Segmental and global longitudinal strain and strain rate based on echocardiography of 1266 healthy individuals: the HUNT study in Norway

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Aims To study the distribution of longitudinal systolic strain and strain rate (SR) as indicators of myocardial deformation according to age and sex in a healthy population.

Methods and results Longitudinal strain and SR were determined in 1266 healthy individuals from three standard apical views, using a combination of speckle tracking (ST) and tissue Doppler imaging (TDI) to track regions of interest (ROIs). To test applicability of the reference values, we used a subset of the population to compare four methods of assessing myocardial deformation: (1) a combination of TDI and ST; (2) TDI with fixed ROIs; (3) TDI with tracking of ROIs; and (4) ST. Mean (SD) overall global longitudinal strain and SR were −17.4% (2.3) and −1.05 s⁻¹ (0.13) in women, and −15.9% (2.3) and −1.01 s⁻¹ (0.13) in men. Deformation indices decreased with increasing age. The combined and ST methods showed identical SR, but values were significantly lower than those obtained by TDI. Strain was overestimated by the ST method (18.4%) compared with the combined method (17.4%).

Conclusion The reference values for global and segmental longitudinal strain and SR obtained from this population study are applicable for use in a wide clinical setting.

Keywords Myocardial deformation • Systolic heart failure • Population study • Reference values • Tissue Doppler • Speckle tracking

Introduction

With tissue Doppler imaging (TDI) and speckle tracking (ST), quantification of left ventricular (LV) function has moved beyond the simple ejection fraction measurements and wall motion score.1–9 From small clinical studies, optimal cut-off values between normal and pathological regional function may be obtained. However, the relation to normal limits is dependent of the degree of overlap between the healthy and sick population. Thus, cut-off values are not the same as normal reference ranges, and to establish normal reference ranges in healthy individuals, larger, population-based studies are needed.

Normal values for annular velocities have been reported,10,11 and deformation indices derived from TDI and ST have been published in populations of <250 healthy individuals.12–14 However, no study has described the distribution of segmental and end-systolic global strain ($S_g$) and peak systolic strain rate ($SR_s$) in healthy individuals, or presented deformation analyses based on ST or a combination of TDI and ST in a large population free from cardiovascular disease.

Therefore, we have used echocardiographic systolic longitudinal deformation measurements to describe the distribution of global and segmental $S_g$ and $SR_s$, according to sex and age in a population of 1266 individuals without known cardiovascular disease or diabetes and compared four different methods to assess longitudinal

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Segmental and global longitudinal strain and SR based on echocardiography

Methods

Study population
The HUNT study\(^1\) of adults from Nord Trøndelag County in Norway was initiated in the 1980s, and the third wave of the study was conducted from 2006 to 2008. A total of 93 210 people were invited and 49 827 (53%) participated. Within the third wave of the study, we conducted this echocardiography study among a random sample of participants in pre-determined communities in the county. To be eligible, people had to be free from known cardiovascular disease, diabetes, or hypertension. Participants were then selected by random sample. Among the 1296 subjects who were selected and consented to participate, 30 were excluded due to significant pathology that merited follow-up by clinical assessment, as this could influence the deformation analysis. Thus, this study is based on echocardiography examinations of 1266 men and women.

The study was approved by the Regional Committee for Medical Research Ethics and conducted according to the Helsinki Declaration. Written informed consent was obtained.

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Comparison of methods
In a subset of 57 participants, colour tissue Doppler images were analysed with the described semi-automatic software using three separate methods: Method 1. The described combination of ST and TDI. Method 2. SR was calculated from the TDI velocity gradient along the ultrasound beam (velocity difference per length), with a stationary region of interest (ROI) placed automatically in the mid-segment at the end-diastole. The latter method is similar to the tissue Doppler analysis commercially available in EchoPAC (GE Vingmed, Horten, Norway).\(^1\) Method 3. TDI with ROIs in the centre of the defined segments as in Method 2, but with tracking of ROIs during the heart cycle. For Methods 2 and 3, the settings were: longitudinal averaging of 10 mm, temporal averaging of 1 ms, lateral averaging of three beams and offset for calculation of SR 10 mm.

Method 4. Grey-scale images from the same participants were also analysed with automated function imaging (AFI; EchoPAC PC version BT 09, GE Vingmed) with tracking of the endocardial border. The ROIs were manually adjusted to include the entire LV myocardium and simultaneously avoid the pericardium. The software automatically tracked speckles frame by frame throughout the cardiac cycles, and segments with poor tracking were excluded manually.

Data reproducibility
Ten healthy volunteers (seven men, aged 24–36 years) were recruited, and all had adequate echocardiographic images. Two physician echocardiographers (A.T. and H.D.) were blinded to each other’s recordings and conducted separate echocardiographic acquisitions (a total of 20 echocardiograms). All recordings were analysed for both conventional and deformation measurements by both echocardiographers.

Data from the separate acquisitions were used to test interobserver variability. In addition, the echocardiographers re-analysed their own recordings, as randomly ordered after a period of ~3 weeks in order to test intraobserver variability.

Statistical analysis
Mean differences were tested using Student’s t-test, and differences in proportions were tested by one-way ANOVA with post hoc analysis with the Bonferroni correction. Deformation indices obtained by different methods were compared and tested by one-way ANOVA with a post hoc least significant difference method to enable detection of significant differences.
of even smaller differences between the four methods. A P-value of <0.05 was considered significant. Coefficients of repeatability (COR) were calculated according to Bland and Altman’s method, and coefficients of variation (COV) were calculated as the within-subject SD divided by the mean of the observations. All statistical analyses were performed using SPSS for Windows (version 15.0, SPSS Inc., Chicago, IL, USA).

Results

Study population

Table 1 shows basic characteristics of the 673 women and 623 men who were randomly selected and consented to participate in the study. Although all participants were free from known cardiovascular disease, hypertension, and diabetes, 10 women and 20 men were excluded from further analyses after detection of moderate-to-severe pathology during echocardiography. Echocardiographic findings among the excluded individuals were aortic aneurysms and/or valvular pathology in 13 individuals, LV dysfunction (cardiomyopathies, hypertensive heart disease, etc.) in 9, atrial fibrillation in 3, and other reasons in 5 individuals, respectively. Among the 1266 who remained for analyses, mean (SD) age was 47.8 (13.6) years among women and 50.6 (13.7) years among men (Figure 2); age was normally distributed in both sexes. Supplementary data online, Table S1 shows the basic characteristics for the pre-stratified age groups.

Analysis of deformation indices

Our aim was to obtain reference values for segmental deformation indices in healthy individuals, and we therefore accepted only segments with optimal tracking of the kernels that were visually evaluated. Out of a total of 22,788 analysed segments, 13,765 were accepted as yielding optimal tracking, and these segments were the basis for estimating reference values for systolic strain and SR, yielding an overall feasibility of 60%. In multivariate analysis, sex and LV internal diameter were not associated with the number of segments discarded, but with increasing age coefficient (95% confidence interval) was $-0.4$ ($-0.5$ to $-0.2$) per 10 years of increasing age ($P < 0.001$). For the increase in body mass index, the correlated data were $-0.3$ ($-0.3$ to $-0.2$) per 1 kg/m$^2$ ($P < 0.001$). This gives that per 25 years of increasing age or 3.3 kg/m$^2$ of increasing body mass index, one additional segment was discarded. $S_{es}$ and SR$_s$ were normally distributed (Figure 3). Table 2 shows mean (SD) longitudinal segmental $S_{es}$ and SR$_s$ for each wall and level (basal, mid-ventricular, and apical) of the LV. The study participants were stratified according to age (<40, 40–59, and >60 years) and sex (Table 3), and the analysis showed that systolic deformation indices were clearly reduced with increasing age. The age dependency was similar for the basal, mid-ventricular, and apical levels of the LV, and the $S_{es}$ and SR$_s$ reduction was consistent across age groups for all levels (all $P < 0.0001$).

The age-related decrease was also consistent for all six standard myocardial walls$^{21}$ (all $P < 0.001$), except for SR$_s$ in the anteroseptal wall ($P = 0.06$). $S_{es}$ and SR$_s$ were significantly and consistently

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**Figure 1** End-systolic strain ($S_{es}$) marked with blue arrows and peak systolic strain rate (SR$_s$) marked with red arrows. Strain curves for the three segments of a myocardial wall are shown in the left image, and the respective strain rate curves in right image. ECG is presented below. The vertical lines display the automated detected avo and avc. The blue curve refers to the measured one, whereas the green curve refers to the average of three segments in the myocardial wall. avc, aortic valve closure; avo, aortic valve opening.
lower in men than women (all $P < 0.0001$), except in the oldest age group ($\geq 60$ years). In multivariate analysis, sex and age were significant predictors of $S_{ae}$ and $SR$, after adjusting for blood pressure, end-diastolic LV internal diameter or body mass index, and non-fasting serum glucose.

**Comparison of methods**

Table 4 shows that Method 1 (ST and TDI) gave significantly lower values ($P = 0.02$) for global $S_{ae}$ compared with Method 4 (ST). However, the mean difference was only 1 percentage point strain, and the difference was not significant when the ventricle was subdivided into basal, mid-ventricular, and apical regions. For $S_{ae}$, the overall difference between the combined method and the TDI methods was small, but the ST method (mean strain, $-18.4\%$) differed significantly ($P < 0.002$) from TDI with tracking of ROIs (mean strain, $-16.7\%$). $SR$ did not significantly differ between Methods 1 and 4. $SR$ values obtained by TDI (Methods 2 and 3) were significantly higher in all parts of LV compared with Methods 1 and 4.

**Data reproducibility**

The COR for segmental $S_{ae}$ and $SR$ in the interobserver analyses were $\pm 8$ (% strain) and $\pm 0.5$ (s$^{-1}$) for the combined method (ST and TDI) and $\pm 7$ (% strain) and $\pm 0.5$ (s$^{-1}$) for the ST method, respectively. The COV for segmental $S_{ae}$ were 12 and 10% in the interobserver analyses for the two methods, and 8 and 6% in the intraobserver analyses, respectively. In segmental analyses of $SR$, COV were 11 and 12% in the interobserver analyses and 9 and 8% in the intraobserver, respectively.

For global $S_{ae}$, COR were $\pm 2$ and $\pm 2$ (% strain) for the combined method and ST method in the interobserver analyses, and COV was 3 and 4%, respectively. For global $SR$, the corresponding COR were $\pm 0.25$ and $\pm 0.21$ (s$^{-1}$), and COV were 6 and 7%, respectively, in the interobserver analyses.

Supplementary data online, Figure S1 displays plots of difference against mean of the two measurements for segmental and global $S_{ae}$ and $SR$ for both inter- and intraobserver variability. Additional data on reproducibility of both conventional echocardiographic data, and tissue Doppler and ST indices are recently published.$^{22}$

**Discussion**

In this population-based study of 1266 men and women without known cardiovascular disease or diabetes, we have described the distribution of global and segmental longitudinal $S_{ae}$ and $SR$ according to age and sex. Overall, mean global $S_{ae}$ for women and men was $-17.4$ and $-15.9\%$, and mean global $SR$ was $-1.05$ and $-1.01$ s$^{-1}$, respectively. With increasing age, there was a general decrease in both indices at all ventricular levels and walls, and the sex difference was not present in the oldest age group. Table 2 shows that there were significant differences between different levels and walls of the LV, but the differences were too small to be of major clinical importance.

**Deformation indices in the study population**

The distribution of systolic longitudinal deformation indices followed a normal distribution. TDI velocity data from the Copenhagen City Heart Study were also normally distributed.$^{10}$ However, Kuznetsova et al.$^{12}$ observed a skewness in the TDI-derived $S_{ae}$ and $SR$, but only data from the basal part of the inferior and inferolateral wall were presented. In that study, the mean values in the normal group was also considerably higher. The presented data are in line with a recent publication of deformation indices assessed by ST.$^{14}$

Signal noise and acoustic artefacts pose a challenge in measuring strain and $SR$, and for TDI measurements, angle dependency also limits measurement applicability. Dropouts and reverberations lead to low or zero values in the area of artefacts. As strain and $SR$ based on the velocity measurements in reality are equivalent to a subtraction of the more apical velocity from the more basal, all measurements below the artefact may result in overestimation. Thus, including only basal segments may induce a systematic error.
Since the aim was to obtain reference values for segmental deformation indices in healthy individuals, we were careful to accept only segments with optimal tracking of the kernels assessed by visual evaluation. Using this customized method, both segments adjacent to the kernel were rejected in case of poor tracking. Commercial softwares like EchoPAC more often accept segments even though they should be discarded for the same reasons, and in addition, the user does not have full information about segment borders and spatial resolution. This is less of a problem for global measurements, but as our aim was to achieve segmental normal values, the use of customized software was in fact the only way to achieve full information about segment borders and the process used to calculate myocardial deformation. The use of customized software was also the only practical solution for using a TDI-based method to assess deformation indices in such a large population. Compared with other methods, this will increase the percentage share of discarded segments, and due to the large study population, we could afford to discard segments with non-optimal tracking, even though tracking of kernels could be reasonably good. Our goal was to reduce the effect of noise, reverberations, and artefacts as much as possible. Thus, the software may be useful in a higher proportion of segments in a clinical population, but in this case, the aim of the analysis was different. However, the need of discarding both segments adjacent to a kernel without sufficient tracking reduces the feasibility and remains a limitation of the method used.

Our data show a reduction by age in LV function measured by $S_e$ and $SR_e$ both in women and men, but deformation values were consistently higher in women, except in the oldest age group (≥60 years). Few previous echocardiographic studies have
Segmental and global longitudinal strain and SR based on echocardiography

Table 2  Segmental longitudinal systolic strain ($S_{es}$) and strain rate ($SR_s$).  

<table>
<thead>
<tr>
<th></th>
<th>Infaroseptum</th>
<th>Anterolateral</th>
<th>Inferior</th>
<th>Anterior</th>
<th>Infarolateral</th>
<th>Anteroseptum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-17.8 (3.9)$</td>
<td>$-14.6 (4.0)$</td>
<td>$-17.6 (4.3)$</td>
<td>$-14.3 (4.7)$</td>
<td>$-15.5 (4.3)$</td>
<td>$-16.1 (3.9)$</td>
<td>$-16.4 (4.3)$</td>
</tr>
<tr>
<td>$SR_s$ (s^{-1})</td>
<td>$-1.08 (0.24)$</td>
<td>$-1.03 (0.29)$</td>
<td>$-1.08 (0.23)$</td>
<td>$-0.98 (0.30)$</td>
<td>$-1.06 (0.28)$</td>
<td>$-0.95 (0.26)$</td>
<td>$-1.04 (0.26)$</td>
</tr>
<tr>
<td>Mid-ventricular</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-17.9 (3.5)$</td>
<td>$-16.4 (3.5)$</td>
<td>$-17.3 (3.7)$</td>
<td>$-17.4 (3.6)$</td>
<td>$-17.0 (3.8)$</td>
<td>$-17.1 (3.5)$</td>
<td>$-17.3 (3.6)$</td>
</tr>
<tr>
<td>$SR_s$ (s^{-1})</td>
<td>$-1.10 (0.20)$</td>
<td>$-0.94 (0.22)$</td>
<td>$-1.08 (0.27)$</td>
<td>$-1.01 (0.31)$</td>
<td>$-1.05 (0.29)$</td>
<td>$-1.05 (0.28)$</td>
<td>$-1.05 (0.26)$</td>
</tr>
<tr>
<td>Basal</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-14.6 (3.9)$</td>
<td>$-19.2 (3.7)$</td>
<td>$-15.9 (3.9)$</td>
<td>$-17.7 (4.1)$</td>
<td>$-17.0 (4.0)$</td>
<td>$-13.9 (4.5)$</td>
<td>$-16.2 (4.3)$</td>
</tr>
<tr>
<td>$SR_s$ (s^{-1})</td>
<td>$-0.85 (0.21)$</td>
<td>$-1.22 (0.27)$</td>
<td>$-0.91 (0.24)$</td>
<td>$-1.07 (0.24)$</td>
<td>$-1.10 (0.25)$</td>
<td>$-0.95 (0.23)$</td>
<td>$-0.99 (0.27)$</td>
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<tr>
<td>Mean</td>
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<tr>
<td>$S_{es}$ (%)</td>
<td>$-16.8 (4.0)$</td>
<td>$-16.6 (4.1)$</td>
<td>$-17.0 (4.0)$</td>
<td>$-16.8 (4.3)$</td>
<td>$-16.5 (4.1)$</td>
<td>$-16.0 (4.1)$</td>
<td>$-16.7 (4.1)$</td>
</tr>
<tr>
<td>$SR_s$ (s^{-1})</td>
<td>$-1.01 (0.25)$</td>
<td>$-1.05 (0.28)$</td>
<td>$-1.03 (0.26)$</td>
<td>$-1.02 (0.28)$</td>
<td>$-1.07 (0.27)$</td>
<td>$-0.99 (0.27)$</td>
<td>$-1.03 (0.27)$</td>
</tr>
</tbody>
</table>

Footnotes refer to significant difference between the respective level/wall of the left ventricle (LV) and 1apical; 2mid-ventricular; and 3basal level of LV and 4anteroseptum; 5anterolateral; 6inferior; 7anterior; 8inferolateral; and 9anteroseptal myocardial wall. Level of significance $P < 0.05$ one-way ANOVA (post hoc Bonferroni).

Table 3  Global longitudinal systolic strain and strain rate

<table>
<thead>
<tr>
<th></th>
<th>Female$^3$</th>
<th>Male$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40 years$^4$ (208 women/126 men)</td>
<td>$S_{es}$ (%)</td>
<td>$-17.9 (2.1)$</td>
</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-10.9 (0.12)$</td>
<td>$-10.6 (0.13)$</td>
</tr>
<tr>
<td>40–60 years$^4$ (336 women/327 men)</td>
<td>$S_{es}$ (%)</td>
<td>$-17.6 (2.1)$</td>
</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-1.06 (0.13)$</td>
<td>$-1.01 (0.12)$</td>
</tr>
<tr>
<td>&gt;60 years (119 women/150 men)</td>
<td>$S_{es}$ (%)</td>
<td>$-15.9 (2.4)$</td>
</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-0.97 (0.14)$</td>
<td>$-0.97 (0.14)$</td>
</tr>
<tr>
<td>Mean$^5$</td>
<td>$S_{es}$ (%)</td>
<td>$-17.4 (2.3)$</td>
</tr>
<tr>
<td>$S_{es}$ (%)</td>
<td>$-1.05 (0.13)$</td>
<td>$-1.01 (0.13)$</td>
</tr>
</tbody>
</table>

Mean (SD) for global longitudinal 1end-systolic strain ($S_{es}$) and 2peak systolic strain rate ($SR_s$) in a 16-segment model of left ventricle (LV) overall and for the three different age groups. $^3P < 0.0001$ for significance of difference between youngest and oldest age group for both deformation indices and both genders. $^4P \leq 0.01$ for significance of difference between genders in the two youngest age groups. There was no significant difference between genders in the oldest age group. $^5$Overall very highly significant difference ($P < 0.0001$) for deformation indices between genders. 

assessed deformation parameters by age, and these studies were too small to reliably assess whether degree of deformation depends on age or gender. However, previous studies have shown age dependency of both diastolic and systolic function assessed by LV filling, mitral annular displacement, and TDI velocities of the mitral annulus. As shown in Table 1, ejection fraction was higher and end-diastolic volume was smaller in women. The difference by sex and age in strain and SR was still present after adjustment for age, body mass index, heart rate, blood pressure, and serum glucose and both sex and age were unique significant predictors of $S_{es}$ and $SR_s$ after in multivariate analysis. In supplement, deformation indices are adjusted for LV size as the method used, as strain and SR, being measures of deformation per length, are already normalized for LV size and normalizing for body size as well is inappropriate. In the large Multi-Ethnic Study of Arteriosclerosis (MESA), deformation indices were calculated by tagged cardiac magnetic resonance imaging (CMR). Although the MESA study had adequate statistical power, it showed no difference by age in peak systolic strain or $SR_s$. The reduced deformation with increasing age that we observed appears to be physiologically plausible, and in line with previous studies that have displayed age dependency of both displacement (corresponding to strain) and tissue velocities (corresponding to SR). This suggests that CMR-derived measurements may be less sensitive to age-dependent changes.

Comparison of methods

Several studies have compared different methods of strain and SR imaging. For analyses of $S_{es}$ and $SR_s$, we have previously shown that speckle-based tools may generally measure lower values compared with TDI-based tools. Compared with the AFI software, the combined method may yield slightly lower values for segmental and global strain, with a mean difference of $\sim 1$ percentage point strain. In a recent study, where different grey-scale-based tools of deformation imaging were validated against tagged CMR, the AFI method was superior to velocity vector imaging (Siemens Medical Solutions, Mountain View, CA, USA). Our results are in concordance with previous studies and therefore, the deformation values for regional and global $S_{es}$ and $SR_s$ that we present here may be applicable in a general clinical setting. The ST-derived SR values should not be used as reference values for TDI-derived SR. However, the TDI-derived values are similar to the ones achieved by the commercial EchoPAC analysis.

The method that we used is validated against tagged CMR in the resting heart, and also against coronary angiography in
Table 4  Mean (SD) segmental longitudinal end-systolic strain (Ses) and peak systolic strain rate (SRs)

<table>
<thead>
<tr>
<th>Method 1 ST and TDI</th>
<th>Method 2 TDI fixed ROIs</th>
<th>Method 3 TDI tracked ROIs</th>
<th>Method 4 ST (AFI)</th>
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<tbody>
<tr>
<td><strong>Apical</strong></td>
<td></td>
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<tr>
<td>Ses (%)</td>
<td>mean (SD)</td>
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<td>Ses (%)</td>
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<tr>
<td>Basal</td>
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<tr>
<td>Ses (%)</td>
<td>mean (SD)</td>
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<td>Ses (%)</td>
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<tr>
<td><strong>Mid-ventricular</strong></td>
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<tr>
<td>Ses (%)</td>
<td>mean (SD)</td>
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<td>Ses (%)</td>
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<td><strong>Mean</strong></td>
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<td></td>
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<tr>
<td>Ses (%)</td>
<td>mean (SD)</td>
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<td>Ses (%)</td>
</tr>
</tbody>
</table>

Comparison of 4 different methods. Mean (SD) segmental longitudinal end-systolic strain (Ses) and peak systolic strain rate (SRs) for four different methods in 57 participants for three different levels of LV and the mean of all analysed segments. Footnotes list significance of difference between the marked measurement and corresponding measurement from method 1 (AFI = automated function imaging (GE Vingmed Ultrasound)), 2 (tissue Doppler imaging (TDI) with fixed regions of interest (ROIs)), 3 (TDI with tracked ROIs), 4 (1 and 3) (where Method 1 is combination of speckle tracking (ST) and TDI), 5 (2 and 3), 6 (2 and 4), and 7 (all other methods) with P < 0.05 (one-way ANOVA, post hoc analysis: least significant difference).

Study limitations

We randomly selected the study sample from a large unselected population. A total of 1296 healthy individuals participated in the echocardiographic study, and 30 were excluded from analyses due to underlying pathology that was detected during the examination. All participants were of northern European Caucasian descent, but in the MESA Study, race was not associated with differences in peak systolic strain and SRs measurements. However, that study did not detect differences by sex or age either.

Only one of the applied methods of this study is commercially available (AFI). This software, like other commercially available ST tools, has limited opportunities to change preferences, and the technology behind the analyses is hidden for the user. Therefore, the analyses of deformation indices were performed with customized semi-automatic software that enables segmental deformation analyses of a large population. Since comparisons showed no clear differences between applications, the normal ranges that we observed may be applicable across different applications with the reservations discussed above.

The TDI analyses are performed with a semi-automatic customized tool, and manual measurements could have improved the accuracy of TDI velocity gradient measurements. However, our group has previously shown that this requires more time and experience than automated methods, and the basic principle for the methods is the same as in the commercial software (EchoPAC tissue Doppler analysis).

Conclusions

In this large population-based study of presumably healthy individuals, we present reference values for global and segmental longitudinal Ses and SRs according to age and sex. Overall, global Ses...
References
All authors received funding from the Norwegian University of Science and Technology, NTNU, Nord-Trøndelag County Council, and The Norwegian Institute of Public Health.

Conflict of interest: H.T. has served as a scientific advisor for GE Vingmed Ultrasound, Horten, Norway. A.S. has received lecture fees from GE Vingmed Ultrasound, Horten, Norway. S.A.A. has previously been employed by GE Vingmed Ultrasound, Horten, Norway.

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Supplementary data
Supplementary data are available at European Journal of Echocardiography online.

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Conflict of interest: H.T. has served as a scientific advisor for GE Vingmed Ultrasound, Horten, Norway. A.S. has received lecture fees from GE Vingmed Ultrasound, Horten, Norway. S.A.A. has previously been employed by GE Vingmed Ultrasound, Horten, Norway.

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Supplementary data
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References