Validation of stroke volume variation assessed by electrical cardiometry to predict fluid responsiveness in patients undergoing coronary artery bypass surgery after closure of the sternum: an observational study

Ahmed Said, Maged Salah, Sherif Mamdouh, Eslam Heggy, Mohamed Wagih

Department of Anesthesia, Critical Care and Pain Management, Kasr Al-Aini Hospitals, Cairo University, Cairo, Egypt

Correspondence to Ahmed Said, MD, Department of Anesthesia, Critical Care and Pain Management, Cairo University Hospitals, Cairo 4452004, Egypt. Tel: +20 100 528 7692; fax: +20224708237; e-mail: Ahmed.Hilal@kasralainy.edu.eg

Received: 3 July 2022
Revised: 31 October 2022
Accepted: 6 November 2022
Published: 3 January 2023

The Egyptian Journal of Cardiothoracic Anesthesia 2022, 16:47–52

Background
Cardiac output is an important determinant of tissue perfusion, with several methods described to assess it. Electrical cardiometry is a new noninvasive method for determination of stroke volume variation (SVV), which is used to calculate the cardiac output.
Aim of work
This study aimed to validate the electrical cardiometry measurements of SVV compared with measurements of SVV taken by transesophageal echocardiography (TEE).
Methods
A total of 38 patients were included in this study. Hemodynamic parameters were obtained by TEE and cardiometry soon after closure of the sternum and after volume expansion.
Results
SVV after 10 min of sternum closure by TEE was 15.5% (SD=7.1), and SVV after 10 min of sternum closure by cardiometry was 14.3% (SD=6.1). Bland–Altman analysis revealed a mean bias of −1.2. The 1.96 SD limits of agreement were −8 to 5.7%.
Conclusion
There is a good correlation between SVV measured by TEE and that measured by cardiometry. Cardiometry can be used as a noninvasive hemodynamic monitoring in patients undergoing coronary artery bypass surgery surgery.

Keywords:
cardiometry, stroke volume variation, transeosphageal echocardiography

Egypt J Cardiothorac Anesth 16:47–52

1687-9090

Introduction

Intraoperative fluid administration in cardiac surgery patients is a crucial issue that affects cardiac output (CO) and must be monitored to avoid hypovolemia and organ dysfunction. For optimum fluid management, the concept of goal-directed therapy was raised to guide fluid therapy using hemodynamic variables, and many devices are used to monitor them; one of these variables is stroke volume variation (SVV) [1–4].

In patients undergoing cardiac surgery, SVV is used to assess hypovolemia and fluid responsiveness by various devices such as the FloTrac/Vigileo system (Edwards Lifescience LLC, Irvine, CA, USA), which uses arterial pressure waveform analysis to calculate stroke volume (SV) and CO, and the PiCCOplus system (Pulsion Medical Systems, Munich, Germany), which is based on two physical principles: transpulmonary thermodilution and pulse contour analysis. Both principles allow the calculation of hemodynamic parameters [5].

Although impedance cardiography was first proposed by Kubicek and colleagues for measurement of SV, CO, and other cardiovascular parameters for aerospace programs [6], cardiometry is considered now a new technique used to measure SVV; the idea of its function depends on continuous measurement of the changes of electrical conductivity within the thorax. By sending low-amplitude, high-frequency electrical current through the thorax, the resistance that the current faces (due to several factors) is measured.

Through advanced filtering techniques, electrical cardiometry (EC) is able to isolate the changes in conductivity created by the circulatory system.

The aim of this study was to validate the accuracy of noninvasive cardiometry to measure SVV and CO

 DOI: 10.4103/ejca.ejca_8_22

against transesophageal echocardiography (TEE) in patients undergoing coronary artery bypass surgery (CABG) following sternal closure.

As SVV is considered a reliable tool to assess the fluid responsiveness under certain conditions as the patient must be mechanically ventilated with adequate tidal volumes and have a closed chest and be in sinus rhythm [7,8], in this study, we used cardiometry in cardiac surgery patients after closing the sternum.

Patients and methods

The study design was approved by ethics and research committee of Department of Anesthesiology, Faculty of Medicine, Cairo University. The study included 38 patients. All of them gave informed consent either by themselves or their legally authorized representatives, and all of them were scheduled for surgical procedures under general anesthesia at Kasr Al-Aini Teaching Hospital, Cairo University.

Inclusion criteria

Age range was from 18–70 years of the included patients undergoing CABG, and ejection fraction was greater than equal to 50%.

Exclusion criteria

Off-pump CABG, renal impairment (creatinine<1.5 mg/dl), hepatic impairment (elevated liver enzymes), congestive heart failure (e.g. orthopneic patients and patients with pulmonary edema and low oxygen saturation), aortic aneurysms (the diameter of the ascending aorta is greater than equal to 1.5 times the expected normal diameter or the diameter of ascending aorta is more than 4 cm in patients less than 60 years), arrhythmias, redo surgeries, or emergency procedures were the exclusion criteria.

All the patients were thoroughly evaluated preoperatively. Chest radiography, ECG, echocardiography, and patient's height and weight were obtained. Routine general and cardiac monitoring was employed. Four leads of cardiometry device ICON Osypka (Osypka Medical, Berlin, Germany) Medical were applied on the left side of the neck and left lateral chest wall. The leads use a highly conductive AgCl wet gel and strong hypoallergenic adhesion to provide instant electrical contact for high-quality signal conductivity.

The skin was inspected to ensure that there are no small abrasions or openings, as these openings may interfere with the pathway of current and affect the measurements. The skin was cleaned thoroughly of any lotion, oils, and dead skin using a wet towel or alcohol if needed, and we were sure that the skin was dry and clean before the electrodes are placed.

Standard anesthesia induction regimen was followed, and TEE probe of Philips HD11XE Ultrasound System (La Jolla, California, USA) was inserted. The patient was ventilated by tidal volume of 6–8 ml/kg. Restricted fluid management was followed throughout the pre\during\post-bypass periods guided by central venous pressure (CVP).

Conclusion of bypass was done according to standard protocols. Inotropic and vasopressor support was initiated according to CVP and cardiac function. Fluid restrictive strategy was followed with replacement of one third the urinary output.

After closure of the sternum, CVP, pulse pressure variation (PPV), and SVV using TEE were measured to detect if the patient is fluid responder or not. Patients with CVP less than equal to 5 mmHg, PPV greater than equal to 13%, and SVV greater than equal to 10% were considered fluid responders, whereas patients with CVP greater than equal to 5 mmHg, PPV less than equal to 13%, and SVV less than equal to 10% were excluded from the study.

Fluid bolus of 5 ml/kg crystalloids (Ringer) was given. Hemodynamic parameters and SVV were measured after closure of the sternum using ICON Osypka Medical, Inc., (La Jolla, California, USA) and Philips HD11XE Ultrasound System using a longitudinal transgastric view at 110–130°, with an angle between the beam and the blood flow always inferior to 20°. Pulse-wave Doppler on the Left ventricular outflow tract (LVOT) was performed to measure velocity-time integral, which was used to calculate SVV.

Data were collected at two intervals: first, after closure of the sternum before volume expansion and the other 10 min after volume expansion. Measurement tools included heart rate (HR), blood pressure (BP) estimated by arterial wave forms, SVV estimated by TEE, and SVV estimated by cardiometry.

Results

A total of 42 patients aged 18–70 years old with ejection fraction greater than equal to 50% were enrolled in the current study. Four patients were excluded as they showed PPV less than equal to 10, SVV less than equal to 13, and CVP greater than equal to 5. Therefore, data from 38 patients were analyzed, showing that the mean age of patients was 57.9±7.1 years. A total of 28 (74%) patients were males, whereas 10 (26%) patients were females.

Regarding demographic data of medical conditions associated in the 38 enrolled patients, the current study showed 35 hypertensive patients with a percentage of 83% and 15 diabetic patients with a percentage of 36% (Table 1).

Fluid responders among diabetic patients were as follow: 12 patients were found to be fluid responders with a percentage of 80% and only three patients were nonresponders with a percentage of 20%; this may be attributed to vasoplegia associated with diabetes (Table 2).

Regarding hemodynamic monitoring after closure of the sternum and 10 min after volume expansion, data are expressed in the form of mean±SD. HR was 92.4 ±13.9 soon after closure of the sternum, whereas after volume expansion HR was 89.5±13.2, with *P* value greater than 0.001. Systolic BP was 115.9±16.7 after closure of the sternum, whereas after volume expansion systolic BP was 123.2±15.4, with *P* value greater than 0.001. Diastolic BP soon after closure of the sternum was 65±11.1, whereas diastolic BP after volume expansion was 67.9±10.7, with *P* value greater than 0.001. SVV by cardiometry after closure of the sternum was 19±6.7, whereas after volume expansion was 14.4 ±6.2, with *P* value greater than 0.001. SVV by TEE was 17±6.1, whereas after volume expansion SVV by TEE was 15.6±7.2, with *P* value greater than 0.001 (Table 3).

Table 1 Demographic data regarding medical conditions

Hypertension	Diabetes mellitus
35	15
83%	36%

Table 2 Number of fluid responders among diabetic patients

	Responders	Nonresponders
Number	12	3
Percentage	80	20

Table 3 Comparison between hemodynamics before and after volume expansion

	Soon	10 min	
	Mean±SD	Mean±SD	*P* value
HR	92.4±13.9	89.5±13.2	<0.001£
Systolic blood pressure	115.9±16.7	123.2±15.4	<0.001£
Diastolic blood pressure	65.0±11.1	67.9±10.7	<0.001£
SVV by cardiometry	19.0±6.7	14.4±6.2	<0.001£
SVV by TEE	17.0±6.1	15.6±7.2	<0.001£

HR, heart rate; SVV, stroke volume variation; TEE, transesophageal echocardiography.

Agreement

SVV after closure of sternum by TTE was 17% (SD=6), and SVV after closure of sternum by cardiometry was 19% (SD=6.6). Bland–Altman analysis revealed a mean bias of 2. The 1.96 SD limits of agreement were −5.1 to 9% (Fig. 1). SVV after 10 min of sternum closure by TTE was 15.5% (SD=7.1), and SVV after 10 min of sternum closure by cardiometry was 14.3% (SD=6.1). Bland–Altman analysis revealed a mean bias of −1.2. The 1.96 SD limits of agreement were −8 to 5.7% (Fig. 2).

Discussion

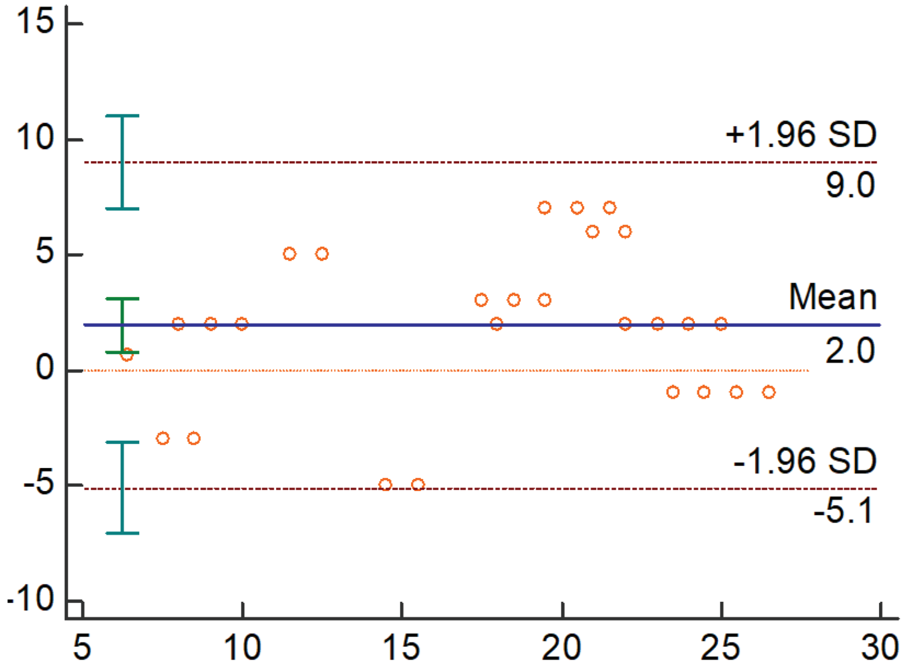
The aim of the current study was to validate using SVV measured by cardiometry as a predictor of fluid responsiveness in patients undergoing CABG using TEE as a standard for measuring SVV. The current study showed a strong agreement between SVV measured by TEE and SVV measured by cardiometry as a predictor of fluid responsiveness.

CO monitoring is one of the most important items to be fulfilled in critically ill patients and those under anesthesia. Several methods were invented to provide a simple, real-time, accurate method for monitoring, one of which is EC. Variable studies were done to validate cardiometry in different clinical situations and in different age groups, most of which were directed to pediatric population.

Erin and colleagues showed that EC accurately measures HR and duration of systole when compared with TTE. SV measurements correlate but have a high bias and percentage error. Knowledge of LVOT area, by a one-time, measurement with TTE, could improve prediction of SV by EC [9]. Our current study showed good correlation between EC and TEE in predicting SVV. However, Erin and colleagues used transthoracic echo and measured SV only, which may explain the difference.

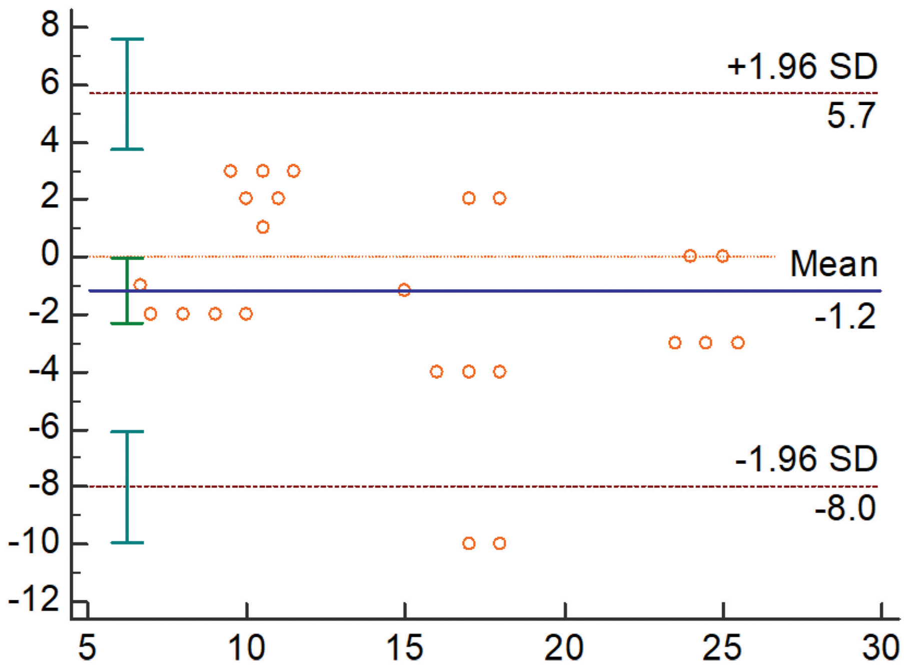
A meta-analysis done by Sanders and colleagues showed that EC cannot replace TD and TTE for the measurement of absolute CO values. The trending ability of EC could not be assessed in this meta-analysis, owing to a lack of agreement on the statistical methodology in the included studies. Therefore, EC might still be applicable as a trend

Figure 1



Bland–Altman plot for SVV after closure of the sternum by TEE and cardiometry. SVV, stroke volume variation; TEE, transesophageal echocardiography.

Figure 2



Bland–Altman plot for SVV 10 min after volume expansion by TEE and cardiometry. SVV, stroke volume variation; TEE, transesophageal echocardiography.

monitor to measure acute changes in CO, which is relevant for clinical decision-making [10]. However, this meta-analysis differs from the current study as it involves cardiac and noncardiac population and that the current study uses TEE as a reference.

Chaiyakulsil *et al.* [11] showed that TTE and EC might be used interchangeably in pediatric critical care settings with stable hemodynamics. Although this study is consistent with our current study, it is to be mentioned that it was conducted on pediatric population and used TTE, whereas the current study was on adult population and used TEE.

Liu *et al.* [12] validated the use of EC for CO monitoring during cardiopulmonary exercise testing, which is consistent with the results of the current study.

Naurala *et al.* [13] demonstrated that cardiac indices measured in children with a variety of structural heart diseases using EC reliably represent absolute values obtained using Pulmonary artery catheter (PAC), which is consistent with the findings of the current study regarding validation of EC.

Jean and colleagues showed that poor correlation and lack of agreement between absolute values of cardiac index (CI) measured by impedance cardiography and transthoracic Doppler echocardiography were found in resting healthy volunteers. The Niccomo device was also unreliable for monitoring changes in CI during hemodynamic load challenge [14]. These results are not consistent with findings of the current study as it uses CI instead of SVV. Moreover, Icon technology is based on a different mechanism other than Niccom, and Jean used TTE, whereas the current study used TEE as a standard.

Ralf *et al.* [15] stated that compared with TTD, EC provides accurate and reliable measurements of SV and CO in clinically stable obese children and adolescents. These findings are consistent with the current study findings; however, they have different populations and standards.

Boet *et al.* [16] stated that measurement of SV and CO with EC in hemodynamically stable preterm infants showed good correlation and variability similar to that of echocardiography. These findings are consistent with the current study findings; however, they have different populations and standards.

Song *et al.* [17] showed that EC correlated with echo findings of right ventricular output and left ventricular output with limitations regarding low output and high-frequency ventilation. These findings are consistent with the current study findings; however, they have different populations.

Zakarias and colleagues stated that the newly engineered, noninvasive tool ICON is based on EC and uses hemodynamic parameters in both neonatal and pediatric care as well as in adults. The operating principle is simple: the conductivity of the blood in the aorta shows time-dependent changes. Before the opening of the aortic valve, the orientation of the red blood cells is random, and the opening of the aortic valve achieves a parallel position of the red blood cells. The tool senses the conductivity between four placed electrodes, and measures the SV and CO, before calculating other additional parameters (e.g. systemic vascular resistance) by tracing the variation of bioimpedance according to changes in the heart cycle. The most important advantages of ICON are the measurements that are made available immediately as well as continuously, and the low complication rate that originates from its noninvasive operation. ICON is a new, promising hemodynamic device in the tool belt of intensive care. Owing to the nature of the device, it is possible to evaluate the status of the patient on a continuous basis, allowing for optimal care [18]. This study is consistent with the findings of the current study.

Hsu and colleagues stated that electric cardiometry and echo have a wide but clinically acceptable agreement in measuring CO in preterm infants with patent ductus arteriosus. However, for infants with high CO or ventilated by high-frequency ventilation, interpretation of COEC should be approached with caution [19]. The results of that study are convenient with the results of the current study, although both study different age groups and medical conditions.

Yoshida and colleagues stated that EC allows noninvasive continuous monitoring of hemodynamics and has recently been used in nonpregnant patients. They compared the use of EC versus transthoracic echocardiography in healthy pregnant women and evaluated hemodynamics immediately after vaginal delivery. A significant correlation was found between the two methods [20], which is consistent with the current study despite using a different standard for comparison.

Cox *et al.* [21] stated that CI obtained by continuous PAC and CI obtained by Aesculon bioimpedance are not interchangeable in cardiac surgical patients. However, our current study used SVV as a variable instead of CI. The current study used ICON as a standard device for detection of SVV. Both studies otherwise are consistent regarding the validation for noninvasive monitoring of cardiac surgical patients.

Limitations

The current study was conducted on patients undergoing CABG. Therefore, further studies are needed on other types of surgeries.

EC must be used in patients on mechanical ventilation, as surgical patients on spontaneous ventilation cannot get the benefit of this noninvasive monitor.

Other limiting factor was the age group. Therefore, further assessment needs to be done in different surgical populations.

Emergency cases were excluded, so further studies need to be done in emergency surgeries with high hemodynamic variability.

Conclusion

There is a good correlation between SVV measured by TEE and that measured by cardiometry. Cardiometry can be used as a noninvasive hemodynamic monitor in patients undergoing CABG surgery following sternal closure.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Bundgaard-Nielsen M, Holte K, Secher NH, Kehlet H. Monitoring of perioperative fluid administration by individualized goal-directed therapy. Acta Anaesthesiol Scand 2007; 51:331–340.

2 Holte K, Sharrock NE, Kehlet H. Pathophysiology and clinical implications of perioperative fluid excess. Br J Anaesth 2002; 89:622–632.

3 Giglio MT, Marucci M, Testini M, Brienza N. Goal-directed haemodynamic therapy and gastrointestinal complications in major surgery: a metaanalysis of randomized controlled trials. Br J Anaesth 2009; 103:637–646.

4 Hofer CK, Senn A, Weibel L, Zollinger A. Assessment of stroke volume variation for prediction of fluid responsiveness using the modified FloTrac and PiCCOplus system. Crit Care 2008; 12:R82.

5 Wiesenacsk C, Fiegl C, Keyser A, Prasser C, Keyl C. Assessment of fluid responsiveness in mechanically ventilated cardiac surgical patients. Eur J Anaesthesiol 2005; 22:658–665.

6 Albert NM. Bioimpedance cardiography measurements of cardiac output and other cardiovascular parameters. Crit Care Nurs Clin North Am 2006; 18:195–202.

7 Green D, Paklet L. Latest developments in peri-operative monitoring of the high-risk major surgery patient. Int J Surg 2010; 8:90–99.

8 Mair S, *et al.* Applicability of stroke volume variation in patients of a general intensive care unit: a longitudinal observational study. J Clin Monit Comput 2017; 31:1177–1187.

9 Martin E, Anyikam A, Ballas J, Buono K, Mantell K, Huynh-Covey T, Archer T. A validation study of electrical cardiometry in pregnant patients using transthoracic echocardiography as the reference standard. J Clin Monit Comput 2016; 30:679–686.

10 Sanders M, Servaas S, Slagt C. Accuracy and precision of non-invasive cardiac output monitoring by electrical cardiometry: a systematic review and meta-analysis. J Clin Monit Comput 2019; 34:433–460.

11 Chaiyakulsil C, Chantra M, Katanyuwong P, Khositseth A, Anantasit N. Comparison of three non-invasive hemodynamic monitoring methods in critically ill children. PLoS ONE 2018; 13:e0199203.

12 Liu YH, Dhakal BP, Keesakul C, Kacmarek RM, Lewis GD, Jiang Y. Continuous non-invasive cardiac output monitoring during exercise: validation of electrical cardiometry with Fick and thermodilution methods. Br J Anaesth 2016; 117:129–131.

13 Narula J, Chauhan S, Ramakrishnan S, Gupta SK. Electrical cardiometry: a reliable solution to cardiac output estimation in children with structural heart disease. J Cardiothorac Vasc Anesth 2017; 31:912–917.

14 Fellahi JL, Caille V, Charron C, Deschamps-Berger PH, Vieillard-Baron A. Noninvasive assessment of cardiac index in healthy volunteers: a comparison between thoracic impedance cardiography and Doppler echocardiography. Anesth Analg 2009; 108:1553–1559.

15 Rauch R, Welisch E, Lansdell N, Burrill E, Jones J, Robinson T, *et al.* Non-invasive measurement of cardiac output in obese children and adolescents: comparison of electrical cardiometry and transthoracic Doppler echocardiography. J Clin Monit Comput 2013; 27:187–193.

16 Boet A, Jourdain G, Demontoux S, De Luca D. Stroke volume and cardiac output evaluation by electrical cardiometry: accuracy and reference nomograms in hemodynamically stable preterm neonates. J Perinatol 2016; 36:748–752.

17 Song R, Rich W, Kim JH, Finer NN, Katheria AC. The use of electrical cardiometry for continuous cardiac output monitoring in preterm neonates: a validation study. Am J Perinatol 2014; 31:1105–1110.

18 Zakariás D, Marics G, Kovács K, Jermendy Á, Vatai B, Schuster G, *et al.* Clinical application of the electric cardiometry based non-invasive ICON® hemodynamic monitor. Orv Hetil 2018; 159:1775–1781.

19 Hsu KH, Wu TW, Wu IH, Lai MY, Hsu SY, Huang HW, *et al.* Electrical cardiometry to monitor cardiac output in preterm infants with patent ductus arteriosus: a comparison with echocardiography. Neonatology 2017; 112:231–237.

20 Yoshida A, Kaji T, Yamada H, Yonetani N, Sogawa E, Yamao M, *et al.* Measurement of hemodynamics immediately after vaginal delivery in healthy pregnant women by electrical cardiometry. J Med Invest 2019; 66:75–80.

21 Cox PBW, den Ouden AM, Theunissen M, Montenij LJ, Kessels AGH, Lancé MD, *et al.* Accuracy, precision, and trending ability of electrical cardiometry cardiac index versus continuous pulmonary artery thermodilution method: a prospective, observational study. Biomed Res Int 2017; 2017:2635151.