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Original Research Article

Simplifying blood pressure measurements in clinical settings

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ABSTRACT

Background: Upper arm sphygmomanometry is the most commonly used method to measure blood pressure in adults. However, variations in upper arm circumference and use of different cuff-sizes results in different pressure readings. When using the same cuff size, pressure readings will be higher for larger arm circumferences and lower for smaller arm circumferences. The objective of this study was to identify an adjustment factor that will allow pressure readings obtained for any combination of arm circumference and cuff size to be compared.

Methods: To investigate the relationship between arm circumferences, cuff size and pressure readings, experiments were conducted using laboratory simulations and blood pressure measurements on nineteen human subjects. Power analysis identified minimum sample size. Results were analyzed using Chi-square and t-tests. The study was conducted between 2019 and 2021 in Boise, Idaho, USA. The University institutional review board approved the use of human subjects.

Results: Simulations revealed a 99% linear correlation between changes in arm circumference coverage and changes in pressure readings. Human subject tests showed a 1% change in upper arm coverage by the sphygmomanometer cuff corresponded to a 1mmHg change in both systolic and diastolic pressure readings.

Conclusions: The proposed adjustment factor can simplify blood pressure measurements in clinical settings by allowing healthcare providers to use only one sphygmomanometer size. It will also provide the basis for a “reference” against which blood pressure values obtained for any combination of cuff size and arm circumference can be standardized.

Keywords: Sphygmomanometers, Cuff size, Upper arm circumference, Adjustment factor

INTRODUCTION

Upper arm sphygmomanometry is the most commonly used method to assess blood pressure in adults. However, errors in measurement due to the use of different cuff sizes are common. Such errors may lead to a misdiagnosis and subsequent inappropriate treatment. Identifying the “correct” cuff size has been a challenge for many years. This issue has been addressed in the literature.[1-5] Variations in pressure readings due to differences in arm circumference have also been reported.[6-9] Arm circumference and cuff-bladder size, in combination and separately, have opposite effects on the sphygmomanometer pressure readings. While sphygmomanometer manufacturers recommend limits on arm dimensions, such guidelines differ among suppliers. The objective of this study was to link pressure readings, cuff bladder size and upper arm circumference to a single “adjustment factor” which can permit a quantitative comparison of blood pressure values obtained for any combination of cuff bladder size and arm circumference. Such an adjustment factor would also allow the adoption of a “standard”, or a reference criterion, that would promote the standardization of blood pressure measurements internationally such as proposed by the American heart association (AHA) recommending a cuff bladder arm circumference coverage of 80%.[10-15]

METHODS

Study design, location and duration

The research was based on an experimental study design. The human subject upper arm circumferences were the independent variable. The sphygmomanometer pressure reading was the dependent variable. A Power Analysis identified the minimum sample size required to achieve statistical significance. The Chi square test and the t-test were used to analyze the results. The research program was conducted from March, 2019 to December, 2021 at Boise State University, located in Boise, Idaho, USA.

Human subject selection

A convenience sample of nineteen human subjects was used. All subjects were healthy. No one exhibited negative cardiovascular health issues. Volunteers who were obese, diabetic or hypertensive were excluded from the study.

Simulations

Four sphygmomanometers with different bladder sizes were tested in order to identify pressure interactions resulting from changes in arm circumference and cuff bladder lengths. The dimensions of the four sphygmomanometer bladders are listed in (Table 1).

Table 1: Sphygmomanometer cuff bladder dimensions.

Cuff no.	Bladder length (cm)	Bladder width (cm)	Bladder area (cm^2)
#1	17	8	136
#2	21	15	315
#3	23	13	299
#4	21	10	210

Data linearity and correlations for bladder geometry and pressure changes were investigated under controlled laboratory conditions using the simulator design illustrated in (Figure 1). The simulator consisted of a 1,000 ml low-density polyethylene compressible chamber (cylinder), 18 cm high and 9 cm in diameter. The system was equipped with an internal water pressure sensor. Each of the four sphygmomanometers were individually placed on the cylinder and inflated until the internal water pressure level reached 10.9 kP. Changes in the cylinder circumference were made using 15 cm-wide, 2 mm-thick felt cloth segments wrapped incrementally around the chamber circumference. All tests were repeated six times and the values averaged.

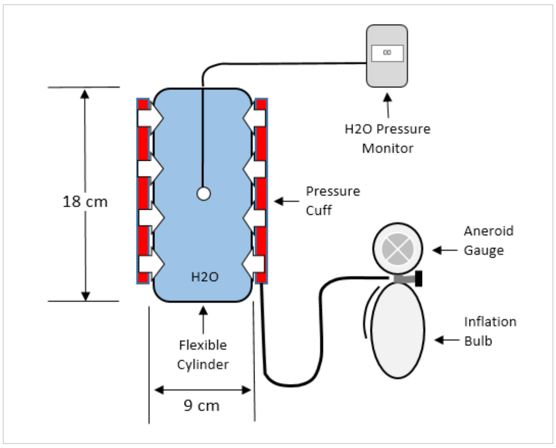

Figure 1: Schematic of the simulator used to evaluate the interaction between sphygmomanometer bladder circumference coverage and changes required in bladder inflation pressures.

Human subjects

A convenience sample of nineteen volunteer subjects (14 females, 5 males) was recruited for this study. The sample size was determined by a Power Analysis based on a data obtained in previous blood pressure studies The mean age of the subjects was 28 years (range 19-72 years), mean height 167.6 cm, and mean weight was 64.4 Kg. All participants were healthy. Persons exhibiting significant disabilities, obesity, high or low blood pressure values were excluded from the study. Each participant was assured anonymity and confidentiality of their personal information. Written informed consent was obtained from each subject prior to their participation. Subjects were briefed about the duration and procedures involved in the study. Their ability to withdraw from the study at any time without penalty was also assured. Institutional compliance with all ethical standards was met. The project was reviewed and approved for inclusion of human subjects in this project by the Boise State University institutional review board.

Blood pressure measurements

Dimensions of the middle upper arm circumferences were determined using a standard anthropometric tape measure. Baseline blood pressure values were obtained using the #2-sphygmomanometer cuff. To reduce data variability, all subjects rested 5-10 minutes while seated in a chair with back support. The left arm rested on a table with the upper arm at heart level. Legs were uncrossed and feet flat on the floor. No talking occurred during the measurement periods. Fifteen minutes after completing the baseline blood pressure measurements, ten subjects were measured again using the smaller #1 sphygmomanometer cuff. Blood pressure values were then obtained for the remaining nine subjects by using the #2 sphygmomanometer cuff after their upper arms were wrapped with a 15 cm-wide, 2 mm-thick felt cloth to increase their middle upper arm circumferences. To reduce observational bias, blood pressure measurements for all nineteen subjects were determined using the WGNBPA-730 automatic oscillometric sphygmomanometer.

RESULTS

Simulations

The observed bladder inflation pressures associated with cuffs #1, #2, #3 and #4 when the sphygmomanometer cuffs were placed around the simulator chamber having a circumference of 29 cm (Figure 2). The independent variable was defined as the circumference coverage (in percent) provided by the length of each of the four sphygmomanometer bladders. Since the circumference of the simulator remained the same, the changes in the required bladder inflation pressure were due only to the individual differences in bladder lengths, not due to any changes in the simulator circumference. The linear relationship between the required inflation pressures using only sphygmomanometer #2 when the simulator circumference was increased from 29 cm to 38 cm is shown in Figure 3. In this case, the changes required in bladder inflation pressure were due only to the changes in the simulator circumference, not due to any change in bladder length.

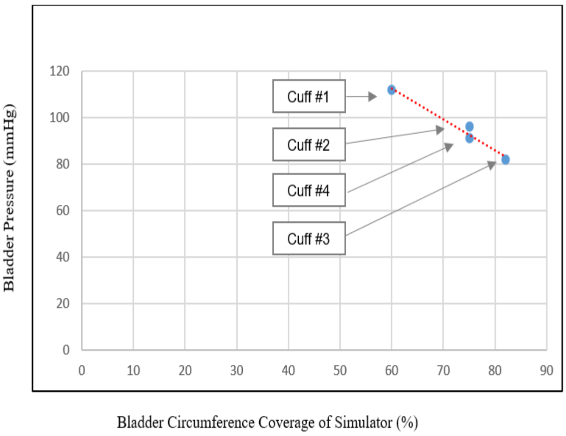

Figure 2: Illustration of the impact of reduced simulator circumference coverage for four different sphygmomanometer cuffs.

Human subjects

The blood pressure values obtained for the nineteen subjects for the baseline (control) conditions and for the reduced circumference coverage conditions are summarized in (Table 2-3). The tables illustrate that a reduction in arm circumference coverage by the cuff bladder increased both the systolic and diastolic blood pressure values. Overall results are summarized in (Table 4). It shows than an average decrease of 10% in the bladder arm circumference coverage lead to an increase in the systolic pressure by 10 mmHg and the diastolic pressure by 10 mmHg. The differences in blood pressures observed between the “control” condition and the augmented arm circumference condition are both statistically significant at p=0.002.

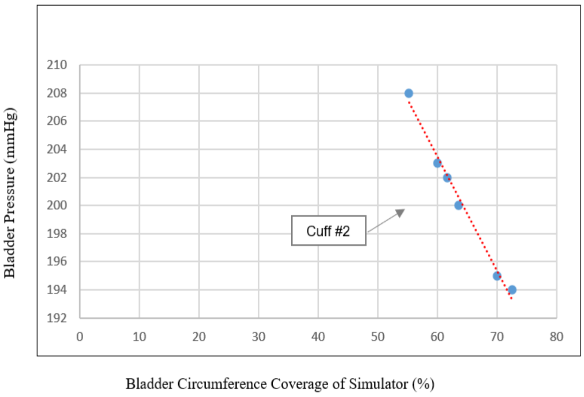

Figure 3: Illustration of the relationship between bladder circumference coverage by cuff #2 and required bladder inflation pressure. The circumference was increased incrementally from 29 cm to 38 cm while the length of the bladder remained the same.

Table 2: Baseline (control) systolic and diastolic blood pressure values observed for nineteen test subjects.

Test Subject no.	Baseline circumference coverage (%)	Systolic pressure (mmHg)	Diastolic pressure (mmHg)
101	66.6	118	79
102	70.9	121	75
103	60.0	137	80
104	70.0	101	72
105	79.2	107	68
106	57.5	129	80
107	70.0	115	73
108	80.5	108	67
109	95.4	97	60
110	66.6	102	60
115	91.3	101	60
116	68.8	106	72
117	95.4	97	60
118	77.7	118	70
119	75.5	104	67
120	76.3	105	69
121	65.4	97	60
122	68.8	106	70
123	81.3	101	68
Avg.	74.3	109.1	69.1
SD	10.8	11.2	6.7

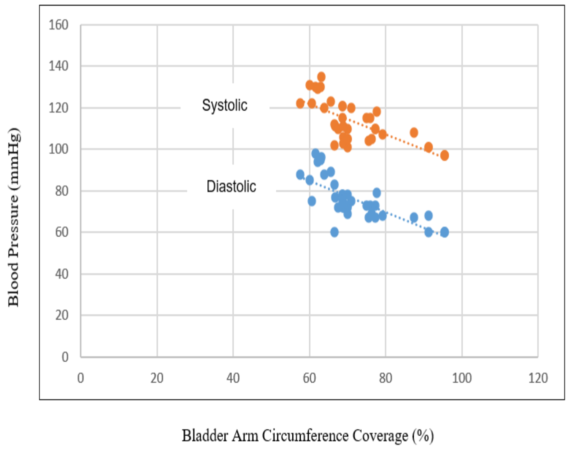

Figure 4: Summary of test subject blood pressure readings when their arm circumferences were increased. The slope of the data points show a 1 mmHg change for every 1% change in bladder arm circumference coverage.

DISCUSSION

Simulations

The simulations provided and accurate assessment of the links between bladder length and changes in pressure readings when the simulator circumference was changed. The changes observed in the required bladder inflation pressures were linearly associated with the bladder circumference coverage when the cuff bladder length was used as the independent variable.

Based on our results, previous suggestions recommending only the "width" of a cuff bladder to be used as the independent variable does not appear to be valid.[16,17] Furthermore, the linear relationship we observed for the inflation pressures required to achieve a reference pressure of 10.9 kP inside the simulator, and the corresponding circumference coverages provided by a cuff bladder, is consistent with the basic laws of fluid mechanics, i.e., P=F/A.

Table 3: Systolic and diastolic blood pressure values observed for nineteen test subjects when their arm circumferences were increased reducing the cuff bladder circumference coverages.

Test subject no.	Reduced circumference coverage (%)	Systolic pressure (mmHg)	Diastolic pressure (mmHg)
101	69.7	123	91
102	54.9	128	83
103	68.1	141	90
104	70.0	105	78
105	60.8	111	72
106	52.5	133	94
107	65.2	130	83
108	67.7	115	75
109	70.0	105	69
110	64.5	110	75
115	78.9	115	76
116	59.7	121	78
117	77.2	110	69
118	62.9	136	85
119	60.7	122	74
120	61.8	111	73
121	77.2	110	70
122	55.7	121	82
123	73.9	115	78
Avg.	64.0	119.0	79.1
SD	8.5	10.5	7.4

Human subjects

The human subject data show that a decrease in the sphygmomanometer circumference coverage results in a linear increase in the required sphygmomanometer inflation pressures. The opposite occurs when the upper arm circumference coverage is increased. This principle is verified by the results obtained with our simulations. Table 4 summarizes the results for the test subjects. It shows that a 1% change in upper arm circumference coverage leads to a change of 1 mmHg in both systolic and diastolic pressure readings. Using this adjustment factor will allow blood pressure values obtained for any combination of sphygmomanometer cuff size and associated circumference coverage to be compared.

Table 4: Changes in measured blood pressure values due to a decrease in arm circumference coverage by the cuff bladder, a 10% reduction in the cuff bladder circumference coverage resulted in an increase of 11 mmHg in systolic pressure and an increase of 10 mmHg in diastolic pressure.

Variables	Baseline Arm Circumference	Augmented Arm Circumference	Δ
Circumference coverage	74%	64%	-10%
Systolic pressure	109 mmHg	119 mmHg	+10 mmHg
Diastolic pressure	69 mmHg	79 mmHg	+10 mmHg

Practical example

Use of the adjustment factor for; to measure a patient's blood pressure, the following steps are needed: measurement of a patient's middle upper carm circumference, determining sphygmomanometer cuff bladder length, dividing cuff bladder length (#3) by the arm circumference (#2) to obtain %

coverage by the bladder, subtracting 80% from #4 and subtracting #4 from from #1=AHA 80% coverage criteria. Example: a patient's measured blood pressure when using a sphygmomanometer having a cuff bladder length of 21 cm: 140 mmHg systolic and 95 mmHg diastolic. Patient's upper arm circumference=30.5 cm, sphygmomanometer cuff bladder length=21.0 cm, 21cm/30.5 cm=68% arm coverage. 68% - 80% = -12 (AHA criteria), adjusting to the AHA criteria: systolic: 140 mmHg-12 mmHg =128 mmHg, diastolic: 95 mmHg-12 mmHg=83 mmHg. The above example illustrates the significant difference in blood pressure values obtained when adjusting to the AHA 80% criteria. While the initial diagnosis would have been hypertension, the adjusted values suggest normal conditions. This information would be important in daily clinical practice.

Limitations

The data generated in this study were obtained using a relatively small number of human subjects. Studies in the future may generate additional information that modify the 1% correction factor. On another matter, it may be difficult for healthcare providers to obtain information about the dimensions of a sphygmomanometer cuff bladder embedded inside a sphygmomanometer cuff. This makes it difficult to determine the actual length of the bladder. Manufacturers do not print this information on their devices. However, the dimensions can be obtained by inflating the sphygmomanometer cuff and measuring the "bulge" created by the bladder.

CONCLUSION

A blood pressure adjustment factor for use with different sphygmomanometers has not been proposed to date. Nevertheless, use of an accurate adjustment factor has the potential of simplifying blood pressure measurements in most clinical settings by allowing healthcare providers to use only one size sphygmomanometer. Such an adjustment factor can also provide the basis for a "reference" against which all blood pressure values obtained with different cuff sizes can be compared. The adjustment factor proposed in this study will allow such a comparison.

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Ethical approval: The study was approved by the Institutional Ethics Committee

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