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Investigating the inaccuracies of indirect method of blood pressure measurement associated to the cuff constructing fabrics

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KEYWORDS

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ABSTRACT

Numerous cuffs have been manufactured using different materials in which textile fabric is the main constituent. There are no specific guidelines for the selection of the cuff fabric and its design. In this investigation, five different types of cuffs (made of woven and non-woven fabrics) were selected, and their pressure distribution was noted while mimicking the process of blood pressure measurement. It was achieved by measuring pressure at the interface of the selected cuffs and a bare metal cylinder. I-scan, an interface pressure measurement system was employed to record the interface pressure profiles under the cuffs against 140 mmHg to 40 mmHg pressure inside the cuffs. The data obtained from the pressure sensing system was processed in MATLAB to examine pressure distribution at 96 points in detail. The results show that the cuffs registered non-uniform pressure distribution at the interface which is also non-identical among the selected cuffs. The pressure at the interface is found to be lower than the pressure inside the cuff, which shows that pressure attenuates as transfers to the surface of the object underneath it. The range of the pressure difference varies from 10 mmHg to 15 mmHg. This study indicates that the pressure distribution under a cuff depends on the constructing fabric and its properties. It is concluded that there is a need to select appropriate fabric with optimized properties for desired pressure distribution which may lead to accurate estimation of blood pressure.

1. Introduction

Ever since the invention of cuffs in 1896 [1], different types of fabrics have been employed to construct Blood Pressure (BP) cuffs for indirect method of blood pressure measurement. BP cuffs are wrapped around the arm and then pressurized over high (systolic) blood pressure and then slowly depressurized. The pressures indicated by the manometer at which blood starts to re-flow in different phases during the cuff deflation are estimated same as high BP (Systolic) and low BP (Diastolic). BP cuffs constructed from fabrics are shown in Fig. 1.

Fabric cuffs transmit pressure from arm to the artery. Theoretically the pressure transmits from the cuffs to the artery must have the identical value for accurate estimation of blood pressure levels. If the cuffs cannot transmit same pressure to the arm, same as inside, it might lead to wrong estimation of blood pressure levels. As a result, patient or subjects may receive unnecessary medication or no medication at all which may lead to serious health complications [2-5].

Since different types of fabrics (woven and non-woven) are used to manufacture cuffs so it is crucial to study the pressure profile under the cuffs. Pressure transmission may vary under those cuffs constructed from different types of material. This study will help in identifying inaccuracies associated to the indirect method of blood pressure measurement which have been reported by previous studies [6-10]. Pressure profiles can be obtained by measuring pressure between the cuffs and arms (interface pressure) using standard equipment.

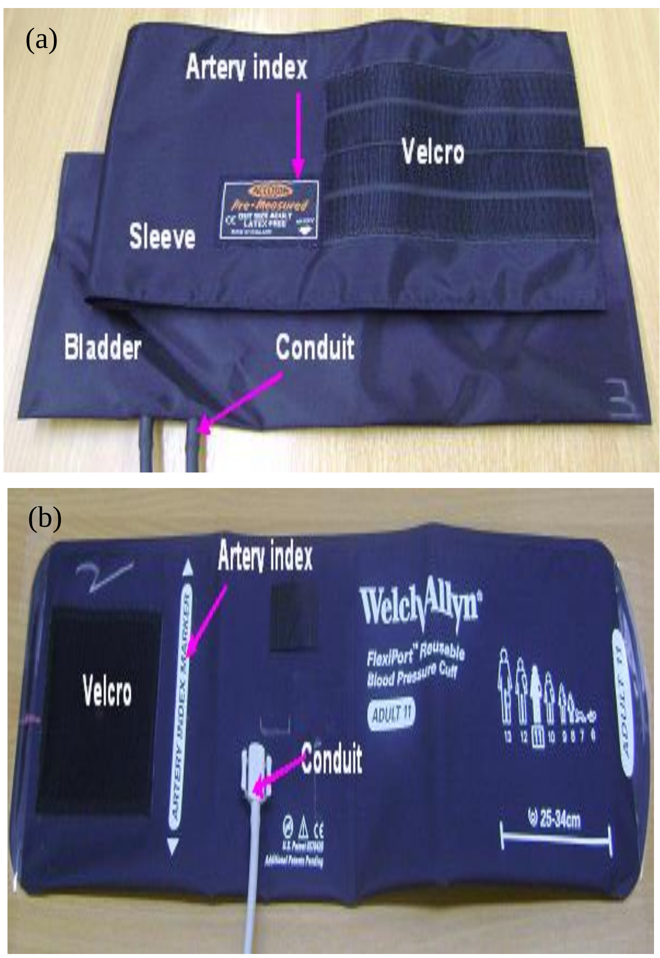

Fig. 1. BP measurement cuffs constructed from (a) four layers and (b) two layers of fabrics

Five different types of commercially available cuffs were selected and then their specifications were determined using standard test methods. After that, pressure at the interface of the selected cuffs and a bare metal cylinder was noted against the pressure inside the cuffs, by mimicking phenomena of blood pressure measurement as per standard guidelines [11]. I-Scan pressure sensing system by Tekscan is employed to measure interface pressure. This system is able to measure and record pressure at 96 points in real time along the length and across the width of the cuffs. A bare metal cylinder is selected for this investigation because tests could not be easily carried out on the human arm because of the numbness and pain experienced by the human subjects in prolonged testing conditions. Further, ethical approval is also required to carry out such type of measurements repetitively. Another purpose of using metal cylinder was to investigate the sole effect of different types of fabrics on pressure distribution underneath the cuffs.

Interface pressure measurement could be found as a good interpreter of the pressure occludes the artery. This additional information may remove the errors reported by the previous studies related to the indirect measurement of blood pressure using cuffs. Pressure ulcer treatment burns treatment using textile products and pressure garments have been employing interface pressure measurement as a valuable tool to evaluate the related products performance. The value of interface pressure under a cuff may be dependent on the type of fabric used to construct it. Cuffs constructed of coated woven fabrics and coated non-woven fabrics may impart variation in the pressure transmittance under the cuffs and for that interface pressure distribution underneath the cuffs needed to be examined along the length and across the width of the cuff in real time during mimicking phenomena of blood pressure measurement.

2. Material and Methods

There are numerous cuffs available worldwide in which variety of fabrics and other materials are used for their construction. They are generally categorized with respect to size, number of fabric layers used for construction, disposable, non-disposable and type of indirect method used to measure blood pressure. Since blood pressure is measured through pressure transfer from cuff to arm so it is required to find whether the desired pressure is transferred to the arm. There are variety of fabrics used to develop cuffs so there is a need to investigate their relative effect on the pressure transferred underneath the cuff which could be linked to the accurate measurement of blood pressure.

Urethane Coated fabrics are fused by Radio Frequency welding or stitched to make an air impermeable inflatable structure. A rubber tube is connected to the cuffs to transfer air from the pump or machine for inflation and deflation during blood pressure measurement. In most of the cuffs, velcro strip is attached to fasten both ends of the cuff after wrapping around the arm before BP measurement.

Both coated woven and coated non-woven fabrics are employed in cuffs construction. The woven fabric has better integrity and strength of the structure properties compared to the non-woven and knits [12]. Non-woven fabrics are developed by the web of the fibres which are adhered together by different bonding techniques. In the web, the fibres alignment could be parallel, horizontal or random with different aerial density. Since cuff fabrics either woven or non-woven are coated with polymer so along with fabric properties, formulation of polymer layer may also affect their properties [13].

Seven unused cuffs which were grouped into five different types were selected for the proposed investigation. IDs were assigned to each type of cuff. Two samples were tested for Cuff 1W and 2W which can be identified for Cuff 1W as 1W-1 and 1W-2 while for Cuff 2W as 2W-1 and 2W-2. One cuff is used as a complete system and used by the physician for long time on multiple patients. The specifications of the fabrics used in the construction of selected cuffs are listed in Table 1.

In order to measure the number of picks and ends in the fabrics or number of thread along the length and across the width of the cuffs (which is cut from the cuffs) and to observe fabric type, Projectina microscope was employed after calibration. The microscope was used because the tightness and the coating of the fabrics made it difficult to count the exact number of threads per unit length using counting glass which is specified in method B of BS EN 1049-2:1994. The image of the cuff fabric is magnified 10 times of the original. Ten observations were made in each direction in five samples of each cuff type. The average number of threads per cm is listed in Table 1. The area density of the cuff fabrics was determined in accordance with BS EN 12127:1998. The tensile behaviour of the available cuff fabrics was determined according to EN ISO 1421:1998 (Grab method) employing Zwick-Roell testing machine.

The advanced pressure measurement system, I-scan, was employed to measure pressure between the selected cuffs and the bare metal mandrel surface. Calibrated sensor was positioned in a way that the centre of the cuff (which is marked as the artery index in all the cuffs) and the centre of the sensor coincided as shown in Fig. 2. A mercury manometer was then connected to the cuffs to measure the pressure inside the cuffs.

Before inflating the cuffs, it was ensured that the pressure between the cuffs and the surface of the metal mandrel was zero mmHg. The bladder was then inflated up to a pressure of 140 mmHg and then deflated back to zero mmHg gradually in steps of 20 mmHg; thus the interface pressure was recorded against the manometer pressure during deflation manoeuvre at intervals of 20mmHg. Deflation manoeuvre was selected because values of blood pressure are recorded while cuff is deflated followed by inflation. Two to three minutes gap was set according to the standard guidelines of blood pressure measurement between two consecutive BP measurements [11]. The interface pressure distribution was recorded as a colour coded real time display and the correspondent numerical values are saved as a text (ASCII) file. For each cuff, interface pressure was measured five times repeatedly. Subsequently, the numerical data was acquired and then programmed in the MATLAB environment.

Table 1
Specifications of the cuff fabrics

Cuff ID	Fabric Type	Number of fabric layers	Threads/cm (along the length)	Threads/cm (across the width)	Area Density (g/m^2)	Modulus of elasticity (MPa)
1W	Woven	2	44	34	216	154
2W	Woven	2	42	34	201	290
3NW	Non-woven	2	-	-	341	100
4W						
Cuff sleeve	Both	4	26	21	182	430
Cuff bladder	Woven		26	20	267	101
5W	Woven	2	43	30	214	220

The average of the observations was plotted in the form of 2D images using MATLAB graphical tools as presented in the Result section. The new graphical presentation of the results (using MATLAB) is more comprehensive for the identification of the high- and low-pressure regions under the cuffs examined in this research.

Fig. 2. Experimental setup for measurement of pressure at interface of cuff and metal cylinder

3. Results

The alignment of calibrated sensors obtained the interface pressure distribution underneath the cuffs. Pressure profiles shown in Figs. 3(a) and 3(b) were obtained during deflation of cuff. Pressure distribution under the cuffs provided below is I-Scan data. Figs. 3(a) and 3(b) also showed the location of pressure sensors under the cuffs because cuffs consist of different accessories like Velcro and a conduit for the air inlet. Effect of these accessories on the pressure distribution can also be analysed.

The 3-D pressure profile obtained under the cuffs using the I-Scan sensor and pressure distribution plotted in the MATLAB are presented in Figs. 4(a) and 4(b) respectively. The results of the pressure distribution under the cuffs are showed against 120 mmHg and 140 mmHg inside-cuff pressures. These pressures were selected because 120 mmHg is in the range of normal blood pressure and 140 mmHg is in the range of the grade 1 mild hypertension (as per BHS guidelines) [11].

The results are shown in a way so that the variations in the pressure distribution under different types of cuffs can be observed. Figs. 4(a) and 4(b) show non-uniform pressure distribution underneath the cuffs which not only varies between cuff made of woven and non-woven fabrics however it is also showing variation among the cuffs constructed of woven fabrics.

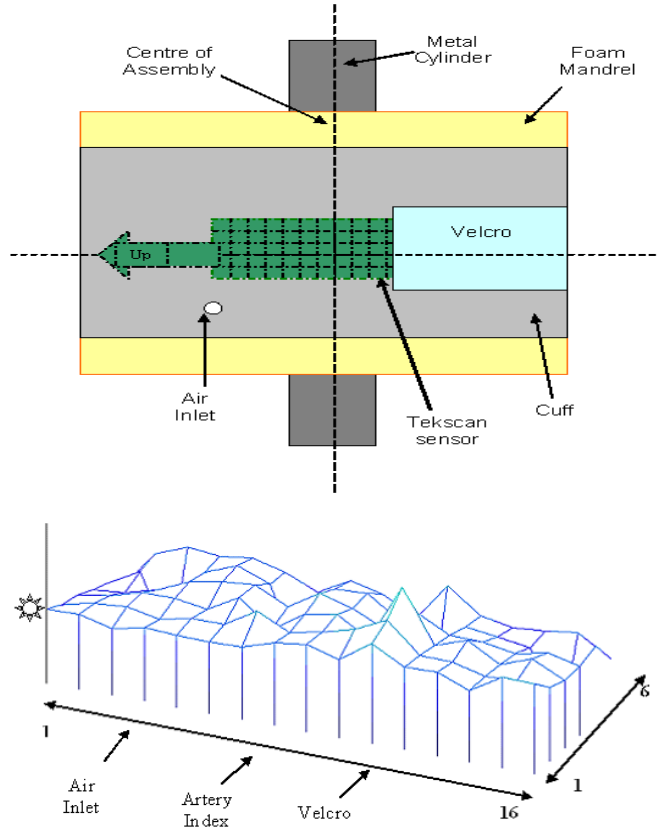

Fig. 3(a) Tekscan sensor arrangement for measurement of pressure at interface of metal cylinder and Cuff 2W, cuff 4W and cuff 5W

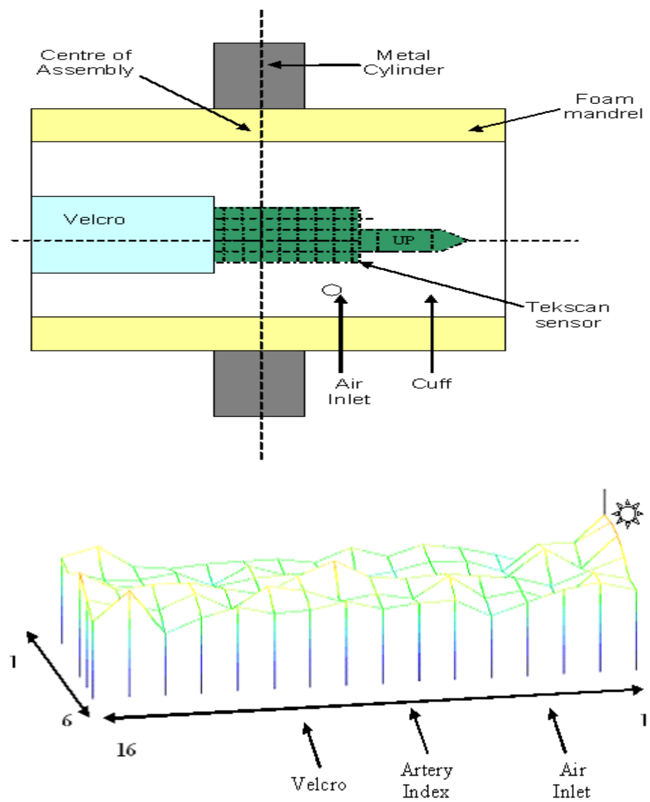

Fig. 3(b) Tekscan sensor arrangement for measurement of pressure at interface of metal cylinder and cuff 1W and cuff 3NW

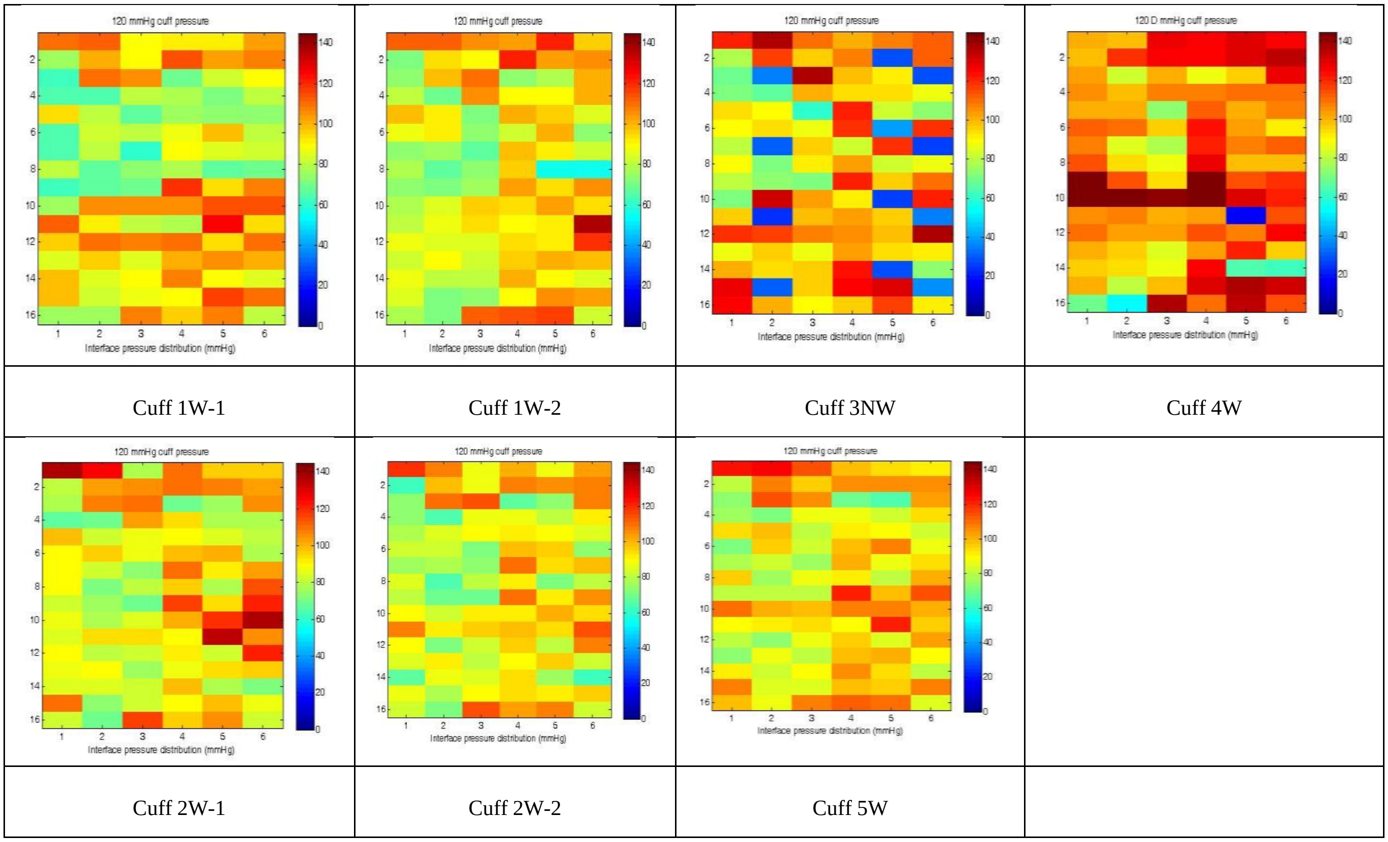

Fig. 4(a) Pressure distribution at cuff – metal cylinder interface at 120 mmHg inside cuff pressure

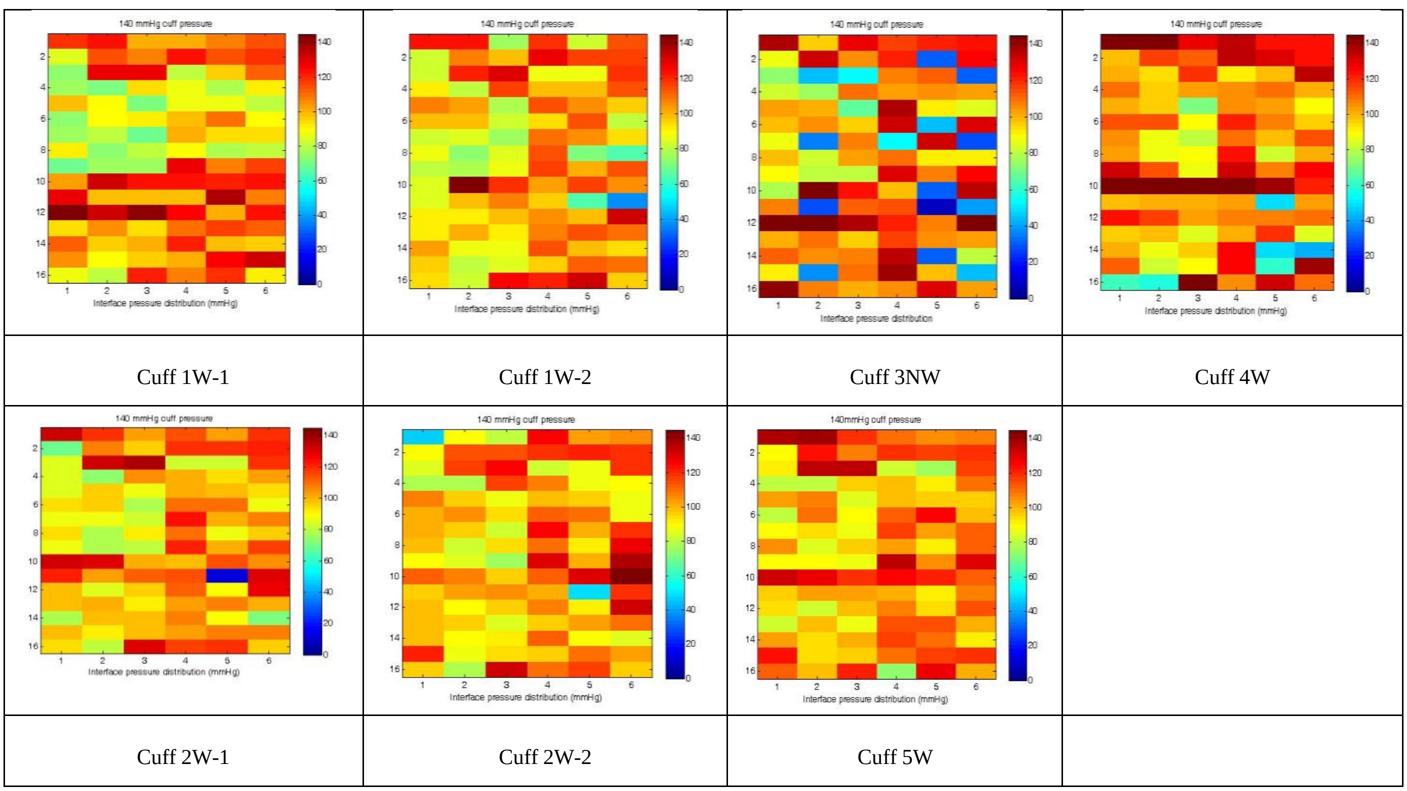

Fig. 4(b) Pressure distribution at cuff – metal cylinder interface at 140 mmHg inside cuff pressure

Along with the numerical data at individual sensing points, Tekscan also displayed an average force acting on over sensor and an active sensing area in the real time window which were also analysed in this study. The average pressure was calculated using average force and active sensing area and results are presented in Fig. 5.

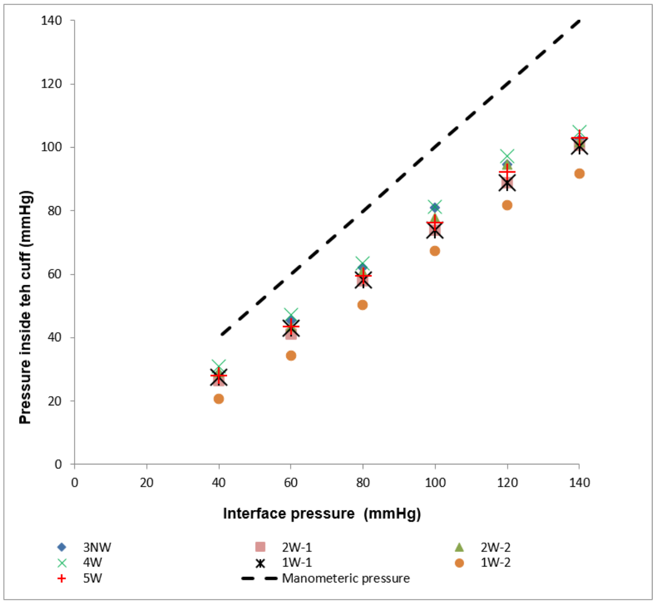

Fig. 5. Average interface pressure against manometric pressure

Table 2

Range of interface pressure

Pressure inside the cuff (mmHg)	Range (Interface pressure measurement, mmHg)
140	13
120	15
100	14
80	13
60	13
40	10

4. Discussion

The aim of this investigation is to study the pressure profile of different types of the cuffs which were constructed of woven and non-woven fabrics using two or four layers. Little prior work was carried out in this domain. It has been found experimentally that the cuffs of various types have different specifications. In this related work, pressure distribution at the interface of the seven cuffs (grouped into five types) and a bare metal cylinder is measured and analysed. The interface pressure was noted against the inside-cuff pressure.

The results presented in Figs. 4(a), 4(b) and 5 show that the cuffs are unable to provide identical pressure distribution reading with regard to the pressure inside the cuffs. The results of the pressure measurement under all the selected cuffs indicated that the interface pressure varies with the fabric type and design. The pressure distribution is also non-uniform either under each type.

Interface pressure distribution has the highest values underneath the cuff 4W among the selected cuffs. The modulus of elasticity and the linear density of Cuff 4W is the highest value among the cuffs tested in this study. Cuff 4W is constructed of four layers of fabrics and applying more pressure at most of the regions compared to the other cuffs although woven but constructed of 2 layers of fabrics. Cuff 3NW which is made of coated non-woven fabric provided different range of readings altogether. The cuff was not completely in contact with the metal cylinder. The pressure distribution is highly non-uniform. Cuff 3NW has the lowest value of elasticity modulus and highest value of GSM. Under Cuff 3NW, most of sensing points shown pressure values below 100 mmHg against the corresponding pressure inside the cuff which was 120 mmHg. In order to occlude the artery under such type of cuff, high pressure inside would be required.

Under Cuff 1W-1 has the high-pressure region is under the Velcro while lower pressure is around the air inlet region and the centre of the cuff. While under Cuff 1W, Cuff 2W and Cuff 5W, the pressure at the interface is lower than the corresponding pressure inside the cuff at most of the sensing points but uniform to some extent. Cuff 1W, Cuff 2W and Cuff 5w are constructed from two layers of woven fabric while Cuff 3NW is made of two layer of non-woven fabric. The difference in their construction and mainly of the elasticity, incurred such difference.

It can also be observed that the even the same cuffs, 1W and 2W are not applying identical pressure over the surface of the metal cylinder (Figs. 4(a) and 4(b)). The region of the highest pressure under the cuff is supposed to be the artery index which should apply either the same or higher pressure under the cuff. Considering pressure under the centre of cuff (artery index), in all the cuffs except Cuff 4W pressure is lower in the centre compared to the pressure applied by the cuff on either sides, under the Velcro. The highest pressure values are observed at the Velcro position and at the point of air inlet (conduit). The results of this investigation depict that cuffs examined do not fulfil the requirement of applying the highest pressure over the artery than the other points along the arm circumference. The highly non-uniform pressure over the artery may give rise to inaccurate measurement of blood pressure.

The pressure under the cuff seems to depend on the elasticity of cuff constructing fabrics. The elasticity of the fabric depends on its construction [14]. It has been found experimentally that elastic modulus of cuff fabrics is not identical (Table 1). The non-uniform pressure distribution under the cuff is due to the distortion of the cuff around the metal. There is a little deformation of cuff inner wall and limited movement during inflation and deflation around metal cylinder. The outer cuff wall expanded and contracted against atmospheric pressure during inflation and deflation respectively.

The deviation of the pressure underneath the cuff (interface pressure) from that of the pressure inside the cuff is also shown in Fig. 5 by plotting dashed line representing pressure inside the cuff (which was measured by manometer). It shows that the pressure transferred by the cuffs is not the same as inside-cuff pressure and also indicates that the cuffs did not perform in the same manner for a given range of manometric pressure (inside cuff pressure).

Range of the interface pressure under the cuffs is also calculated and listed in Table 2. It shows wide variation of pressure transfer under the cuffs. The value of range is varying from 10 mmHg to 15 mmHg which is quite wide with respect to the measurement of blood pressure as the change in 5 mmHg pressure misclassifies level of blood pressure. This range could be wider if cuffs tested on soft materials like human limb due to the deformation of arm and transfer of more pressure from the cuff during blood pressure measurement. In this case, the amount of pressure transfer inside the tissues would vary under each cuff. Subsequently, the pressure exerted over the artery under different cuffs would differ depending on the value of pressure applied over the surface of the arm. The cuffs that registered higher interface pressure are likely to close the artery well before the cuffs that registered lower interface pressure. The cuffs that applied higher or lower pressure on the arm surface than the manometric pressure may register varying BP values. The relationship between the pressure distribution under a cuff and its construction (mechanical properties) is complex which needs to be studied in detail for more types of cuffs.

Aforementioned, the cuffs used in this study are constructed from woven and non-woven fabrics. The woven fabrics are constructed in a very controlled manner as compared to the non-woven fabrics and therefore, it is easy to maintain the properties of fabric uniform throughout the construction. Unlike, the non-woven fabrics which are manufactured by laying fibre, it is difficult to keep the properties of fabric uniform throughout the manufacturing. The non-woven fabrics are less compliant than the woven fabric. Cuff walls stretch and relax during inflation and deflation respectively which cause a pressure transfer to the limb. The interface pressure variations depend on the mechanisms of the deformation of cuff fabrics.

5. Conclusion

The pressure distribution at the interface of the selected blood pressure measurement cuffs and a bare metal cylinder were measured and studied in this investigation. The pressure measured at the interface of the cuff and metal cylinder was lower than the corresponding pressure inside the cuff. Pressure transmitted by the cuffs was not same as the pressure applied inside the cuff.

Pressure profiles under different cuffs are not identical against the same pressure inside the cuff. It indicates that the subsequent pressure distribution inside the arm tissues and over an artery may vary due to the different types of fabrics used to construct cuffs. It may lead to the different blood pressure values of human subjects if measured by these cuffs and variation could be more wide if used for the different types of human limbs (muscular or soft). For the same patient, value of blood pressure measured would not be repeatable for different types of cuffs. Value of blood pressure would depend on the type of the cuff being used for the assessment. The fabric selection and related properties should be optimized for the correct estimation of blood pressure. Measuring pressure profile under the cuffs may indicate their performance during blood pressure measurement. It needs to find the value of pressure which cuff should transmits to the arm because pressure changes as it transmits to the artery so with the help of appropriate fabric selection, desired pressure can be transmitted to the artery. Artery index which is supposed to be the area of highest pressure than the rest of the cuff for arterial occlusion has lower pressure compared to the pressure applied by the cuffs at their edges so redesign of cuffs should be done in a way so that the highest pressure region must be in the centre of the cuffs to occlude artery completely during blood pressure measurement.

5. Acknowledgement

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