Non Invasive Blood Pressure Measurement Techniques: A Survey

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Abstract— Blood pressure fluctuation is the most common health problem in all human beings. It is the root cause of cardiovascular diseases. During the last decades noninvasive blood pressure measurement devices are more commonly used in the hospitals and home care for routine examinations and monitoring. Comparatively low prices, less complicated in use and automatic measurement features making these devices more popular. However, non-invasive measures devices have lower accuracy and yield small systematic differences in numerical results. In this paper we review recent developments in the methodology of non-invasive arterial blood pressure measurement .Noninvasive pressure measurement techniques include: Oscillometry, Auscultation, Doppler ultrasound, Palpation. Particular importance will be placed on describing the methods' strong and weak points .The noninvasive auscultatory measurements are quick and simple, and give less strain to the patient. Require less expertise in fitting, have virtually no complications, and are less unpleasant and painful for the patient.

Key words: Sphygmomanometer, Auscultatory method, Tonometric method

I. INTRODUCTION

A. *Sphygmomanometer:*

The circulation of blood within the body has been a subject of study for many thousands of years. A sphygmomanometer is a device used to measure blood pressure, it consist of an inflatable cuff to collapse and then release the artery under the cuff in a controlled manner,[1]. In 1881, the first sphygmomanometer was invented by Samuel Siegfried Karl Ritter von Basch.It consisted of a rubber bulb that was filled with water to restrict blood flow in the artery. The bulb was then connected to a mercury column, which would translate the pressure required to completely obscure the pulse into millimeters of mercury.(2)Scipione Riva-Rocci introduced a more easily used version in 1896.The standard design includes a cuff that could be affixed around the arm to apply even pressure to the limb. The difference between the systolic and diasystolic blood pressure which is the base of modern blood pressure measurement was discovered by Dr. Nikolai Korotkoff in1905.While the cuff deflates, the appearance and disappearance of sound, Known as Korotkoff sounds, can be used to determine systolic and diastolic blood pressure, respectively. The use of systolic and diastolic sounds is now standard in blood pressure measurement. In manual sphygmomanometer ,to determine at what pressure blood flow is just begins, and at what pressure it is unrestricted(free) mercury or mechanical manometer is always used in conjunction with a stethoscope .

B. *Auscultatory Method:*

In this method the relaxed subject sits on a chair with the lower arm supported roughly the same vertical height as the heart. The blood pressure cuff is placed on the subject's right arm, allowing 1 inch between the bottom of the cuff and the crease of the elbow as shown in fig (2). The brachial pulse is palpated just above the angle of the elbow. The diaphragm is placed over the brachial artery in the space between the bottom of the cuff and the crease of the elbow. At this point no sounds should be heard. The cuff pressure is inflated quickly to a pressure about 30 mm Hg higher than the systolic pressure determined by the method of palpation. As the pressure in the cuff slowly released, a sound is heard known as korotkoff sound, when blood flow first starts again in the artery. The pressure at which this sound began is noted and recorded as the systolic blood pressure. The laminar flow that normally occurs in arteries produces little vibration of the arterial wall and therefore no sounds. However, when an artery is partially constricted, blood flow becomes turbulent; causing the artery to vibrate and produce sounds. The cuff pressure is further released until the sound can no longer be heard. This is recorded as the diastolic blood pressure. The auscultatory method may yield erroneous results if the cuff is not of the proper size. if the cuff is too small the blood pressure readings may be higher and If the cuff is too big, the readings may be lower than the actual readings. Also a slow inflation of cuff causes venous congestion, which in turn causes the Korotkoff sounds to be faint; this result in false readings with the systolic value being too low and the diastolic reading too high.

Fig. 1: Sphygmomanometer

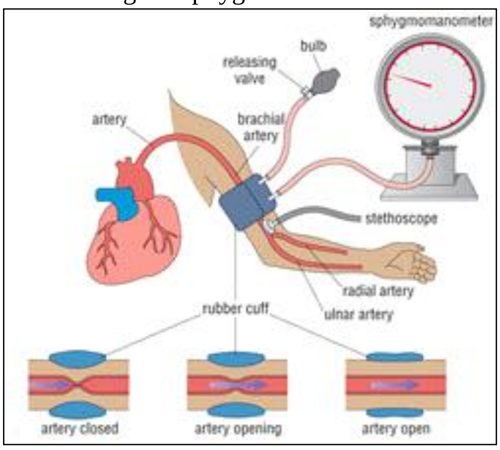

Fig. 2: Measurement of arterial blood pressure

C. Oscillometric Method:

The oscillometric method was first introduced by Marey in 1876. In 1904 Erlanger further upgraded this by attaching a Riva-Rocci cuff around the upper arm. Rotating drum was used to record pressure oscillations. In 1909 Pachon used dual-dial gauges, one for oscillation amplitude and the other for showing cuff pressure. In those days, it was thought that maximum oscillation amplitude indicated diastolic blood pressure.

Oscillometric measurement is now the standard method for automated Blood Pressure measurement. These devices use an electronic pressure sensor with a numerical readout of blood pressure. In the majority of non-invasive automated blood pressure measuring devices the cuff is inflated and released by an electrically operated pump and valve, which may be fitted on the upper arm elevated to heart height. Initially the cuff is inflated to a pressure in excess of the systolic arterial pressure, and then the pressure reduces to below diastolic pressure. Once the blood flow is present, but restricted, the cuff pressure will vary periodically in synchrony with the cyclic expansion and contraction of the brachial artery. Both the systolic and diastolic value is calculated with the help of an algorithm. The calculated values are than visualized on the display.

The oscillometric method records and evaluates the oscillations of the arteries. Those oscillations have a very typical curve. It has been established that the maximum oscillations actually correspond with cuff pressure equal to mean arterial pressure, confirming Marey"s early idea. When the blood flow first is interrupted the oscillation occurs and then starts flowing again. They become stronger, than diminish until they disappear when the blood starts flowing normally. Traditionally, the arterial pulsations in oscillometric devices are picked up from the occluding cuff by means of a manometer. However, in some implications a photoelectric detection directly from the tissue (PPG) is also used.

Diastolic and systolic blood pressures can be determined using special fractions of the maximum oscillation amplitude, also known as characteristic ratios. There are no definite correct values for the systolic and diastolic characteristic ratios; rather different manufactures use different values.

Due to the simplicity and reliability of this method, it is increasingly used in majority of present-day automatic and semiautomatic noninvasive blood pressure monitors [3]. However, the accuracy of these devices may be questionable; these automated devices should be validated against standards.

D. Volume Clamp, Or Vascular Unloading, Method:

The volume-clamp method was first introduced by Czech physiologist Prof. J Peňáz in 1967. In this method, finger arterial pressure is measured using a finger cuff and an inflatable bladder in combination with an infrared plethysmograph, which consists of an infrared light source and detector. The infrared light is absorbed by the blood, and the pulsation of arterial diameter during a heartbeat causes a pulsation in the light detector signal.

The first step is determining the proper unloaded diameter of the finger arteries, the point at which finger cuff pressure and intra-arterial pressure are equal and at which the transmural pressure across the finger arterial walls is zero, the 'set point'. Then the arteries are clamped at this unloaded diameter by varying the pressure of the finger cuff inflatable bladder using the fast cuff pressure control system. Changes in diameter are detected by means of an infrared photo-plethysmograph built into a finger cuff . If during systole an increase is detected in arterial diameter the finger cuff pressure is immediately increased by a rapid pressure servo-controller system to prevent the diameter change. To fully collapse the finger artery requires a cuff pressure larger than the finger intra-arterial pressure. At zero transmural pressure the artery is not collapsed but ‘unloaded’, that is, the arterial walls are held at zero transmural pressure which corresponds with their unstressed diameter (Wesseling et al. 1995; Imholz et al. 1998). As a result, finger cuff pressure equals intra-arterial pressure when the volume-clamp method is active at the proper unloaded diameter of the finger artery.

For the accuracy of the measurement it is very important to defining the correct unloaded diameter of a finger artery. The unloaded diameter is usually not constant during a measurement and must be verified at intervals due to changes in stress and the tone of smooth muscle in the arterial wall. Therefore, periodically constant cuff pressure are used to adjust the correct unloaded diameter of the finger artery based on the signal from the plethysmograph in the finger cuff.

E. Tonometric Method:

Arterial tonometry is a technique for blood pressure measurement in which an array of pressure sensors is pressed against the skin over an artery. The primary application for tonometry instruments is blood pressure monitoring during surgery. Due to it's real-time, continuous monitoring, Small, lightweight, and portable design they offer unique advantages for applications in home and clinical medical and physiological measurement, and psychological research.

This method was first presented by Pressman & Newgard in 1963, the arterial tonometer method can noninvasively and continuously record pressure alterations in a superficial artery with sufficient bony support, such as the radial artery.

This method uses a rigid sensor array (e.g., by Colin Electronics) a miniature transducer (e.g., by Millar Instruments) or a flexible diaphragm (Drzewiecki et al 1983) which is attached on the skin above the pulsating artery [4].Skin and tissue located between the sensor and the array transfer pressure pulsations between them. The sensor is regarded as correctly positioned, when the pulsations reach their strongest level. This can be making easy by using a sensor array and selecting sensor elements with the strongest amplitude. In this method the sensors should be closely alike in terms of sensitivity. And the sensor array is pushed towards the vessel using; for example, air pressure. The vessel flattens when the pressure and, consequently, the force against the artery wall increases. Arterial pressure in the top of the flattened artery’s center equals the supporting pressure, allowing the recording of an accurate blood pressure profile. If the pressure increases too much, the artery will block totally and the measurement will be erroneous. Thus, with the use of stress distribution information, the hold-down pressure must be continuously controlled. Also, the sensor material must be rigid, which has led to the use of piezoelectric or piezoresistive (made of silicon) materials and the size of the sensor or sensor element must be small relative to the artery .Furthermore, to improve the signal-to-noise ratio, sensor arrays enable the use of motion artifact cancellation methods.

F. Pressure Pulse Transit-Time Method:

Non-invasive blood pressure measurements using cuff based methods provide accurate data for many applications in medicine. However, they have some disadvantages, which limit their application in some cases. The patient may be influenced by pumping the cuff, which may alter the blood pressure. Night time blood pressure measurements using conventional process affect the sleep of the patient and consequently the blood pressure. Furthermore, these methods do not allow continuous monitoring of the blood pressure. A reliable continuous noninvasive blood pressure measurement method is highly desirable. Indirect measurement of blood pressure is based on the elastic properties of arterial vessels and the detection of the pulse transit time (PTT). Pulse wave velocity (PWV), which is the speed of a pressure pulse propagating along the arterial wall, can be simply calculated from PTT. Pulse transition time is the interval between the R-wave of the electrocardiogram and the arrival of the pulse wave in the periphery. It has been reported to an indirect, continuous measure of blood pressure (BP) changes.

When the heart ejects stroke volume to the arteries, it takes a certain transit time until the blood pressure wave arrives in the periphery. This pulse transit time (PTT) indirectly depends on blood pressure – the higher the pressure, the faster PTT. This circumstance can be used for the noninvasive detection of blood pressure changes.

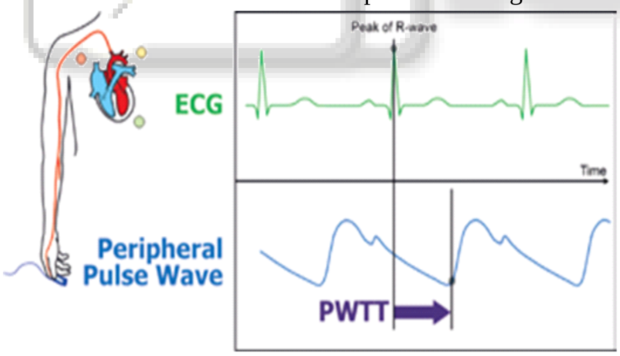

Fig. 3: How PWTT detects change in blood pressure

Arterial blood pressure (BP) was estimated from Electrocardiography (ECG) and PPG waveform. PTT is a time interval between an R-wave of electrocardiography (ECG) and a photoplethysmography (PPG) signal. This method does not require an air cuff and only a minimal inconvenience of attaching electrodes and LED/photo detector sensors on a subject. It was proposed quite early that the elasticity of an artery is related to the velocity of the volume pulses propagating through it. Moens (1878) and Korteweg (1878) derived a mathematical expression for the velocity of the pulse front traveling along an artery as a function of such factors as the elasticity coefficient, the thickness of the arterial wall and the end-diastolic diameter of the vessel lumen. As shown in the formula below, where PWV is pulse wave velocity; t the thickness of the vessel wall, d the diameter of the vessel, ρ the density of blood and E stands for Young's modulus describing the elasticity of the arterial wall (Asmar 1999, McDonald 1974)

$$PWV=sqrt(tE/\rho d)$$

Being dependent on pressure, Young's modulus E is not a constant. The relationship is of the form $E = E_0 e^{\alpha P}$, where E0 is the zero pressure modulus, α is a constant that depends on the vessel, and e is 2.71828 (Geddes 1991, reading 100-103). Thus, Formula (1) can be expressed as

$$PWV=sqrt(tE_0 e^{\alpha P}/\rho d)$$

In practice, it is difficult to estimate how well PWV reflects BP and in how far severe age-dependent or disease-related changes (e.g., atherosclerosis) influence the arterial wall stiffness. In fact, investigations in a larger number of subjects showed that age, BP, gender, and cardiovascular risk factors significantly influence PWV (Yamashina et al. 2003; Mitchell et al. 2004; Schiffrin 2004; Foo and Lim 2006). These results suggest that PWV can only be used for measurement of relative BP changes as it has been shown by a number of studies in human beings and animals (Ochiai et al. 1999; Barschdorff and Erig 1998). However, determination of the individual the PWV–BP relation and calibration of the system would allow the measurement of the absolute BP using the indirect method using PTT. This procedure is time consuming and not feasible in most of the situations.

G. Photoplethysmography for the Pulse Transit Time Method:

During the recent years, healthcare is a very vast and growing market in developing countries. It is now very popular among a people to have check on their health regularly without spending much time and money. This can be solved by usage of so many portable, cheap, reliable and user friendly health monitoring devices. Pulse transit time is a physiological measure which has shown capabilities to address numerous clinical applications.PTT can be measured as the time it takes a pulse wave to travel between two arterial sites.

It can be measured by use of both an Electrocardiograph and a photoplethysmograph or it can be measured by the use of photoplethysmograph (Lutter et al. 2002; Kazanavicius et al. 2003) at two different arterial sites. An ECG machine generates a curve based on the depolarization of the heart while the oximeter measures the pressure wave, or pulse, at any arterial site. A value for pulse transit time is given by calculating the difference in time between the peak of the R wave from the ECG and the peak of the pressure wave from the oximeter or by calculating difference in time between the peaks of two pressure wave from the photoplethysmograph.

A relatively short PTT is observed with high blood pressure (BP), aging, arteriosclerosis and diabetes mellitus. Most methods used for measuring the PTT are cumbersome and expensive. In contrast, the interval between the peak of the R-wave on the electrocardiogram and the onset of the corresponding pulse in the finger pad measured by photoplethysmography can be easily measured. It can be also helpful for measurement of respiratory effort, detection of micro arousals and monitoring stress.

Electronic palpation method:

The noninvasive electronic palpation method for measuring blood pressure was introduced in 1998 [5]. Pressure array transducers based on EMFi-material have been produced, tested and used to measure the heartbeat rate of immobile and moving persons [6] In these measurements, a cuff was applied to the upper arm and pulsations were sensed on the distal side of the wrist.

In blood pressure measurements of this kind, based on the electronic palpation of the amplitude and the transit time of pressure pulse waves, pulsations are detected by a wrist array transducer during the inflation or deflation of the cuff. In the deflation mode, cuff pressure is rapidly inflated over the presumed systolic pressure level and then slowly deflated under the diastolic level. The onset of pulsations corresponds to systolic blood pressure. Diastolic blood pressure, on the other hand, can be determined by the point where the delay in the pressure pulse sensed by the transducer array stops to diminish. Though the same method can be used during cuff inflation or deflation, the latter mode is preferable.

II. CONCLUSION

Blood pressure is an important parameter for health assessment. Noninvasive continuous beat per beat blood pressure measurement is still a complicated and expensive procedure. There is a lack of agreement on the optimal blood pressure measurement technique. This study first described noninvasive blood pressure measurements methods in detail, starting from the historical background and extending to modern methods, focusing on scope of utilization. Potentially the most useful indirect parameter for blood pressure monitoring could be pulse wave velocity or the inverse – pulse transit time. PTT has shown its capabilities in very broad area of clinical applications. Blood Pressure changes, Heart Rate and the compliance of the arterial walls, and so on influence the PTT. [2]. There are a number of different sophisticated pulse transit time measurement techniques, However, the simplest and most convenient method is measured by photoplethysmography (Lutter et al. 2002; Kazanavicius et al. 2003). The reported disadvantage of this described method however is that it is not possible to obtain a “true” value of the pulse transit time, because of a varying pre-ejection time (Robin et al. 1999). However the EP method offers a feasible alternative to the other methods, particularly because it also produces information on the delay and waveform of pressure pulses.

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