscultation

The mean values and standard deviations of blood pressure measurement data for each stethoscope are shown in Table 4. These values are used to describe the distribution of blood pressure readings, not to evaluate against standards. The results of the analysis in Table 3 showed that the automatic methods on the Littmann stethoscope tended to produce higher systolic and diastolic blood pressure than manual method. In contrast, the automatic method with the ABN stethoscope produced higher systolic but lower diastolic values than the manual measurement.

Table 4: Mean and standard deviation of blood pressure measurements for all participants

Stethoscope	Method	Pressure	Mean ± Standard Deviation (mmHg)
ABN	Manual	Systolic	112.02 ± 15.67
		Diastolic	72.96 ± 14.81
	Automatic	Systolic	114.02 ± 16.81
		Diastolic	72.85 ± 15.69
Littmann	Manual	Systolic	105.93 ± 15.11
		Diastolic	69.16 ± 12.50
	Automatic	Systolic	107.33 ± 15.06
		Diastolic	71.22 ± 13.16

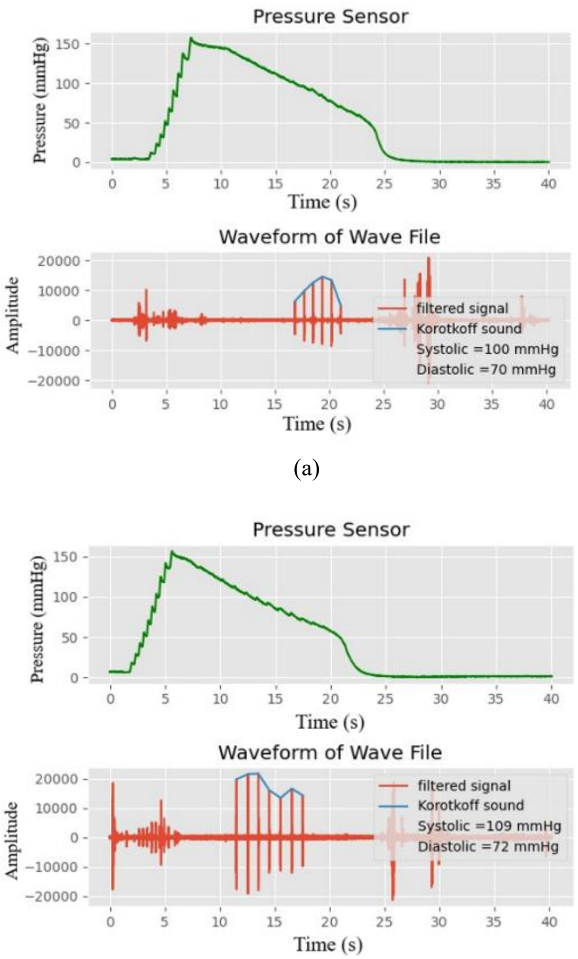
On the ABN stethoscope, there was an average difference of 2.00 mmHg for systolic and 0.11 mmHg for diastolic compared to the manual method. However, the automatic method showed a larger standard deviation, indicating higher measurement variation compared the manual method.

On the other hand, the Littmann stethoscope showed an average difference of 1.40 mmHg for systolic and 2.60 mmHg for diastolic compared to manual method, with almost the same standard deviation for systolic and slightly larger for diastolic. This shows that measurements using Littmann are more consistent than ABN especially in systolic.

The example of pressure signal and sound waveform graphs of the ABN and Littmann stethoscope in Figure 4 shows significant differences in the detection of Korotkoff sound during blood pressure measurement. In the ABN , the pressure signal has a smooth inflation and deflation pattern with lower Korotkoff sound amplitude, but less noise making it easier to identify the sound low noise environments. In contrast the Littmann produces higher Korotkoff sound amplitude with a longer and clearer detection range, reflecting superior acoustic sensitivity, although accompanied by more noise. In conclusion, the Littmann is superior in the sensitivity of Korotkoff sound detection, while the ABN is more suitable for environments requiring low-noise operation.

Evaluation of the performance of the high-end (Littmann) and economical (ABN) stethoscope in Table 5 based on AAMI/ANSI/ISO and BHS standard showed that both met the international validation criteria for systolic and diastolic blood pressure measurement. The Littmann had a lower mean error in systolic blood pressure measurement of 3.4 mmHg compared to the ABN at the 4.4 mmHg with a smaller standard deviation of 3.5 mmHg compared to 4.8 mmHg. In diastolic blood pressure measurement, the mean error and standard deviation for both stethoscopes were similar at 4.1 mmHg.

Based on BHS standards, in systolic blood pressure, the Littmann recorded 80% of measurements within 5 mmHg, 96% within 10 mmHg, and 98% within 15 mmHg, higher than the ABN which recorded 75%, 91%, and 95% within the same tolerance range. For diastolic pressure, both



(a)

(b)

Fig 4: Pressure signal and sound wave graphs using stethoscopes (a) ABN (b) Littmann

stethoscopes performed nearly equally at the 10 mmHg and 15 mmHg limits. However, at the 5mmHg tolerance limit, the Littmann showed a 78% advantage over the ABN at 77%. Overall, the Littmann showed a higher level of precision and consistency, especially in systolic pressure measurements, while both still met applicable international standards.

Statistical testing on systolic and diastolic pressure using ABN and Littmann stethoscopes are shown in Table 6, comparing manual and automated blood pressure measurements. For diastolic pressure of ABN, the p-value of 0.984 ($p \geq 0.05$) indicated no significant difference between the two measurement methods. However, significant difference was observed in in both systolic and diastolic values for the Littmann stethoscope, as well as for the systolic values of the ABN stethoscope ($p < 0.05$).

The results of Wilcoxon Signed-rank Test between ABN and Littmann for 32 paired subjects are shown in Table 7. For systolic pressure, a significant difference was observed in the manual measurement ($p = 0.047$), while automatic systolic pressure showed a marginal significance ($p = 0.055$). For diastolic pressure, no significant differences were found in manual ($p = 0.843$) and automatic ($p = 0.164$) measurements, except for the error in diastolic pressure, which was significantly different ($p = 0.002$).

In the unpaired group analysis (53 subjects per group), a Mann–Whitney U test (Table 8) showed highly significant differences between ABN and Littmann in both manual and automatic systolic ($p = 0.000$), as well as manual and automatic diastolic ($p = 0.000$ and $p = 0.007$, respectively). However, the error difference was only significant for systolic ($p = 0.012$), and not for diastolic ($p = 0.065$).

Table 5: Instrumentation evaluation results

Stethoscope	Pressure	AAMI (mmHg)		BHS (%)		
		Mean Error	SD Error	≤5 mmHg	≤10 mmHg	≤15 mmHg
Standard Limits		≤ 5	≤ 8	50	75	90
ABN	Sys	4.4	4.8	75	91	95
	Dia	4.1	4.1	77	94	98
Litt	Sys	3.4	3.5	80	96	98
	Dia	4.1	4.1	78	94	98

Figures 5 to 8 present the Bland–Altman and linear regression plots for systolic and diastolic blood pressure measurements using the ABN and Littmann stethoscopes. On the ABN stethoscope, the graph in Figure 5a (Bland–Altman) shows a lot of data outside the tolerance limits, especially in systolic measurements which show greater variation. The distribution of data on diastolic

Table 6: Wilcoxon signed-rank test between automated auscultation devices and manual for each stethoscope

Pressure	Wilcoxon Signed-rank Test (between Manual and Automatic)	
	ABN	Littmann
Systolic	0.000	0.000
Diastolic	0.984	0.000

Table 7: Wilcoxon Signed-rank Test between ABN and Littmann based on manual and automatic measurements paired analysis (N = 32 per group)

Pressure	Wilcoxon Signed-rank Test (between ABN and Littmann)		
	Manual	Automatic	Manual
Systolic	0.047	0.055	0.595
Diastolic	0.843	0.164	0.002

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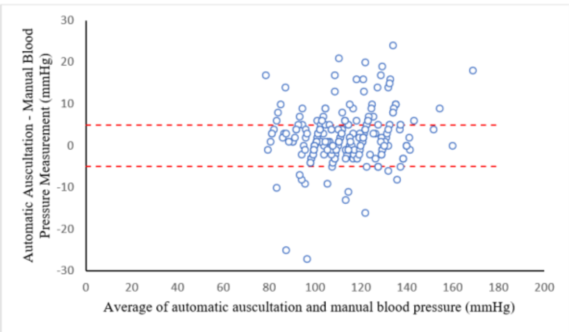
Table 8: Mann–Whitney U Test between ABN and Littmann based on manual and automatic measurements for unpaired analysis (N = 53 per group)

Pressure	Mann–Whitney U Test (between ABN and Littmann)		
	Manual	Automatic	Error
Systolic	0.000	0.000	0.012
Diastolic	0.000	0.007	0.065

measurements (Figure 6a) tends to be denser around the zero line than systolic, but there are still significant deviations, including several points outside the negative limits. This shows that the ABN has a greater variation in measurement results than the manual method, especially in systolic, making it less consistent to be used as the main method of blood pressure monitoring.

In contrast, the Bland-Altman graph in Figure 5b and 6b for Littmann shows better results. In systolic measurements, most data points are within the tolerance limit of ±5 mmHg, with data distribution more concentrated around the zero line. Diastolic measurements with Littmann also show a more compact and consistent data distribution pattern, with most points within the tolerance limits. Although there are some small deviations, the Littmann results still show smaller differences than manual.

The results of the linear regression analysis in Figure 7-8 showed that the ABN stethoscope had an R^2 value of 86% for both systolic and diastolic pressure, reflecting the



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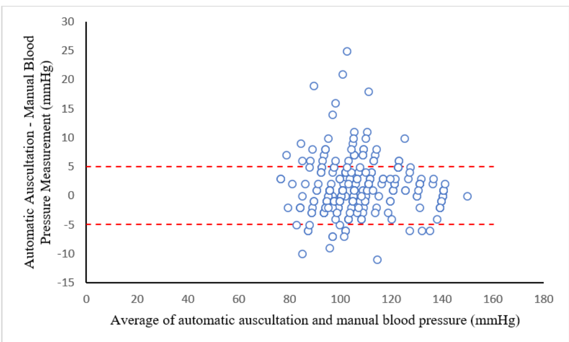
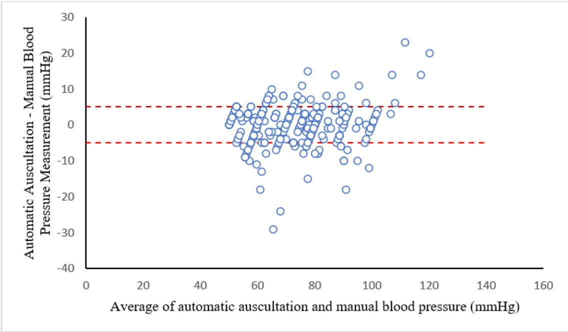
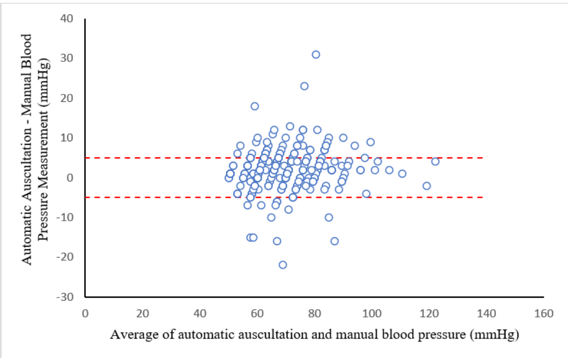


(b)

Fig 5: Bland-Altman plot for systolic blood pressure using (a) ABN and (b) Littmann



(a)



(b)

Fig 6: Bland-Altman plot for diastolic blood pressure using (a) ABN and (b) Littmann

model's ability to explain 86% of the data variation well. Meanwhile, the Littmann stethoscope showed superior performance in systolic pressure measurement with an R^2 value of 90%, meaning that Littmann was more accurate in predicting systolic pressure than ABN. However, for diastolic pressure, Littmann had an R^2 value of 83%, slightly lower than ABN.

4. Discussion

The development of autonomous auscultation devices is continuing, from hardware design to signal processing[13]. However, no one has discussed the effectiveness of the stethoscope. In fact, the employment of a stethoscope in this study is critical in capturing sound signals for transmission to the system as a whole. Littmann is the most popular type due to its high quality. However, their relatively high cost presents a barrier to integration into affordable automated systems. Redesigning or adapting a premium-grade stethoscope such as Littmann may significantly increase the total production cost, making it less suitable for large-scale or low-resource applications.

It is known in the literature review in Figure 1 that the ABN stethoscope is also used to design automatic auscultation hardware at a more affordable price. Nevertheless, its performance relative to the Littmann stethoscope has not been previously compared. In terms of material and thickness of the stethoscope tube, there are also differences between the two.

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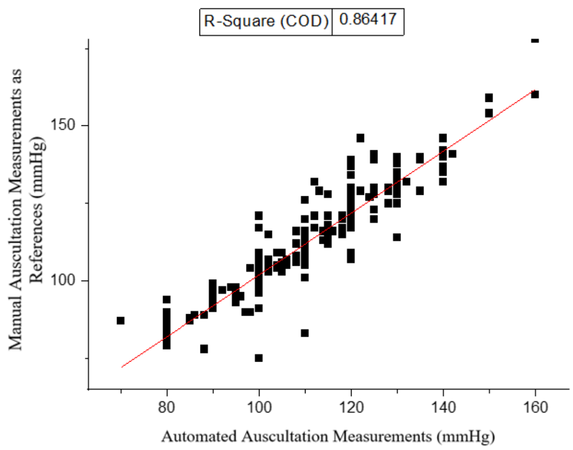
Comparison of the two commercial stethoscopes on this automatic auscultation device cannot be directly compared due to methodological limitations. If two stethoscopes are measured simultaneously, there will be two stethoscope heads on one arm at the same time. This will result in spatial variations in the brachial artery being measured. Because the Korotkoff sound is so weak, it causes a delay at one of the measurement points. Thus, each stethoscope's performance is evaluated separately against a reference (manual method).

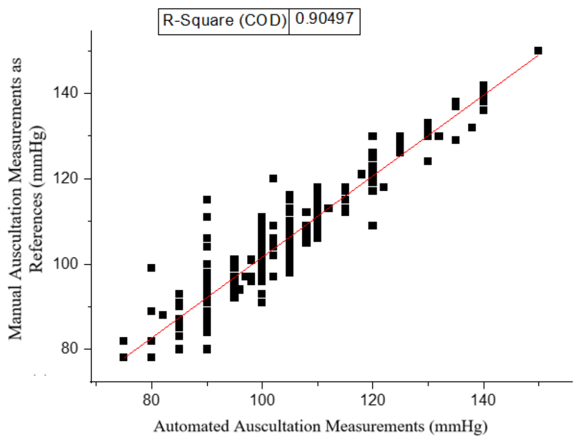
While this study primarily followed a between-subject design due to limited resources, available time, and measurement feasibility for each participant, a subset of participants (32 individuals) was assessed using both the ABN and Littmann stethoscopes. A full within-subject comparison was not applied to all participants due to potential physiological fluctuations (e.g., reactive hyperemia and anxiety) and increased participant burden. To minimize inter-group variability, both groups were matched by age range, gender distribution, and general health status, all measurements were conducted under the same environmental conditions and by the same trained operator using standardized procedures. As a result, the characteristics of participant data distribution must also be assessed in order to determine the similarities between the two measurement groups. Although baseline characteristics were matched and protocols standardized, future studies should consider a randomized crossover approach to eliminate this source of variability.

The evaluation of each stethoscope’s performance followed a single structured procedure consisting of multiple steps. The first step is to compare the two stethoscopes using statistical data such as the average and deviation of systolic and diastolic pressure, which are displayed in Table 4. Then, compare the Waveforms in Figure 4. Next, compare the standards (see Table 5). Statistical tests are also performed, comparing manual and instrument measures (Table 6) and ABN and Littmann measurements (Table 7 and 8). The final one graphically contrasts both Bland-Altmann and linear regression plots.

In terms of quantity, ABN produces higher average systolic and diastolic pressures compared to Littmann. However, Littmann tends to have smaller measurement variability than ABN based on its standard deviation

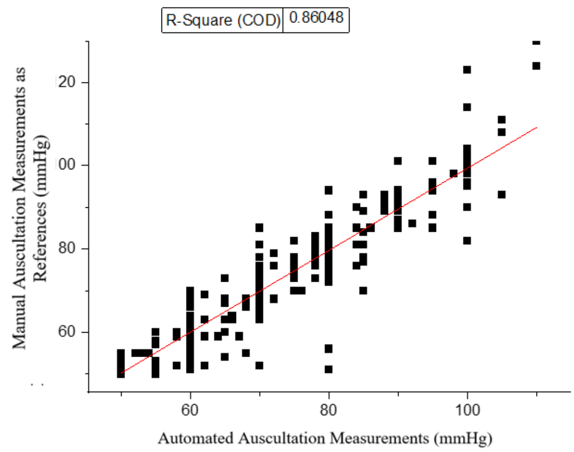


(a)

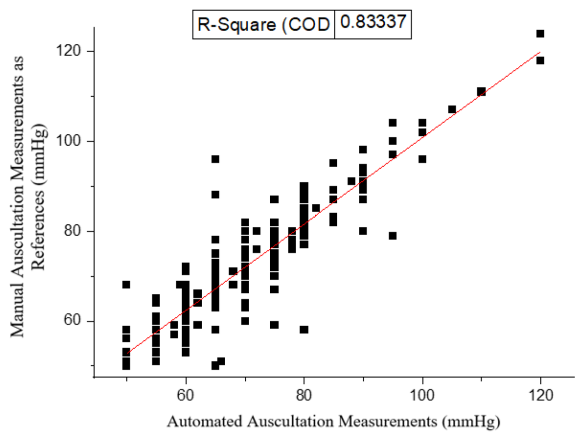


(b)

Fig 7: Linear regression graph for systolic blood pressure using (a) ABN and (b) Littmann



(a)



(b)

Fig 8: Linear regression graph for diastolic blood pressure using (a) ABN and (b) Littmann results. In terms of quality, the sound signal produced by Littmann is clearer than the audio signal captured by ABN. The difference in results between statistical testing (Table 6) and evaluation against standards such (Table 5) as BHS and AAMI/ANSI/ISO reflects different evaluation focuses and parameters. Based on international standards, Littmann showed better performance in consistency and accuracy, especially at a tolerance limit of ± 5 mmHg. Littmann recorded a higher percentage of measurements within the tolerance range than ABN, indicating a higher degree of agreement with blood pressure validation standards. This confirms the superiority of Littmann in producing more consistent measurements, although, from a statistical perspective, the ABN stethoscope showed no significant difference between manual and automated measurements in diastolic pressure (Table 6), indicating a high level of agreement for that parameter. These complementary findings suggest that while Littmann offers better overall validation, ABN maintains acceptable performance in specific conditions.

This is consistent with the findings in Table. The paired analysis, which offers the most valid comparison between the two devices, showed a significant difference in manual systolic pressure, but no difference in diastolic pressure. This suggests that Littmann and ABN may perform similarly for diastolic detection but differ slightly in systolic assessment under manual conditions.

Meanwhile, unpaired comparisons (Table 8) showed consistent significant differences across nearly all parameters, but these findings should be interpreted cautiously due to between-group variability and lack of within-subject control. The inconsistency between paired and unpaired results reinforces the importance of within-subject analysis in evaluating device performance. For other values that exhibited statistically significant differences, these may be attributed to variations in acoustic sensitivity, signal transmission quality, or algorithmic interpretation during automated measurement.

Overall, Littmann, as a high-end stethoscope, showed better performance in automated auscultation applications, especially for systolic pressure measurement, making it a more optimal choice. However, ABN, as an economical alternative, demonstrated acceptable performance under specific conditions, such as for diastolic pressure monitoring. This is supported by the fact that ABN met international standard requirements and showed no significant difference compared to Littmann in certain parameters.

For hospitals and research labs requiring high precision, Littmann is recommended due to its lower error margin and higher consistency. For general practitioners and community clinics, ABN could be a cost-effective alternative, particularly if diastolic pressure monitoring is the primary focus.

Using a high-quality stethoscope will make signal processing easier. When signal processing is done efficiently, it saves energy and power needed by the measuring device as a whole, resulting in lower battery utilization. More efficient power consumption on the gadget is advantageous in medical equipment used in hospitals and homecare.

According to current findings, there are several promising developments in research on automated auscultation, such as improving robust signal processing so that Korotkoff signals can be classified, for example, based on cardiac signals, abnormalities, or other artifacts[47)]. Furthermore, the hardware component can be integrated multimodally with skin temperature sensors to improve diagnostic tools[48)], combined with AI and Machine Learning to enable predictive analysis and early detection of pathological conditions[49)], monitored in real-time via IoT and remote access[50)], and synchronized with real-time video streaming for clinical documentation[51)]. Along with the increasing use of computers among professionals up to 80% in developed countries[52)], the incorporation of a solid database system to store auscultation data is critical. This system must not only be scalable, accessible, and simple to use, but it also needs to be capable of overcoming data security challenges in order to secure patient data from any cyber threats[53)].

5. Conclusion

Based on the analysis conducted with reference to the international standards AAMI/ANSI/ISO and BHS, the Littmann stethoscope showed superior performance in automatic Korotkoff sound detection compared to the ABN stethoscope, especially in systolic pressure measurements. The average systolic pressure error in Littmann (3.4 ± 3.5 mmHg) was smaller than ABN (4.4 ± 4.8 mmHg), with a higher percentage accuracy rate (80%, 96%, and 98%). Meanwhile, in diastolic pressure measurements, both stethoscopes showed similar average errors (4.1 ± 4.1 mmHg).

Although both stethoscopes met international standards for blood pressure measurement accuracy, a paired analysis among participants assessed with both devices revealed a significant difference in manual systolic pressure, suggesting better consistency for the Littmann in that parameter. However, no significant differences were found in diastolic measurements, indicating comparable performance between the two stethoscopes for that parameter.

Overall, although both stethoscopes provide statistically comparable results in certain parameters, the high-end Littmann stethoscope shows superior consistency and lower variability in systolic pressure measurements, making it a more reliable choice for automated blood pressure detection systems. However, the economical ABN stethoscope still can be alternative for the design of automatic auscultation, especially in contexts where affordability and accessibility are critical considerations. The findings of this study are therefore applicable to both devices, reinforcing their roles as representatives of high-end (Littmann) and economical (ABN) stethoscope categories, depending on specific clinical, technological, and economic contexts.

Future direction can be explored in both hardware and software aspects. In hardware, it can be developed by comparing other methods of capturing sound signals besides stethoscopes. In addition, the system can also be developed with telemedicine. In software development, one can be done by enhancing signal processing algorithms utilizing deep learning or using AI-based sound classification. With the rapid advancement of digital signal processing, the performance of the ABN stethoscope could be further enhanced through the integration of more robust filtering and analysis techniques, potentially narrowing the gap with high-end models like Littmann.

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