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Echocardiographic Assessment of Left Ventricular Twisting and Untwisting Rate in Normal Subjects by Tissue Doppler and Velocity Vector Imaging: Comparison of Two Methods

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Background: The torsional parameters of the left ventricle (LV) are sensitive indicators of the cardiac performance. The torsion/twist of the LV is the wringing motion of the heart around its long axis created by oppositely directed apical and basal rotations and is determined by contracting myofibers in the LV wall which are arranged in opposite directions between the subendocardial and subepicardial layers. This motion is essential for regulating the LV systolic and diastolic functions.

Objectives: Recent advances in echocardiography techniques have allowed for quantification of LV mechanics. The aim of the present study was to compare various LV twisting and untwisting parameters in healthy human subjects determined by velocity vector imaging (VVI) and tissue Doppler imaging (TDI) at rest.

Patients and Methods: All volunteers (47 healthy subjects in two groups: 24 subjects in VVI group and 23 subjects in TDI group) underwent complete echocardiographic study, and LV torsional parameters were assessed by VVI or TDI methods. In addition, LV torsion and LV twisting/untwisting rate profiles were calculated throughout cardiac cycle.

Results: Twist degree was significantly lower in the VVI group than in the TDI group (P = 0.008, r = 0.56). LV torsion was lower in the VVI group but was not significant. (P = 0.13, r = 0.38). Twisting rate (P = 0.004, r = 0.66) and untwisting rate (P = 0.0001, r = 0.61) were lower in the VVI group, but when timing of untwisting rate was normalized by systolic duration, there was no significant difference between the two groups (P = 0.41, r = 0.59). Similarly, when peak untwisting rate was normalized by LV length, there was a significant decline in normalized peak untwisting rate in the VVI group (P = 0.004, r = 0.62), but not in peak twisting rate normalized by LV length (P = 0.12, r = 0.42). Peak untwisting rate normalized by LV torsion was not statistically different between the two groups (P = 0.05, r = 0.53).

Conclusions: Results suggest that these methods cannot be interchanged, and VVI showed significantly lower LV peak twist, peak twisting rate and peak untwisting rate. However, when LV twist and LV twisting rates were normalized to LV length, values were comparable for both imaging techniques.

Keywords: Echocardiography; Ventricle; Blood Flow Velocity

1. Background

The torsional parameters of the left ventricle (LV) are sensitive indicators of the cardiac performance (1, 2). The torsion/twist of the LV is the wringing motion of the heart around its long axis created by oppositely directed apical and basal rotations and is determined by contracting myofibers in the LV wall (3, 4), which are arranged in opposite directions between the subendocardial and subepicardial layers (2, 5, 6). This motion is essential for regulating the LV systolic and diastolic functions (7). According to consensus, the LV twist, expressed in degrees, and LV torsion, expressed in degrees/cm, both refer to the same phenomenon in the cardiac function and define the base-to-apex gradient in a rotational angle along the longitudinal axis of the LV (8-10). When viewed from the apex, the systolic rotation of the base is clockwise and that of the apex is counterclockwise. The LV twist is measured by means of echocardiography. Initially, the measurement was done by studying the rotational motion of the papillary muscles (11).

Implication for health policy/practice/research/medical education:
LV torsion is a new method in assessment of LV function and very good point for research in new area of Echocardiography.

More recently; however, the LV twist has been assessed by measuring rotational mechanics via tissue Doppler imaging (TDI) and speckle tracking echocardiography (STE) (12-15). TDI can be derived from primary velocity data with higher temporal resolution but with intrinsic angle dependency constraints common to all Doppler methods and STE by frame-to-frame tracking of unique speckle patterns created by the interference of ultrasound beams within the tissue. The accuracy of these novel technologies has recently been validated by sonomicrometry and tagged magnetic resonance imaging (12, 14, 15). Both TDI and STE can also assess the LV torsional parameters such as torsion, twisting, and untwisting rate. Although a close correlation has been reported between different imaging modalities when obtaining the LV torsional parameters, these parameters are clearly based on different concepts and operate at different temporal resolutions. In a study, the ability of STE to assess the LV torsional deformation against the TDI method and tagged MRI was validated mainly by linear regression and Bland-Altman analysis at isochronal time points (15). In another study (16), in order to estimate the impact of the acquired temporal resolution on the measured peak values, the LV torsional deformation was studied in a closed-chest animal model, using both tissue Doppler and STE. Velocity vector imaging (VVI) is a novel quantitative echocardiographic method which can track routinely- two-dimensional echocardiographic images and is, therefore, angle independent (13, 17). The aim of our study was to compare various LV torsional parameters as determined by VVI and TDI in healthy human subjects.

2. Objectives

Recent advances in echocardiography techniques have allowed for quantification of LV mechanics. The aim of the present study was to compare various LV twisting and untwisting parameters in healthy human subjects determined by velocity vector imaging (VVI) and tissue Doppler imaging (TDI) at rest.

3. Patients and Methods

3.1. Study Population

Forty-seven healthy men and women (41 ± 9 years old) were included in the present cross-sectional study. All volunteers (47 healthy subjects in two groups: 24 subjects in VVI group and 23 subjects in TDI group) underwent complete echocardiographic study, and LV torsional parameters were assessed by VVI or TDI methods. None of the study participants had a history of cardiovascular disease, and all had normal physical examinations, ECG, and resting echocardiography. If a participant was more than 40 years old or had a risk factor for coronary artery disease or had chest pain, he would be under stress echocardiography and those with normal stress echocardiography were included. Exclusion criteria were diabetes mellitus and more than mild hypertension. The study was approved by the institutional Ethics Committee, and informed consent was obtained from all the participants.

3.2. Echocardiography

Two-dimensional (2D) conventional, pulse, and transthoracic echocardiographic study was performed with commercial GE Vivid seven System (Horten, Norway), equipped with an M3S multi-frequency harmonic phased array transducer for the assessment of torsional parameters via the tissue Doppler-based method and MyLab60 (ESAOTE, Florence, Italy) for the VVI method. Images were acquired from the subjects at rest, lying in the left lateral supine position at the end of expiration. Two-dimensional ECG was superimposed on the images, and end-diastole was considered at the peak R-wave of the ECG. The LV global systolic function was evaluated using a modified biplane Simpson method for calculating the LV ejection fraction (LVEF) by measuring end-diastolic and end-systolic volumes in the 2D images.

3.3. Doppler Myocardial Imaging and Off-Line Analysis

Measurement of the LV twist by tissue Doppler velocity data sets was introduced recently by Notomi et al (12). In the present study, this method was used for the assessment of the LV function. Using standard parasternal short-axis views in two base and apical levels, color Doppler myocardial imaging (CDMI) was recorded throughout the three cardiac cycles according to the guidelines of the ASE. An appropriate velocity scale was chosen to avoid CDMI data aliasing and sector angle was adjusted to ensure the highest possible sampling frequency. Care was taken to keep the anterior and posterior LV segments perpendicular to the ultrasound beam and aligned at near zero degrees to the radial motion, and the images were stored digitally in cine-loop format in the memory of the scanner. The digitally stored CDMI data sets were processed off-line using the EchoPac quantitative analysis software, equipped with the regional myocardial velocity. The tissue velocity imaging analysis with 8mm volume samples was conducted from the anterior and posterior segments of the LV walls (Figure 1) for extracting radial velocity-time curves and the lateral and septal segments (Figure 2) for extracting the tangential component of velocity in both base and apical short-axis levels.

The velocity-time data set of each sample throughout the cardiac cycle was saved on compact disc using the CD writer of the system and was transferred to a spread-

sheet Excel 2003 program for the basal and apical rotations, LV twist, twist rateand torsion calculations. All the calculations were averaged for at least three consecutive heart beats.

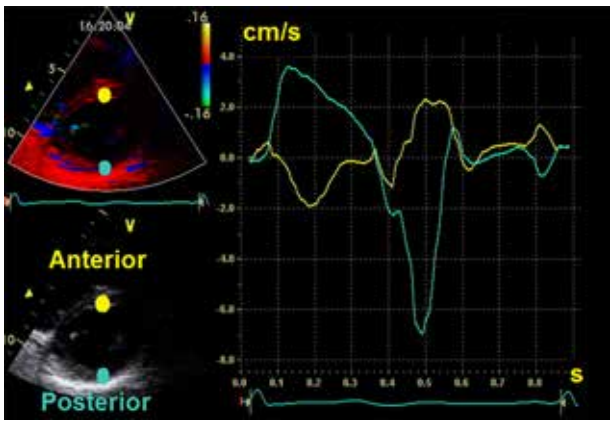

Figure 1. The Profile Curves of the Myocardial Anterior and Posterior Velocities in the Basal Level Used to Track the LV Radius Throughout One Cardiac Cycle

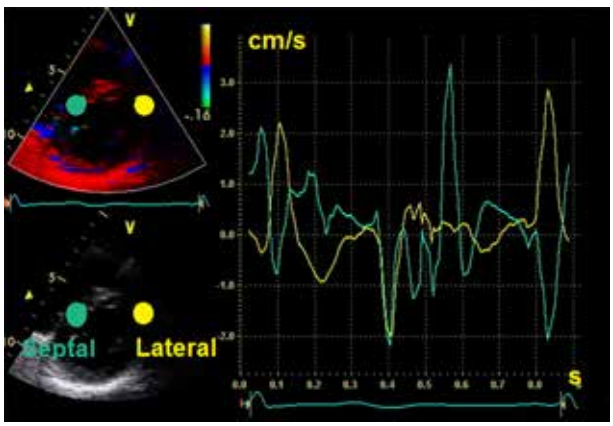

Figure 2. The Profile Curves of the Myocardial Septal and Lateral Tangential Velocities in the Basal Level Used to Calculate the LV Rotational Velocity Throughout one Cardiac Cycle

To convert the tangential velocity (cm/s) into angular velocity (degree/s), the time-varying radius of the LV [R(t)] both at the basal and apical levels was estimated using the anterior and posterior velocity data sets (Figure 1, Equation 1) (12):

$$R(t) = R(0) + \frac{\int_0^t [Va(t) - Vp(t)].dt}{2}$$

Equation 1.

Where *Va* and *Vp* are the myocardial velocity at the anterior and posterior regions, and *R(0)* is the end-diastolic radius.

From the lateral and septal velocity data sets, the LV rotational velocity was estimated from the averaged tangential velocity corrected with *R(t)*, as Equation 2 :

$$Vrot(t) = \frac{(Vl - Vs)}{2 \times R(t)}$$

Equation 2.

Where *Vl* and *Vs* are the myocardial velocity at the lateral and septal regions, and *Vrot(t)* is the LV rotational velocity (degree/s) both at the basal and apical levels.

The LV twist rate (degrees/s) was calculated as Equation 3 :

$$LV\ Twistrate = ApicalVrot(t) - BasalVrot(t)$$

Equation 3.

Where Apical *Vrot(t)* and Basal *Vrot(t)* are the rotational velocity (degree/s) at the apical and basal levels, respectively.

The LV rotation (degrees) at the basal and apical levels was calculated as Equation 4 :

$$LV\ rotation = \int_0^t Vrot(t).dt$$

Equation 4.

The LV twist (degrees) was calculated as Equation 5:

$$LV\ Twist = Apical\ LV\ rotation - Basal\ LV\ rotatior$$

Equation 5.

The peak systolic twist, twisting rate and peak untwisting rate were measured as is demonstrated in Figures 3 and Figure 4. The LV torsion was calculated as the LV twist was divided by the LV diastolic longitudinal length. In addition, the peak twisting and untwisting rates were normalized through division by the LV diastolic longitudinal length and also, the peak untwisting rate was normalized through division by the LV torsion. The time-to-peak untwisting velocity was also measured, and the intervals were expressed as percentages of the systolic duration.

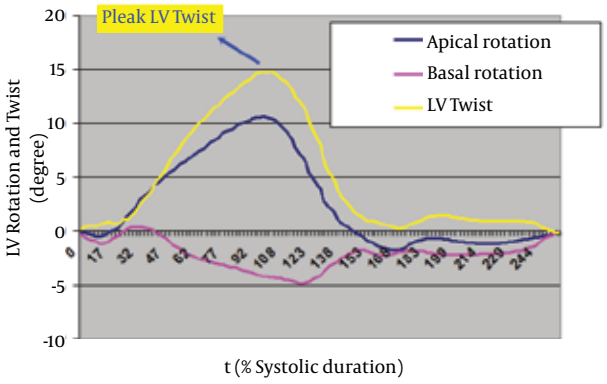

Figure 3. The Profile Curves of the LV Rotation in the Basal and Apical Levels and the LV Twist and Untwisting Throughout one Cardiac Cycle via the TDI Method

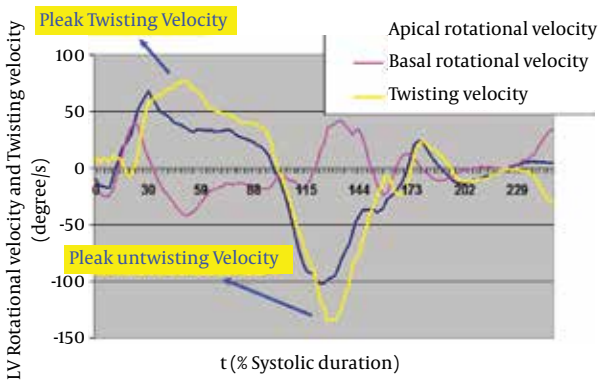

Figure 4. The Profile Curves of the LV Rotational Velocities in the Basal and Apical Levels and the Lv Twisting and Untwisting Velocities Throughout one Cardiac Cycle via the TDI Method

3.4. Vector Velocity Imaging and Off-Line Analysis

From each subject studied, two echocardiographic images were obtained using standard parasternal short-axis views in the basal and apical levels. Similar to TDI, the proper basal short-axis level was defined as what's containing the mitral valve and the proper apical short-axis level was defined as what's containing the LV cavity with no visible papillary muscles. The LV cross-section was made as circular as possible. The two short-axis views were subsequently processed off-line by the speckle tracking X Strain software. For the initial position of the tracking points based on the ASE's 18 segments of the heart, the aided heart segmentation (AHS) mode was utilized to insert well equal-spaced tracking points over the 2D echocardiographic images and the points were tracked automatically. Accordingly, at the end of diastole, 12 and 8 tracking points were positioned at the mid-wall of the basal and apical levels (Figure 5), respectively. The system then applied a sequence of processing steps to track the motion of the segments frame to frame. The rotation of the LV segments around the LV central axis at each short-axis level was calculated separately on the basis of the average motion of the mid-wall points.

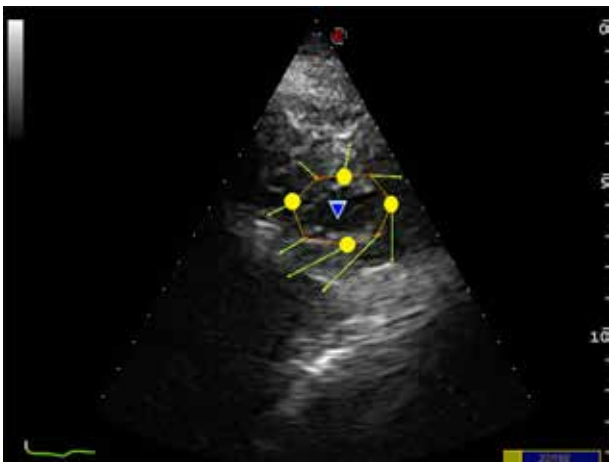

Figure 5. Delineation of the Apical Myocardial Short-Axis View during VVI Analysis

The data of all the sample regions tracking (6 segments for basal and 4 segments for apical levels) were transferred to a spreadsheet Excel program for the LV average rotation and rotational velocity calculation. For example, Figure 6 and Figure 7 show the plots of the LV rotational velocity versus time and the LV rotation versus time derived from each segment of the apical short-axis and also the average values throughout one cardiac cycle (white profile curves).

The LV twist rate (degrees/s) was calculated as Equation 6:

$$\text{LV Twistrate} = \text{ApicalVrot}(t) - \text{BasalVrot}(t)$$

Equation 6.

Where Apical Vrot(t) and Basal Vrot(t) are the rotational velocity (degree/s) at the apical and basal levels, respectively. Also, the LV twist (degrees) was calculated as Equation 7 :

$$\text{LV Twist} = \text{Apical LV rotation} - \text{Basal LV rotatior}$$

Equation 7.

Figure 8 shows the average rotational velocity data in the basal and apical levels, the resultant LV twisting rate and untwisting rate and Figure 9 demonstrates the average rotational data in those levels and the resultant LV twist and untwist. These data were achieved by the VVI

method in one of the studied subjects throughout one cardiac cycle.

The counterclockwise LV apical rotation and torsion as viewed from the apex were expressed as positive values, and the clockwise LV rotation were expressed as negative values for the basal level in both TDI and VVI analyses.

Similar to the TDI method, various LV torsional parameters such as peak systolic twist, peak twisting velocity, and peak untwisting velocity were measured as demonstrated in Figures 8 and 9. In addition, the normalized LV torsional parameters such as LV torsion, normalized peak twisting rate, normalized untwisting rate, and normalized time-to-peak untwisting velocity were calculated by the VVI data.

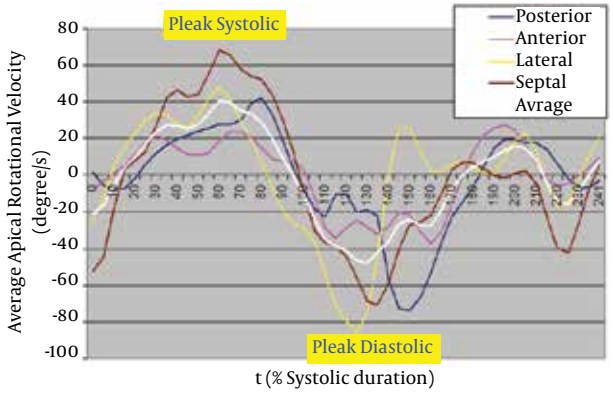

Figure 6. The profile Curves of the Apical Segmental (Yellow Points in Figure 5) and Average Rotational Velocity via the VVI Method (White Profile Curve)

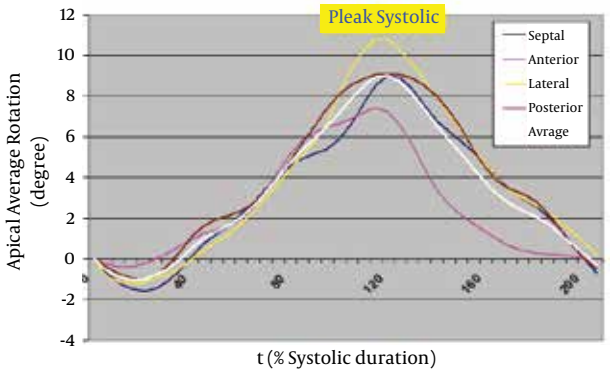

Figure 7. The Profile Curves of the Apical Segmental (Yellow Points in Figure 5) and Average Rotation via the VVI Method (White Profile Curve)

3.5. Statistical Analysis

All the continuous variables are presented as mean (SD). The normal distribution was tested using the Kolmogorov-Smirnov (K-S) test. To determine whether the difference in the values between the two methods was statistically significant, an independent samples t-test was performed. A P value ≤ 0.05 was considered statistically significant. All the statistical analyses were performed using the SPSS v.13.0 software package (SPSS Inc. Chicago, IL, USA).

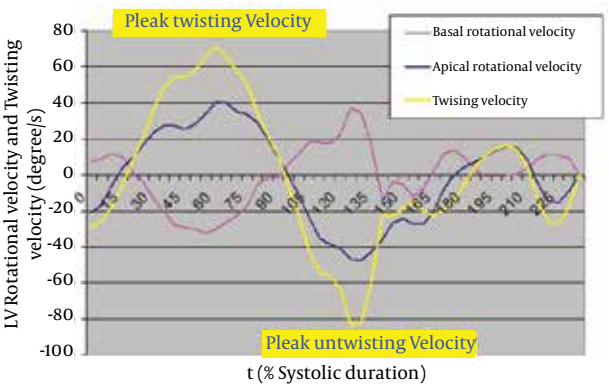

Figure 8. The Profile Curves of the LV Rotational Velocities in the Basal and Apical Levels and the LV Twisting and Untwisting Velocities Throughout one Cardiac Cycle via the VVI Method

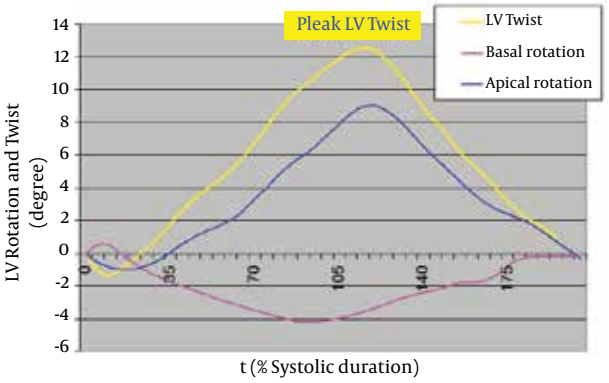

Figure 9. The Profile Curves of the LV Rotation in the Basal and Apical Levels and the LV Twist and Untwisting Throughout one Cardiac Cycle via the VVI Method

4. Results

4.1. Clinical and Echocardiographic Characteristic

The clinical characteristics and echocardiographic data of the two groups are summarized in Table 1 and Table 2, respectively. The results of the comparisons between the two study groups showed no significant difference in terms of the demographic, hemodynamic, and echocardiographic characteristics.

Table 1. Demographic and Hemodynamic Characteristics of the Study Participants

	(n = 24)	TDI group (n = 23)	P value
Gender, Male/Female, No.	11/13	10/13	0.936
Body surface area, mean (SD), m^2	1.8 (0.3)	1.8 (0.1)	> 0.99
Age, mean (SD), y	40 (9)	41 (13)	0.760
Heart rate, mean (SD), beats/min	81 (12)	77 (15)	0.317
SBP , mean (SD), mmHg[a]	127 (12.5)	124.9 (15.6)	0.629
DBP , mean (SD), mmHg[a]	76 (12.9)	78.9 (14.1)	0.422

[a] Abbreviation: DBP, Diastolic Blood Pressure; SBP, Systolic Blood Pressure

Table 2. Resting Echocardiographic Characteristics of the Study Participants

	(n = 24)	TDI group (n = 23)	P value
LA volume[a]**, mean (SD), mL**	111.1 (34.0)	108.0 (29.8)	0.750
LA volume/BSA [a]**, mean (SD), mL/m^2**	60.9 (20.9)	58.1 (18.9)	0.611
LVEDD [a]**, mean (SD), cm**	5.8 (0.5)	5.4 (0.8)	0.048
LVEDD/BSA, mean (SD), cm/m^2	3.2 (0.3)	3.0 (0.4)	0.058
LVESD, mean (SD), cm	3.7 (0.6)	3.6 (0.7)	0.601
LVESD/BSA, mean (SD), cm/m^2	2.1 (0.3)	2.3 (0.5)	0.102
E/A ratio, mean (SD)	1.8 (0.3)	1.7 (0.6)	0.471
E/E', mean (SD)	8.0 (3.6)	7.6 (2.6)	0.665

[a] Abbreviation: BSA, body surface area; LA, left atrium; LVEDD, left ventricular end diastolic diameter; LVESD, left ventricular end Systolic diameter

4.2. Twist and Torsion Results

The twist degree was significantly lower in the VVI group than that in the TDI group (11.05 ± 2.45° vs.13.95 ± 4.27°; P = 0.008). There is relatively acceptable correlation between twist degrees in VVI and TDI methods [r (95%CI) = 0.56 (0.37-0.78)]. The LV torsion was lower in the VVI group but not was not significant (1.53 ± 0.42 °/cm vs. 1.76 ± 0.56 °/cm; P = 0.132). We found week correlation in LV torsion between the two study groups [r (95%CI) = 0.38 (0.16-0.57)].

4.3. Twisting Rate and Untwisting Rate Results

The twisting rate (75.88 ± 17.25 °/s in VVI vs. 95.79 ± 24.87 °/s in TDI; P = 0.004) with good correlation coefficient [r (95%CI) = 0.66 (0.39-0.81)] and untwisting rate (-73.79 ± 24.45 °/s in VVI vs. -110.96 ± 34.65 °/s in TDI; P = 0.0001) with acceptable correlation [r (95%CI) = 0.61 (0.33-0.74)] were lower in the VVI group, but when the timing of the untwisting rate was normalized by the systolic duration (t=100% at end systole), there was no significant difference between the two groups (136.77 ± 21.30% in VVI vs. 131.86 ± 15.82% in TDI; P = 0.411); however, [r (95%CI) = 0.59 (0.23-0.77)] remained relatively unchanged.

Similarly, when the peak untwisting rate was normalized by the LV length, there was a significant decline in the normalized peak untwisting rate in the VVI group (-10.08 ± 3.33 °/s/cm vs. -14.02 ± 4.92 °/s/cm; P = 0.004) with good correlation coefficient [r (95%CI) = 0.62 (0.30-0.84)], but not in the peak twisting rate normalized by the LV length (10.53 ± 3.12 °/s/cm vs. 12.09 ± 3.42 °/s/cm; P = 0.125) and r (95%CI) = 0.42 (-0.08-0.69) . The peak untwisting rate normalized by the LV torsion was not statistically different between the two groups (-8.49 ± 3.12 1/s vs. -6.77 ± 2.31 1/s; P = 0.055; r (95%CI) = 0.53 (0.07-0.72).

4.4. Reproducibility

The intra-observer variability for twisting rate in VVI group and TDI group were 3% and 5% , respectively. The inter-observer variability for twisting rate in VVI group and TDI group were 4% and 8%, respectively.

5. Discussion

Normal LV torsion is a component of the systolic function and contributes to an efficient ejection; it is; however, difficult to measure. Ventricular torsion is a sensitive marker of dysfunction and is a useful clinical measure

for the early recognition of subclinical LV dysfunction before the other indices of the systolic and diastolic functions are impaired (18).

Over the years, different methods have been employed for the assessment of the LV torsion: cine-angiographic markers, rotational devices, echocardiography, and tagged MRI (5, 19-24). For a long time, cardiac magnetic resonance with tissue tagging was deemed gold standard for the quantification of the LV rotation, twist, and absolute myocardial torsion between the basal and apical LV slices. Nevertheless, it is not a practical technique for clinical use on account of the fact that it is a costly and cumbersome technique, is not widely available, and has a long analysis time with low temporal resolution (2, 3, 13, 20). In recent years, echocardiography has evolved from a diagnostic tool into a complex technique being able to provide quantitative information to alter the management of most cardiac diseases. The following are some echocardiographic techniques for calculating the LV torsion.

TDI is used to quantify regional myocardial velocity, contractility, and torsional parameters (21-23). Unfortunately, TDI face several limitations such as the angle of incidence dependency, noise, artifacts, tethering, and translation, all of which compromise the validity of results. As a case in point, when the angle between the ultrasonic beam and the tissue is $> 20^{\circ}$, real velocity is underestimated and thus loses its validity (17, 23, 24), which is a major limitation for the evaluation of the torsion of the different segments in the short-axis views. Moreover, in the TDI method, the measurement of the LV angular velocities is limited to two septal and lateral segments. STE as another echocardiographic technique was first introduced in 2004 (25). It has been validated as a feasible method for measuring the LV rotation and torsion (15, 26). The STE technique is based on the frame-by-frame tracking of the ultrasound speckles within the image; myocardial strain and torsion can be assessed by displacement of theses speckles relative to each other and angle dependency can thus be overcome (23).

VVI is an advanced echocardiographic method. Applied on routine gray scale echocardiographic images, VVI was originally developed for the analysis of the LV myocardium. VVI is based on myocardial feature tracking and assesses the myocardial motion in two dimensions, permitting angle-independent measurement of tissue velocity, deformation and rotation (27-29). Whereas both TDI and STE techniques are time-consuming and thus have limited application in the human heart, the STE and VVI methods have been improved and used in the study of the human heart over the recent years. In these methods, an endocardial, myocardial, or epicardial tracing of a single frame is manually derived from a routine digital cine-loop, and periodic displacement of these regions is tracked in subsequent frames (12, 27, 28, 30).

Yoon et al. showed both TDI and speckle tracking imaging as sufficiently accurate and reliable alternatives to MRI in the non-invasive assessment of the LV torsion (25). Because our center was not equipped with an MR tagging system, we could not compare our results with those that could have been obtained by that system. Baykan et al. evaluated the VVI method for the assessment of different parameters of LV wall motion and found VVI as a reliable non-invasive method for evaluating the LV torsional deformation and synchronization in both dilated cardiomyopathy patients and normal individuals (31). In the current study, we compared the torsional parameters obtained by the TDI and VVI methods in a healthy population. The profile curves of the LV twisting and untwisting and also the LV twisting velocity and untwisting velocity by the TDI and VVI methods, in our healthy study population, are represented in the result section. We included different healthy subjects in our study population and tried to match them with respect to demographic, hemodynamic, and echocardiographic characteristics. The torsional parameters via the two methods were obtained separately by two expert echocardiographers, completely blinded to the subjects and results. Evaluation of the study results showed that although there were no significant differences between such parameters as torsion, twisting velocity normalized by the LV length, and untwisting velocity normalized by torsion, the significant differences between important parameters like twist, twisting velocity, untwisting velocity, and untwisting velocity normalized by the LV length was observed. Consequently, because the VVI method led to the underestimation of the parameters, these techniques cannot be used interchangeably in as much as each one may yield different results. It is worthy of note that the time-to-peak variables measured by the two methods were similar in our study.

Notomi et al. assessed the LV twist and LV twisting velocity in 13 patients with a variety of cardiac pathologies. Regression analysis by repeated-measures regression models for the measurement of the LV twist and LV twisting velocity by STE indicated a strong correlation with those estimated by MRI and TDI ($r = 0.93$ and 0.76, respectively; $P < 0.0001$). The limits of agreement analysis demonstrated a non-significant mean difference in the measurement of the LV twist and LV twisting velocity (15). Also, Kim et al. compared the twist-related values determined by VVI and STE and found that the peak twist as determined by STE and VVI was well correlated with regard to the fact that twist and untwist velocities were moderately correlated with the two methods (26). We made use of the VVI and TDI methods to extract various LV torsional parameters in a healthy population: our findings showed that there was a significant difference in the twist and twisting velocity between the two methods, the difference was not significant for the LV torsion which was obtained by normalizing the LV twist to the LV length at end-diastole. The fact that we

included different healthy subjects in the study groups precluded a comparison between the results of the two methods by regression and Bland-Altman analyses; this seems to be a limitation of this study and further studies are required to probe into this issue in a more meticulously matched study population. Ferferieva et al. designed a study using both tissue Doppler and STE to test the influence of the temporal resolution on the accurate assessment of the LV peak untwist rate in 8 pigs (16). These researchers reported that at rest, the LV peak twist, peak untwist rate, and peak torsion values were comparable in both imaging techniques, so the P value is not significant (P = NS), but the TDI-estimated LV peak twisting rate was significantly higher than the STI-derived values (89.5 + 27.9 °/s vs. 64.3 + 25.3 °/s). During dobutamine stimulation, the TDI-estimated peak untwist rate was predominantly higher than that measured by STI (112.1 + 64.5 °/s vs.75.5 + 31.4 °/s, $P < 0.05$). In the present study, we assessed healthy groups at rest (with the limitation of assessment during stress) and found that not only the twist rate but also the twist and untwist were significantly different between the VVI and TDI methods. The VVI method led to the underestimation of the parameters; be that as it may, if we had normalized the parameters by torsion, there would have been no significant difference. The frame rate in TDI was significantly higher than that in VVI (130 + 20 fps vs. 60 + 10 fps, $P < 0.05$): it is conceivable that at least some of our findings may have been affected by the difference in time resolution between the methods. By comparison with TDI, the ability to achieve a higher frame rate in the VVI method is a limitation of this method. It is important to note that future studies utilize the same frame rate for the evaluation of the LV torsional parameters in the same time resolution so as to test the influence of the temporal resolution on the accurate assessment of the LV torsional parameters. The aim of the present study was to compare various LV torsional parameters as determined by the VVI and TDI methods at rest in healthy human subjects. The results suggest that these methods cannot be employed interchangeably and VVI yielded significantly lower LV peak twist, peak twisting rate, and peak untwisting rate. However, when the LV twist and LV twisting rate were normalized to the LV length, the values were comparable in both imaging techniques. It may confirm the finding of previous studies maintaining that a wide variability in the reported values depends on the different methods employed to evaluate the LV torsional parameters.

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Authors' Contribution

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