An investigation into the accuracy of different types of medical devices used in measurement of blood pressure, temperature and blood glucose

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ABSTRACT

Background: **A variety of methods are now available to measure blood pressure, blood glucose and body temperature using different devices. As an example, blood pressure can be measured by the standard mercury sphygmomanometer method, it can also be measured electronically. It is not known to what extent they are correlated with each other when used in our locality.**

Objectives: **To compare the quality and accuracy of different methods used to measure blood pressure (manual versus automated office blood pressure measurements), blood glucose (glucometer with the laboratory reference method) and body temperature (glass mercury thermometer and digital thermometer).**

Methods: **All measurements were done at Basrah General Hospital during the period from 5th of March to 15th of March, 2017. Measurements for each patient were performed by the same subject. Patients were selected from the surgical wards of Basrah General Hospital. Blood pressure was recorded using both automated oscillometric blood pressure device (Beurer blood pressure monitor) and the standard manual mercury sphygmomanometer for each patient. Blood glucose was estimated using the Accu-Chek glucometer and compared with laboratory data of the same hospital. Capillary blood samples were collected and checked on a glucometer and venous blood sample was sent to the laboratory for glucose estimation at the same time. The laboratory value was used as a reference for comparison. Temperature was recorded using glass mercury thermometer and two types of digital thermometers; one used on forehead (Pic thermometer) and the other used orally (Beurer thermometer). SPSS version 20 was used for statistical analysis.**

Results: **There was no significant difference in the measurement of systolic and diastolic blood pressure by the two methods used in this study; mercury sphygmomanometer and automated oscillometric device (systolic blood pressure 127.75 ± 22.01 mercury versus 128.95 ± 18.7 electronic; similarly for diastolic). The two methods were significantly correlated with each other. Random blood glucose measured by a glucometer and a hospital laboratory method showed that glucometers gave significantly higher values by around 30%. Despite these higher readings, the two methods were still significantly correlated. The three methods used to measure body temperature showed a significant correlation with similar mean values (36.46 ± 0.58, 36.62 ± 0.57, and 36.41 ± 0.51 for forehead electronic, oral electronic, and oral mercury respectively).**

Conclusion: **The methods used to measure blood pressure, blood glucose and body temperature are well correlated with each other, and gave approximately similar readings except the measurement of blood glucose by Accu-check glucometer which gave higher values than the reference laboratory method.**

Keywords: Blood pressure, temperature, blood glucose, measurement

تقصي دقة أنواع مختلفة من الأجهزة المستعملة في قياس ضغط الدم وحرارة الجسم وسكّر الدم

خلفية الدراسة: تتوفر الان طرائق مختلفة لقياس ضغط الدم وسكر الدم وحرارة الجسم باستعمال أجهزة مختلفة. فعلى سبيل المثال يمكن قياس ضغط الدم بالطريقة القياسية باستعمال مقياس ضغط الدم الزئبقي، كما يمكن قياسه الكترونياً. ولا يعرف الى أي مدى تنسجم الطريقتان مع بعضها باستعمالها محلياً.

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الأهداف: لمقارنة جودة ودقة الطرائق المختلفة المستعملة لقياس ضغط الدم (الطريقة المكتبية اليدوية والطريقة الالية الاوتوماتيكية)، وسكر الدم (باستعمال مقياس السكر والطريقة القياسية المختبرية)، وحرارة الجسم (باستعمال المحرار الزئبقي الزجاجي والمحرار الرقمي).

الطرائق: أجريت القياسات كلها في مستشفى البصرة العام خلال الفترة من الخامس والخامس عشر من اذار ٢٠١٧. وأخذت قياسات كل مريض من قبل نفس الشخص. حيث تم اختيار المرضى من الردهات الجراحية في مستشفى البصرة العام، وأجري لهم قياس ضغط الدم باستعمال جهاز قياس ضغط الدم الاوتوماتيكي (جهاز مراقبة ضغط الدم نوع بورر) والطريقة القياسية اليدوية باستعمال مقياس ضغط الدم الزئبقي للمريض نفسه. وقيس سكر الدم باستعمال مقياس السكر نوع أكيوجك، وتمت مقارنته بالطريقة المختبرية المتبعة في المستشفى، حيث استعملت عينات من الدم الشعيري للأولى والدم الوريدي للطريقة المختبرية في الوقت نفسه، واتخذت الطريقة المختبرية كطريقة مرجعية للمقارنة. أما الحرارة فتم قياسها باستعمال المحرار الزجاجي الزئبقي ونوعين من المحرار الرقمي، أحدهما يستعمل على الجبهة (محرار نوع بك) والاخر عن طريق الفم (محرار نوع بورر). وأجريت التحليلات الاحصائية باستعمال البرنامج الاحصائي للعلوم الاجتماعية رقم ٢٠.

النتائج: لا يوجد فرق معتد في قياس ضغط الدم الانقباضي والانبساطي بالطريقتين المذكورتين في هذه الدراسة، الزئبقية والاتوماتيكية (الضغط الانقباضي ١٢٧.٧٥ ± ٢٢.٠١ للزئبقي مقابل ١٢٨.٩٥ ± ١٨.٧ للإلكتروني)، وكذلك بالنسبة للانبساطي. والطريقتان مرتبطتان مع بعضهما بشكل معتد. أما سكر الدم العشوائي المقاس بمقياس السكر وبالطريقة المختبرية في المستشفى فقد ظهر أن مقياس السكر أعطى قيماً أعلى وبنسبة حوالي ٣٠% وبشكل معتد. وعلى الرغم من هذه القراءات العالية، فان الطريقتين لا زالتا مرتبطتين مع بعضمهما وبشكل معتد. أما الطرائق الثلاثة اللاتي استعملت لقياس حرارة الجسم فأظهرت إرتباطاً معتدّاً وبمعدلات متشابهة (± 36.46 0.51 ± 36.41 0.57 ± 36.62 ,0.58 للزئبقي عن طريق الفم والالكتروني عن طريق الفم والالكتروني في جبهة الرأس على التوالي).

الاستنتاج: إن الطرائق التي استعملت لقياس ضغط الدم وسكر الدم وحرارة الجسم مترابطة مع بعضها وأعطت قراءات متشابهة تقريباً عدا قياس سكر الدم باستعمال مقياس السكر أكيوجك والذي أعطى قيماً أعلى من الطريقة المختبرية القياسية.

الكلمات المفتاحية: ضغط الدم، سكر الدم، حرارة الجسم، قياس

INTRODUCTION

Diabetes mellitus has been reported to reach an epidemic proportion globally. Direct relationship between the glycemic control and the risk of systemic complications was found in both type 1 and type 2 diabetes.[1,2] The American Diabetes Association (ADA) suggested self-monitoring of blood glucose (SMBG) to achieve and maintain specific glycemic targets. ADA recommends that all insulin-treated patients perform SMBG to achieve and maintain glycemic control, prevent and detect hypoglycemia, and to adjust changes in lifestyle. SMBG is also used in establishing the need for insulin therapy in gestational diabetes mellitus.[1] The introduction of glucometers has allowed greater accuracy and reliability of results compared with strip technology. However, despite the advances in technology, there is a significant variation among these monitoring devices, which has led to the development of performance guidelines by organizations such as the ADA,[1,2] and the International Standardization Organization (ISO). The ISO guidelines recommend that the accuracy criteria for values < 100 mg/dl to ±

10% and ± 20% for values ≥ 100 mg/dl. However, the ADA recommends a ± 5% variation for all values.[3,4]

Taking a body temperature is the most frequently performed clinical observation. Although the use of digital thermometer is gradually increasing, glass mercury thermometer (GMT) is still the most common device used in the pediatric setting, especially in developing countries in spite of having longer dwelling time, danger of breakage, potential harmful and toxic vapor effects, difficulties in reading, and possible role in spread of hospital acquired infections.[5-7] Controversial results were reported regarding the accuracy of GMT (glass mercury thermometer) and DT (digital thermometer) in measuring true body temperature and their ability to detect fever and hypothermia.[8,9] Research in this area is scarce. Even the little documented studies have large discrepancies.[10] Due to these inconsistencies, nurses are challenged in selecting the measurement method that is most appropriate for a patient and provides the most accurate and precise approximation of core temperature. False low or high results in thermometer measurements and the dwelling time may lead to misdiagnosis and wrong treatment. DTs may become the standard device used in clinical settings. Thus, they must be subjected to rigorous investigations about their accuracy to improve clinical practice and to see whether or not DT is a suitable alternative to GMT in children.

Accurate measurement of blood pressure is critical for making appropriate clinical decision in management of high blood pressure to reduce cardiovascular risk and prevent target organ damage. An inaccurate measurement of blood pressure could lead to a patient being falsely classified as hypertensive or having high normal or normal blood pressure.[11,12] Therefore, an accurate reading is essential. There are three non-invasive modalities commonly used to check blood pressure namely the manual mercury sphygmomanometer, aneroid meter and the automated oscillometric device.[13,14] The manual mercury sphygmomanometer is considered to be the gold standard if used by a trained nurse or doctor. [15] There is an ongoing debate whether mercury sphygmomanometers should be replaced with the automated oscillometric devices. Mercury is a toxic substance and is considered an environmental hazard. It has been banned in various European countries such as Sweden and Netherlands as well as in numerous hospitals in the United States. [15,16] A number of factors can affect manual blood pressure measurements such as the site of placement of the cuff, the size of the cuff, type of stethoscope, following proper protocol, patient's age group, pregnancy, exercise, arrhythmias and white coat response.[17] Readings can also vary depending on whether the nurse or the doctor is conversing while taking the measurement and whether there is a background noise or not. All these factors can contribute towards possibly inaccurate BP readings, with a potential for misdiagnosis and inappropriate treatment.[13] Apart from the above-mentioned causes that are mostly associated with the manual mercury sphygmomanometer, there are causes that might influence the readings of both automated oscillometric BP devices and the manual BP like respiration, emotion, tobacco, alcohol, temperature, bladder distension, pain and exercise. Most of these are controllable, while some are non-modifiable like age, race and diurnal variation Automated oscillometric devices are seen to be less influenced by most of these factors and recent studies indicate that they virtually eliminate the white coat response. [14] This study was performed to check the validity of automated oscillometric BP measurements as compared to the manual BP measurements, and also the different methods used to measure blood glucose and body temperature.

PATIENTS & METHODS

All measurements were performed at Basrah General Hospital during the period from 5th of March to 15th of March / 2017. Measurements for each patient were performed by the same investigator. Patients were selected from the surgical wards of Basrah General Hospital. Blood pressure was recorded in adult patients using both automated oscillometric blood pressure device (Beurer blood pressure monitor) and a manual mercury sphygmo-manometer for the same patient.

Procedure

Mercury sphygmomanometer[15]

Prepare the patient: Make sure the patient is relaxed by allowing 5 minutes to relax before the first reading. The patient should sit upright with their upper arm positioned so it is level with their heart and feet flat on the floor. Remove excess clothing that might interfere with the BP cuff or constrict blood flow in the arm. Be sure you and the patient refrain from talking during the reading.

Determine a systolic estimate of the patient's blood pressure by inflating the cuff until the radial pulse can no longer be palpated. Inflate 30mmHg and release the valve at 2mmHg per second until the radial pulse reappears. Record this reading as the systolic blood pressure estimate.

Wait 3 minutes to allow adequate circulation to return.

Inflate cuff to 30mmHg higher than the "systolic estimate". Slowly deflate the cuff at 2mmHg per second and, using a stethoscope, record measures corresponding to the 1st and 5th korotkoff sounds.

Record systolic and diastolic measures on data collection form.

Double Check for Accuracy: The AHA recommends taking a reading with both arms and averaging the readings. To check the pressure again for accuracy wait about five minutes between readings. Typically, blood pressure is higher in the mornings and lower in the evenings.

Breuer blood pressure device[16]

Fit the cuff round your bare left upper arm. Blood circulation in the arm should not be restricted by tight clothing or other objects. The cuff should be placed on the upper arm so that the lower edge is 2 to 3 cm above the bend of the elbow and above the artery. The tube should be in line with the centre of the palm. Now place the free end of the cuff snugly, but not too tightly, around the arm, and fix it with the Velcro fastener.

The cuff should be fitted tight enough to allow just two fingers to fit beneath the cuff. Insert the cuff tubing into the socket for the cuff attachment.

Correct posture

- Rest for approx. 5 minutes before each measurement. Otherwise there may be divergences.
- You can perform the measurement either sitting or lying down. Always make sure that the cuff is on a level with your heart.
- To carry out a blood pressure measurement, make sure you are sitting comfortably with your arms and back leaning on something. Do not cross your legs. Place your feet flat on the ground.
- In order not to distort the result, it is important to keep still during the measurement and not talk.

Blood glucose [17]

Blood glucose was measured in diabetic and non-diabetic adults, using Accu-Chek® Active glucometer (Ser.No.GU03602852, 50 tests strips REF=06656757, Roche}, and compared with hospital laboratory data based on spectrophotometer methods. Capillary blood samples were checked on the glucometer and venous blood sample was sent to the laboratory for glucose estimation. The laboratory value was used as a reference for comparison. Efforts were made to cover all ranges of plasma glucose in the samples that were collected. Glucose

levels were estimated as random blood glucose from diabetic and non-diabetic patients.

Random blood glucose: is a [blood sugar] test taken from a non-[fasting] subject-recorded irrespective of when food was last ingested-[18].

Temperature

The temperature was recorded in 43 individuals, using glass mercury thermometer (GMT) and two types of digital thermometers (DT); one used on forehead (Pic thermometer) and the other used orally (Beurer thermometer). Both digital and mercury thermometers were used orally, and the Pic thermometer applied to the forehead on the temporal artery distribution, as follow:

The digital oral thermometer [19-21]

- Clean the pointed end (probe) with soap and warm water or rubbing with alcohol or antiseptic material. With the mouth open, put the covered tip under the tongue.
- Close the lips gently around the thermometer.
- Keep the thermometer under the tongue until the digital thermometer beeps.
- Read the numbers in the window. These numbers represent the temperature.

The oral mercury thermometer [22,23]

- Hold the thermometer by the end opposite the colored (red, blue, or silver) tip.
- Clean the thermometer with soap and warm water or rubbing alcohol. Rinse with cool water.
- Turn the thermometer in your hand until you see the red, blue, or silver line. The line should read less than 96° F (35.6°C). If the line reads more than 96° F (35.6°C), firmly shake the thermometer downward several times.
- With the mouth open, put the end with the red, blue, or silver-colored tip under the tongue.
- Close the lips gently.
- Keep the thermometer under your tongue for 3 minutes.
- Remove the thermometer without touching the tip.

The Pic thermometer

- The forehead measurement that taken is converted into its oral equivalent, the temporal artery is connected to the heart through the carotid artery, and the device is designed to measure the surface of the skin along the temporal artery.
- Press the button on, for approximately two seconds, the complete display will appear and the two beeps will sound, after 5 seconds it will record the result.
- Statistical analysis of the results was made using SPSS version 20. ANOVA and Paired t-test was used to compare between the measurements of each patient. Pearson's correlation coefficient was used to test the significance of the association between measurements.

RESULTS

1. Blood pressure measurement: Correlation between mercury and electronic methods

There is no significant difference between the mean readings of systolic and diastolic blood pressure measured by mercury and electronic methods (Table-1). The two methods are well and significantly correlated (Figure 1&2, $P < 0.01$).

Table 1. Measurement of systolic and diastolic blood pressure by mercury phygmomanometer and electronic methods

Method	Number	Systolic	Diastolic	Significance
Mercury	55	127.75 ± 22.01	79.25 ± 13.33	No significant difference
Electronic	55	128.95 ± 18.7	81.05 ± 13.52	

Data are expressed as means ± SD of n=55.

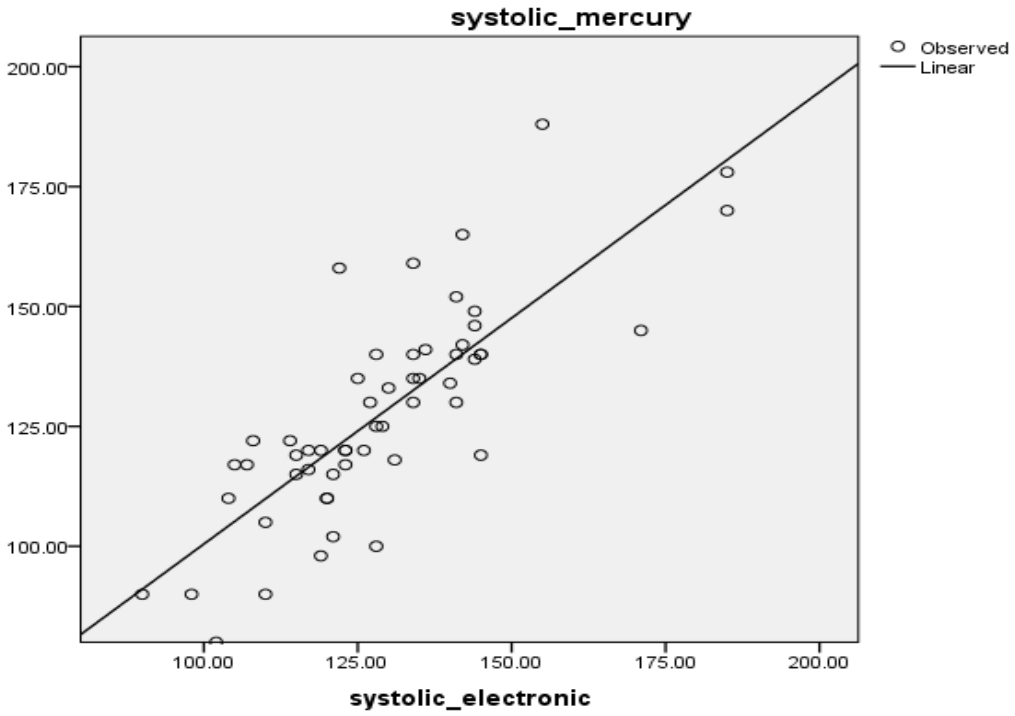


Fig 1. Correlation between systolic blood pressure measured by mercury and electronic methods, (r = .801 , P < 0.01)

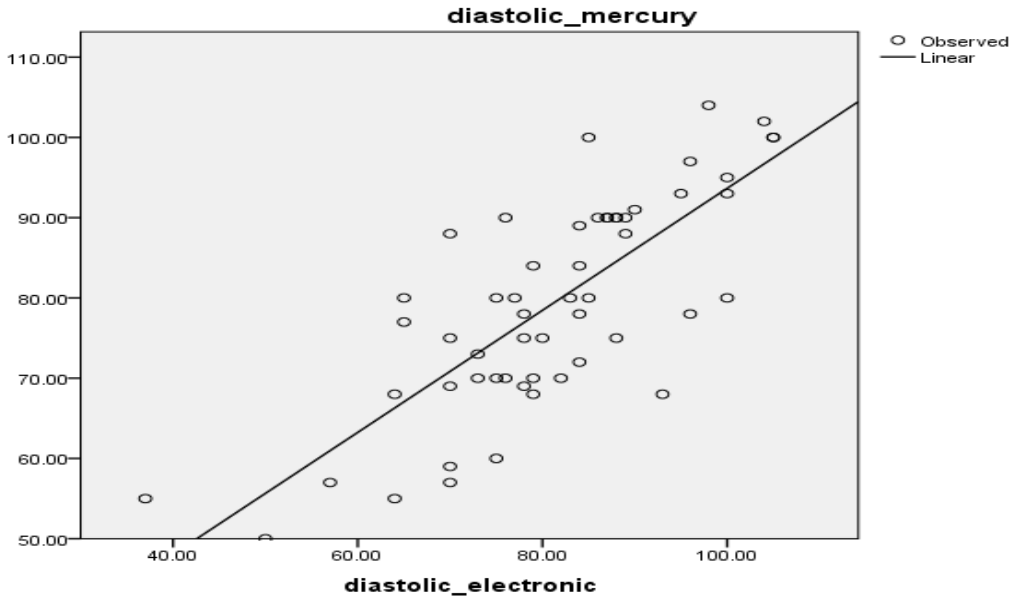


Fig 2. Correlation between diastolic blood pressure measured by mercury and electronic methods (r = .771 , P < 0.01)

2. Comparison between laboratory and glucometer methods in measurement of blood glucose

Measurement of random blood glucose by the glucometer gave a mean value higher than the reference laboratory method by 29.6% (193.6 vs 149.1 mg/dl, Figure-3). This difference is statistically significant (P < 0.001). Still, the two methods are significantly correlated (r = .888, P < 0.01, Figure 4). When the correlation between the two methods were compared using normal and high values of blood glucose separately, similar trend was found (An increase by 36% and 25.5% for normal and high blood glucose levels respectively when measured by the glucometer method, Table-2).

Table 2. Comparison between normal and high blood glucose levels measured by laboratory and glucometer methods.

Blood glucose level (mg/dl)	Number	Laboratory method	Glucometer method	Correlation
Normal (62 - 130)	29	93.44 ± 16.72	127.2 ± 27.04	P < 0.05
High (144 - 550)	15	256.67 ± 119.5	322 ± 132	P < 0.01

Data are expressed as means ± SD

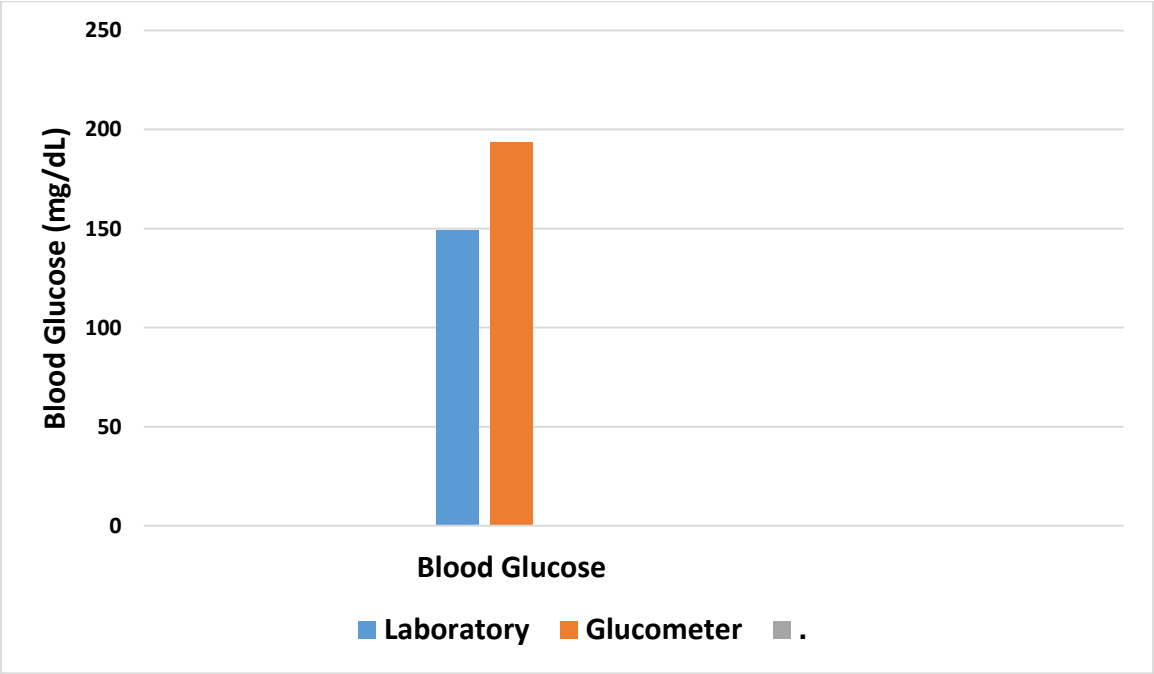


Fig 3. Blood glucose level measured by laboratory and glucometer methods

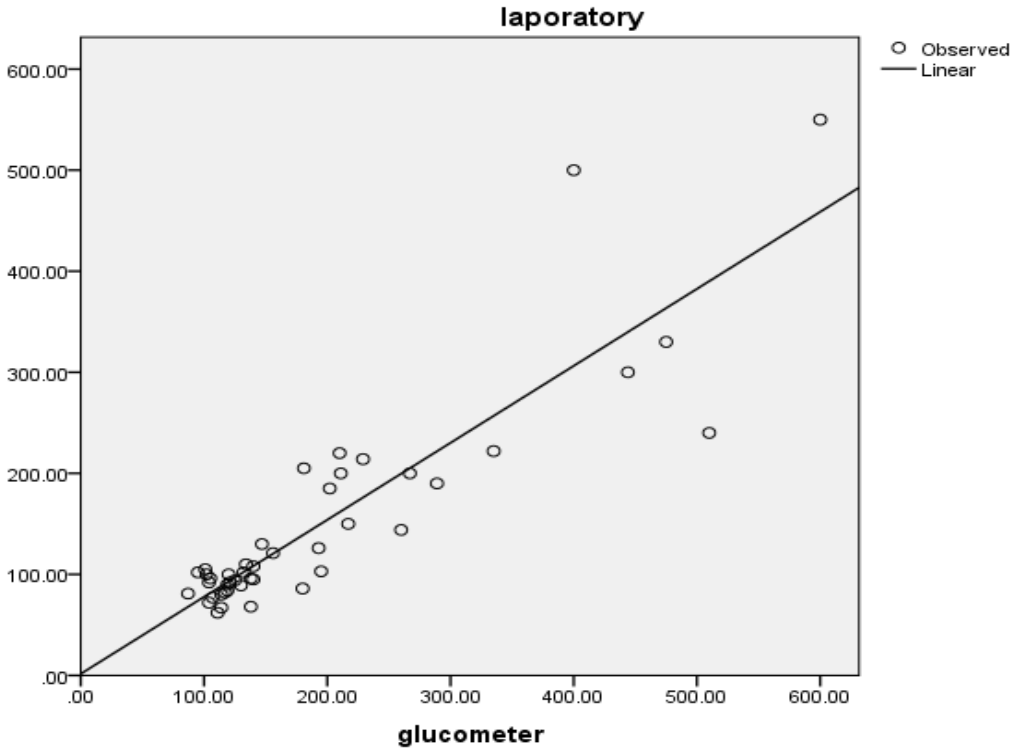


Fig 4. Correlation between blood glucose level measured by laboratory and glucometer methods. (r = .888 , P < 0.01)

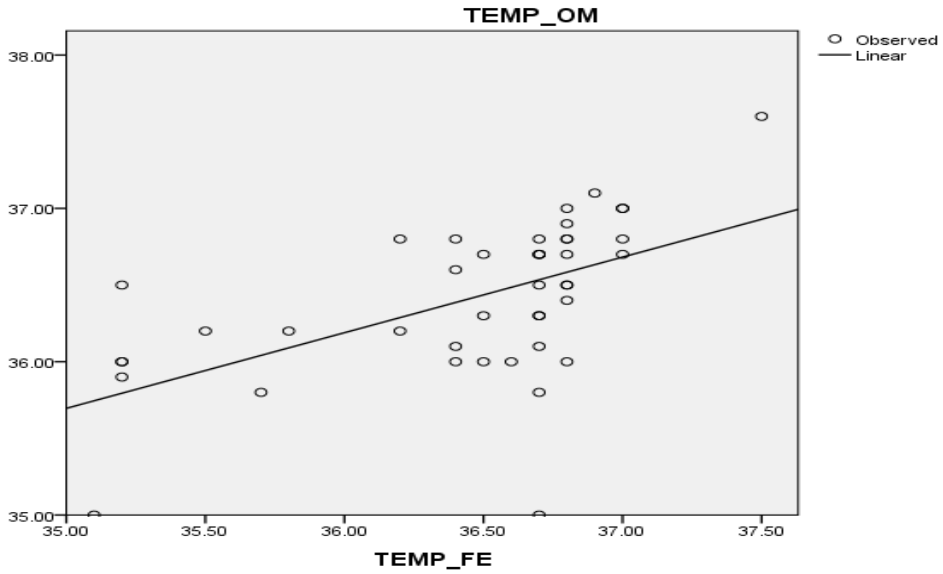
3. Comparison between body temperature measured by 3 methods: forehead electronic, oral electronic, and oral mercury.

The mean values of body temperature measured by the three methods (forehead electronic, oral electronic, and oral mercury) are not significantly different (Table-3). The three methods are significantly correlated ($P < 0.001$, Figure 6-A,B,C, Table-4).

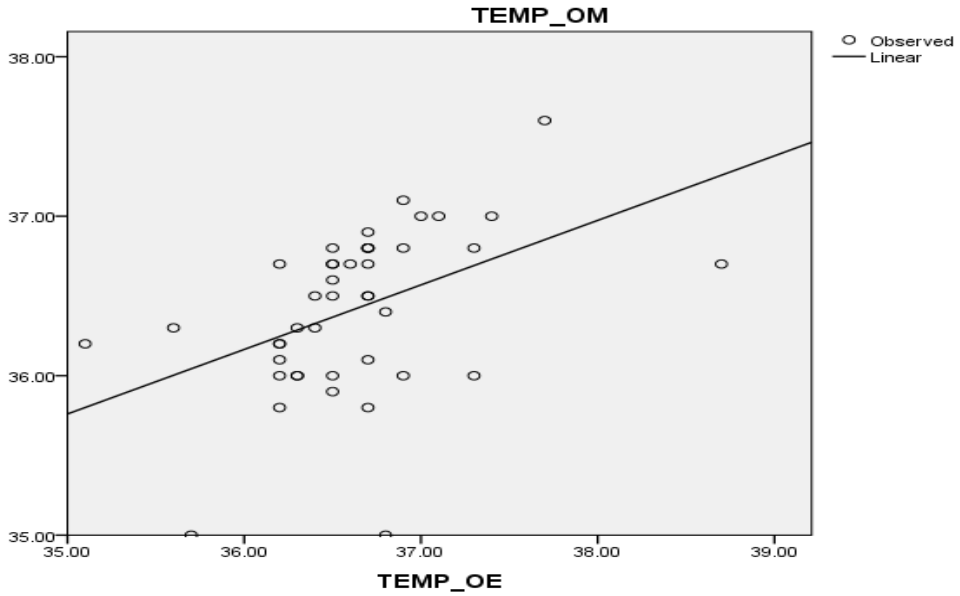
Table 3. Comparison between body temperature measured by three methods: forehead electronic, oral electronic, and oral mercury.

Method	Number	Body temperature	Significance
Forehead electronic	43	36.46 ± 0.58	No significant difference
Oral electronic	43	36.62 ± 0.57	
Oral mercury	43	36.41 ± 0.51	

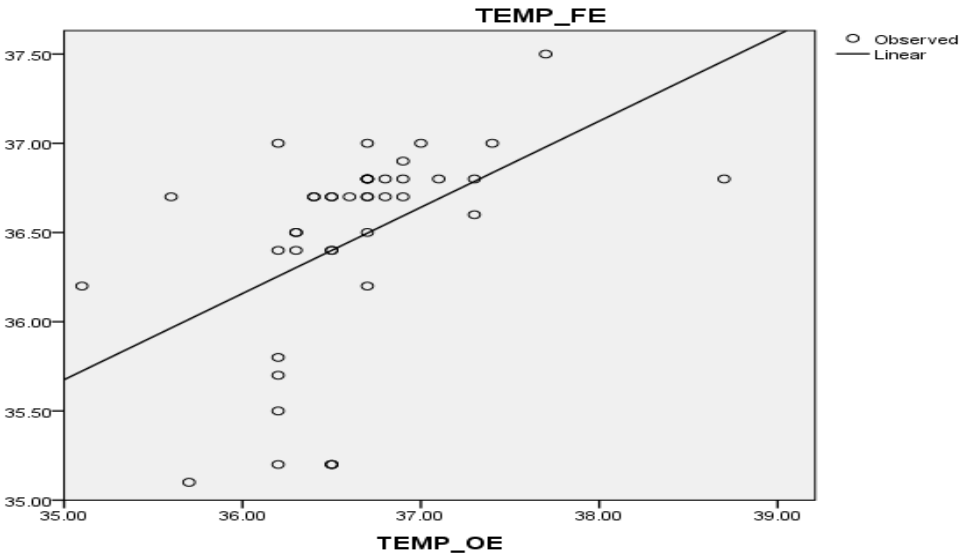
Data are expressed as means ± SD of n=43.



(A) Correlation between forehead-electronic and oral-mercury methods in measurement of temperature ($r = .563$, $P < 0.001$)



(B) Correlation between oral-electronic and oral-mercury methods in measurement of temperature (r = .448, P < 0.001)



(C) Correlation between forehead-electronic and oral-electronic methods in measurement of temperature (r=.469, P < 0.001)

Fig 5 (A, B, C). Correlation between the three methods of measurement of temperature: forehead-electronic, oral-electronic and oral-mercury

Table 4. Statistical analysis of the correlation of temperature measured by the 3 methods.

Correlation between:	Number	Pearson's correlation (r)	Significance at 0.01 level (2 tailed)
FE vs OE	43	.469	P < 0.001
FE vs OM	43	.563	P < 0.001
OE vs OM	43	.448	P < 0.001

FE: Forehead electronic, OE: Oral electronic, OM: oral mercury

DISCUSSION

Accurate measurement of blood pressure, blood glucose and temperature is essential for correct diagnosis and effective treatment. Self-measurement of blood pressure, blood glucose and temperature provides valuable information for diagnosis and for control of diseases. It also improves compliance with antihypertensive and antidiabetic therapies.[23,24] Although, it is appropriate to encourage the widespread use of self-recorded blood pressure, blood glucose and temperature, it is equally important to make sure that these methods are accurate and precise.[25] The latter statement becomes the aim of this study. The general impression of the local population is that electronic devices for measurement of blood pressure and glucose levels as well as temperature are less accurate than mercury and laboratory methods. The present study showed that measuring blood pressure by mercury sphygmomanometer as a standard method and Breuer electronic blood pressure device are well correlated with each other with mean values close to each other. Blood pressure measurement by a trained subject using auscultatory techniques, for example, mercury sphygmomanometer remains the gold standard and most accurate of indirect blood pressure measurement.[26] The alternative devices using auscultation have similar observer bias associated with auscultation itself. However, oscillometric instruments are currently replacing the mercury sphygmomanometers with more accurate devices are now appearing on the market.[26] Oscillometric techniques, however, cannot measure blood pressure accurately in all situations, particularly in patients with pre-eclampsia, and arrhythmias such as atrial fibrillation.[26,27] All alternative blood pressure measurement devices need to be clinically validated against the current mercury sphygmomanometer.[28] Measurement of glucose by a glucometer, on the other hand, gave higher values of the mean blood glucose levels than the hospital laboratory method; although they are still significantly correlated. Arterial blood is expected to give higher glucose levels compared to venous blood because arterial blood is being delivered to the tissues where glucose is absorbed as an energy source.[29] Measurement of body temperature by the three methods (forehead electronic, oral mercury, oral electronic) resulted in a very close reading with a statistically significant correlation. Finally, it can be concluded that blood pressure measurement can accurately be measured using electronic devices. Similar finding with electronic thermometers for measurement of

temperature. However, the glucometer used in this study gave higher but well correlated results than the hospital laboratory method.

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