Over all variability of mitral annular plane peak systolic velocity and peak global longitudinal strain rate in relation to age, body size, and sex: The HUNT Study

Asbjørn Støylen MD1,2 | Harald E. Mølmen MD, PhD3,4 | Håvard Dalen MD, PhD1,2,5

1Department of Medical Imaging and Circulation, Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway
2Department of Cardiology, St. Olav’s University Hospital, Trondheim, Norway
3Morbid Obesity Centre, Division of Medicine, Department of Endocrinology, Vestfold Hospital Trust, Tønsberg, Norway
4Asgardstrand General Practice, Horten, Norway
5Department of Medicine, Levanger Hospital, Nord-Trøndelag Hospital Trust, Levanger, Norway

Correspondence
Asbjørn Støylen, Department of Circulation and Imaging, NTNU. Det Medisinske Fakultet, Institutet for Sirkulasjon og Bildediagnostikk, Postboks 89057491 Trondheim, Norway.
Email: asbjorn.stoylen@ntnu.no

Funding information
Norwegian University of Science and Technology

Abstract
Background: Left ventricular (LV) systolic global function can be assessed by peak annular systolic velocity S′. Global longitudinal strain rate (GLSR) is relative LV shortening rate, equivalent to normalizing S′ for LV length (S′n). It has previously been shown that mitral annular plane systolic excursion (MAPSE) and global longitudinal strain (GLS) have similar biological variability, but GLS normalizes for one dimension only, inducing a systematic error, increasing body size dependence. The objective of this study was to compare S′ with GLSR in the same way, comparing biological variability and body size dependence.

Methods and Results: A total of 1266 subjects from the third wave of Nord-Trøndelag Health Study (HUNT), without evidence of heart disease, were examined. Strain rate, S′ and wall lengths were measured in the four walls of the two- and four-chamber views. Mean S′ was 8.4 (1.4) cm/s, (S′n) was 0.7 (0.14)s−1 and GLSR 1.02 (0.14)s−1. All measures declined with age. Normalization of mitral annular velocities for LV length, or the use of GLSR, did not reduce overall biological variability compared with S′. S′ did show a weak, positive correlation to BSA, while S′n and GLSR a slightly stronger, negative correlation to BSA.

Conclusions: S′, S′n, and GLSR have similar biological variability, which is mainly due to age, not body size variation. Normalizing S′ for LV length (as in S′n or GLSR) reverses correlation with BSA inducing a systematic error, due to the one-dimensional normalization for one dimension only.

Keywords
mitral annular velocity, normalization, strain rate imaging, tissue Doppler echocardiography

1 | INTRODUCTION

Systolic left ventricular (LV) shortening can be assessed by peak mitral annular systolic velocity (S′) by spectral Doppler,1-3 which correlates with EF in dilated heart disease,1 although slightly less than mitral annular plane systolic excursion (MAPSE).4 S′ is reduced in pathological hypertrophy2,3 and especially in heart failure with preserved EF,5,6 shows better correlation with brain natriuretic peptide than

Abbreviations: EF, ejection fraction; GLS, global longitudinal strain; GLSR, global longitudinal strain rate; HUNT, Nord-Trøndelag Health Study; LV, left ventricle; MAPSE, mitral annular plane systolic excursion; S′, peak systolic mitral annular velocity; S′n, peak systolic mitral annular velocity divided by mean LV wall length; SD, standard deviation; WL, wall length.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2020 The Authors. Echocardiography Published by Wiley Periodicals, Inc.
EF\(^7\) and has prognostic predictive value in hypertension.\(^8\) By tissue Doppler, both systolic and diastolic function can be measured by the same method, showing the interdependence between systolic and diastolic function.\(^2,9\) Our group has previously published age and sex-specific normal values for S’ from the HUNT Study,\(^9\) showing higher values in men, and lower velocities with increasing age. S’ shows differences between walls in healthy individuals, so for a global measure, measurements of S’ from different walls have to be averaged\(^9,13-15\) as shown in Figure 1A.

Systolic strain rate is velocity difference per length unit\(^12\) and has been validated as a measure of segmental systolic dysfunction\(^13-15\) (Figure 1B). Peak global longitudinal strain rate (GLSR), being the mean of all segments is a global measure of LV function, the rate of LV shortening normalized for LV length. Normalizing annular velocity (S’\(_n\)) for wall length (WL) is also a measure of global strain rate as shown in Figure 2. Thus, both GLSR and S’\(_n\) are measures of shortening rate, normalized for LV length. Normalized measures were supposed to compensate for differences due to heart, and thus, body size, reducing biological variability. However, recent data from the Nord-Trøndelag Health Study (HUNT) have shown that for MAPSE and global longitudinal strain (GLS) normalizing for LV length did not reduce biological variability, in fact normalizing for LV length induced a systematic error, with subsequently increased dependence on body size and sex.\(^16\) The basic measures of S’, wall lengths and GLSR in this material, have all been published previously\(^9,10,16-18\) but the normalized values of S’\(_n\) and the comparisons of variability and relation to body size are new. The aim of the present study was to ascertain the biological variability of S’ vs the normalized values S’\(_n\) and GLSR in terms of the relations to age, body size and sex, and to see if the relations were similar to those of MAPSE and GLS.

2 | METHODS

2.1 | Study subjects

The study population was recruited from 50 839 participants of the third wave of the Nord-Trøndelag Health Study (HUNT3) and has been extensively described in previous papers.\(^9,10,16,17,19\) Briefly, a random sample restricted to two communities was invited to the echocardiographic study, excluding subjects with a history of heart disease, hypertension, or diabetes. A total of 1296 were included. After echocardiography, another 30 individuals with significant pathology on the echocardiogram were excluded. Thus, the study consisted of 1266 subjects aged 19-89 years. All subjects in the HUNT Study gave their written consent to participate in both main and sub-studies. The study was approved by the regional ethical committee (REK 4.2009.397 and 2018/929). Basic characteristics are given in Table 1. Echocardiographic measures were all normally distributed. Blood pressure was measured during the visit, as the mean of the two last of three automated measures. Despite excluding subjects with known hypertension, it is evident from Table 1 that some untreated hypertension may be present in the material, although this was spot blood pressures on a single day. In the three age groups, <40, 40-60, and >60 years, respectively, 7%, 18%, and 44% had Systolic blood pressure (SBP) >140 mm Hg, and 3%, 9%, and 10% had diastolic blood pressure (DBP) >90 mm Hg. Both (SBP) and (DBP) correlated with age: R = .40 and .24, respectively (both P < .001).

2.2 | Echocardiography

One experienced echocardiographer (HD) conducted all the examinations. Subjects were examined in left lateral supine position with a Vivid 7 scanner (version BT06, GE Vingmed Ultrasound). Transducers were phased-array matrix transducers (M3S and M4S). The examination included apical four- and two-chamber and apical long-axis views. Mean B-mode frame rate was 44 FPS. Pulsed-wave tissue Doppler recordings of mitral annular velocities were acquired from the base of the septum and lateral wall in four-chamber, and anterior and inferior walls in the two-chamber views, S’ was measured by spectral tissue Doppler and averaged per patient for global measure in accordance with general usage.\(^13,16,17,18\) Wall lengths (WL) were approximated by the straight line from the apex to the mitral ring at end-diastole in B-mode, as shown in Figure 1B. S’\(_n\) was calculated as S’/WL and averaged for all four walls per patient for global value.

Color tissue Doppler images from the three standard apical planes were acquired separately with mean Doppler frame rate of 100 FPS, and B-mode images in the background. Peak systolic strain rate was measured by the combined segmental tissue Doppler and speckle tracking method described earlier\(^17,20\) as shown in Figure 1B. Care was taken to avoid visible clutter areas. Global average (GLSR) was calculated of all six walls (16 segment model) from the three standard planes.\(^21\) We also calculated the mean from the four walls of the four-chamber and two-chamber views, for comparison with S’ and S’\(_n\). Longitudinal systolic strain rate is shortening, being negative, but the main objective was to compare with S’, so strain rate values are here referred as numerical values.

2.3 | Calculation and statistics

Calculations and statistics were done in SPSS (IBM, corp). Echocardiographic indices are presented as means and standard deviations (SD). Strain is given in numeric values. Differences between genders were tested by independent samples Student’s t-test, differences between age groups by one-way ANOVA, with Bonferroni post hoc comparisons. As strain rate and velocity have different units, the relative SD (SD/mean) was used as variability measurement. Correlations were assessed by Pearson’s correlation coefficient. Linear regression was used for assessing the interaction of BSA, age, and gender. Repeatability of the different measures has been extensively studied previously\(^9,10,16-18\) Shorty inter-observer variations in repeated acquisitions had a coefficient of repeition (CoR) of 1.7 cm/s and mean error (ME) of 8% for S’ averaged from four walls which increased to 11%
when using mean of only two walls. The corresponding CoR and ME was 0.2 s\(^{-1}\) and 9% for GLSR and 1.6 mm and 4% for WL, respectively.

3 | RESULTS

Feasibility was 97% for global S', 93% for S'_n, and 97% for GLSR. However, as segmental strain is susceptible to clutter, almost 40% of segments were rejected in order to obtain representative normal segmental values for SR and strain. Feasibility per wall was 96%-97% for all four walls for S’, 93% for S'_n, and 58%-90% for SR, lowest in anterior wall.

Distribution of measures are shown in Figure 3, panel A. GLSR was normally distributed, while S' and S'_n showed significant, but modest skewness (near normal) of ~0.24 and 0.35, respectively. As seen by Table 2, the relative SD was not very different between S' and the two normalized measures S'_n and GLSR.

Sex- and age-related values are given in Table 2. For direct comparison, numerical values are given and discussed, even though the correct usage for GLSR and S'_n should be negative systolic values as explained in Figure 2.

As pulsed-wave tissue Doppler conventionally is taken in four points from four- and two-chamber views, values for the mean of all four walls as well as for only septal and lateral walls (being a time-saving practice in everyday clinic) are given as secondary measures. Differences between two and four walls for S' and S'_n were both significant, although differences are negligible in practice. GLSR was measured in all six walls, but for comparison, mean of the same four and two walls are also given. Again, differences were statistically significant, but in practice negligible. GLSR, however, was significantly higher than S'_n.

Mean S' was highest in men (8.2 (women) vs 8.6 (men) cm/s, \(P < .001\)), while S'_n (0.89 (women)s\(^{-1}\) vs 0.85 s\(^{-1}\)(men)) and GLSR (1.05 (women)s\(^{-1}\) vs 1.01 s\(^{-1}\) (men)) were highest in women, both \(P < .001\).

S' correlated with MAPSE (\(R' = 0.55\)). There was a weak positive univariate correlation of BSA with S' of 0.13, while S'_n and GLSR showed numerically slightly higher, but negative correlations with BSA as seen in Table 3. The relation between the three measures and BSA is shown in Figure 3, panel B. BSA was also significantly different between sexes (Table 1, \(P < .001\)). In linear regression with sex, age, and BSA, BSA was independently associated with S'_n, and sex was independently associated with S' and GLSR as seen from Table 3.
Differences between age groups were highly significant (post hoc \( P < .001 \) overall and for difference between all age groups) as seen in Table 2. Relations with age are shown in Figure 3, panel C. There was almost no correlation between age and BSA (\( R = -.06, P = .04 \)), not significant if multiple correlations were taken into account. In line with this, there was little difference between univariate and multivariate correlations of the echocardiographic measures and age as seen from Table 3.

Age correlated with BP, in linear regression against age and blood pressure, age had the strongest association with \( S' \), \( S'_n \), and GLSR with \( \beta \) of \(-0.39, -0.245, \) and \(-0.25\), respectively (all \( P < .001 \)), SBP was not significant, while DBP was also associated with all three (\( \beta \) of \(-0.1, -0.19, \) and \(-0.12\), all \( P < .005 \)).

4 | DISCUSSION

The main findings in this study were as follows:

- Normalization of mitral annular velocities for LV length, or the use of GLSR, do not reduce overall variability compared with \( S' \).
• All measures are age dependent.
• $S'$ shows a weak, positive correlation to BSA, while $S'_n$ and GLSR are somewhat stronger, negatively correlated to BSA.

The findings mainly confirm what was recently found for MAPSE vs GLS in the same material. Both GLSR and $S'n$ are measures of global strain rate by different methods, and both are included to show that findings about strain rate are general, not method dependent. Biological variability (relative SD) is similar for both GLSR, $S'_n$, and $S'$, as age is the greatest source of biological variability of all three (Tables 2 and 3, and Figure 3). Age correlated with BP, and linear regression showed a negative independent association with DBP as well. However, this was similar for all three measures, and less important for the relation between the measures.

Global longitudinal strain rate and $S'_n$ normalize for length only. Both LV length and diameter are proportional to BSA, while the ratio...
between them remains constant across the BSA range.\cite{22} As the main contribution to the stroke volume is the AV-plane motion,\cite{22} this means that with larger BSA and larger hearts, the main SV increase is related to the cross-sectional LV area, and the square of the radius. Thus, a larger heart generates a larger SV even without the effect of increased AV-plane motion, as illustrated in Figure 4, meaning that even with a higher SV, there is very little increase in MAPSE with increasing BSA. This is thus also the case for \( S' \), which correlates strongly with MAPSE, and thus changes very little with heart size, despite change in SV. The weak correlation between \( S' \) and BSA, however, is sufficient to give a statistically significant sex difference, although for practical purposes the difference is negligible as seen in Table 2, the mean sex differences are small compared with the prediction interval.

As previously shown for global strain,\cite{16} GLSR and \( S'_{n} \) show a slightly stronger, negative correlation with BSA, due to the systematic error that they are normalized for LV length only as explained in Figure 4. As \( S' \) is nearly unchanged with larger heart size, GLSR and \( S'_{n} \) will decrease by the larger denominator (length), as seen by the numerically higher, but negative correlations with BSA.

The diagnostic discriminatory capability of a parameter is related to both the variability of the parameter and the separation of means between normalcy and disease. As normalization for length does not reduce overall biological variability compared to \( S' \), there seems to be no advantage of using global strain rate as a global LV contractility measure compared to \( S' \). Basically, strain rate is a method to assess regional dysfunction and differences in timing, while regional \( S' \) is not.\cite{4} This is important in diseases with regional uneven function, as coronary artery disease and conduction abnormalities. Here, GLSR may still be important in assessing global function. The diagnostic accuracy in specific patient populations must be assessed in direct comparative studies.

Global longitudinal strain rate and \( S' \), on the other hand, have been shown to have about the same reproducibility, where image quality is good.\cite{10} However, spectral tissue Doppler is much more robust in the presence of clutter.\cite{23} Also, tissue Doppler has an additional advantage of measuring systolic and diastolic function with the same method, while diastolic strain rate indices so far lack similar documentation.

The correlation between MAPSE and \( S' \) in this material were 0.55, indicating that they are relatively interchangeable as global function measures. However, this again is limited to the normal range seen in this study. \( S' \) has a slightly lower reproducibility than

---

**TABLE 2** Normal values for left ventricular shortening according to gender and age

| Age (years) | N   | S’ (cm/s) | S’ (cm/s) | S’ (s⁻¹) | S’ (s⁻¹) | GLSR (s⁻¹) | GLSR (s⁻¹) | GLSR (s⁻¹) |
|-------------|-----|-----------|-----------|-----------|-----------|------------|------------|------------|
|             |     | 4 walls   | 2 walls   | 4 walls   | 2 walls   | (4 walls)  | (2 walls)  | (4 walls)  |
| Women       |     |           |           |           |           |            |            |            |
| <40         | 208 | 8.9 (1.1) | 8.8 (1.1) | 0.94 (0.12)| 0.94 (0.13)| 1.09 (0.12)| 1.01 (0.16)| 1.02 (0.18)|
| 40-60       | 336 | 8.2 (1.2) | 8.1 (1.2) | 0.88 (0.13)| 0.88 (0.14)| 1.06 (0.12)| 1.02 (0.15)| 1.02 (0.16)|
| >60         | 119 | 7.2 (1.2) | 7.3 (1.2) | 0.81 (0.13)| 0.82 (0.12)| 0.98 (0.14)| 1.01 (0.13)| 1.01 (0.15)|
| All         | 663 | 8.2 (1.3) | 8.2 (1.3) | 0.89 (1.3) | 0.89 (0.14)| 1.05 (0.13)| 1.02 (0.15)| 1.02 (0.16)|
| Men         |     |           |           |           |           |            |            |            |
| <40         | 126 | 9.4 (1.4) | 9.3 (1.4) | 0.90 (0.14)| 0.90 (0.14)| 1.06 (0.13)| 1.01 (0.12)| 1.02 (0.14)|
| 40-60       | 327 | 8.6 (1.3) | 8.6 (1.3) | 0.84 (0.13)| 0.84 (0.15)| 1.01 (0.12)| 1.04 (0.14)| 1.03 (0.15)|
| >60         | 150 | 8.0 (1.3) | 8.1 (1.3) | 0.82 (0.14)| 0.83 (0.13)| 0.97 (0.14)| 1.03 (0.15)| 1.03 (0.16)|
| All         | 603 | 8.6 (1.4) | 8.6 (1.4) | 0.85 (0.14)| 0.85 (0.14)| 1.01 (0.13)| 1.03 (0.14)| 1.03 (0.15)|
| Total       | 1266| 8.4 (1.4)| 8.4 (1.3) | 0.87 (0.14)| 0.87 (0.14)| 1.03 (0.13)| 1.02 (0.14)| 1.02 (0.16)|

| Relative SD |     | 16.7 | 15.5 | 16.1 | 16.1 | 12.6 | 13.7 | 15.6 |

Note: Values are mean (SD). All differences between sex and age were significant; all \( P < .001 \). Overall standard deviations are given as % of mean in the bottom line, to compare the biological variations between normalized and non-normalized measures. MAPSE\(^n\) and \( S'_{n} \) MAPSE and \( S' \) normalized for LV mean diastolic wall length, respectively. MAPSE\(^2\) and \( S'_{n} \) normalized for both mean LV diastolic wall length and LV diastolic external diameter, respectively.

Abbreviations: GLS = global longitudinal strain; GLSR = global longitudinal strain rate; MAPSE = mitral annular plane systolic excursion; \( S' \) = peak mitral annular systolic longitudinal velocity.

**TABLE 3** Linear regression coefficients for \( S' \), \( S'_{n} \), and GLSR vs BSA, sex, and age

| Measure | \( R \) (univariate) | \( \beta \) | \( P \) |
|---------|-----------------------|------------|-------|
| \( S' \) | BSA \( .13 \) | \( -0.02 \) | NS    |
|         | Age \( -.40 \) | \( -0.42 \) | <.001 |
|         | Sex \( 0.20 \) | \( 0.08 \) | <.001 |
| \( S'_{n} \) | BSA \( -.22 \) | \( -0.29 \) | <.001 |
|         | Age \( -.29 \) | \( -0.31 \) | <.001 |
|         | Sex \( 0.08 \) | \( 0.03 \) | <.001 |
| GLSR    | BSA \( -.17 \) | \( -0.17 \) | <.001 |
|         | Age \( -.29 \) | \( -0.30 \) | <.001 |
|         | Sex \( 0.03 \) | \( 0.03 \) | NS    |
MAPSE, partly related to the width of the spectrum. An important point is also that values obtained by color tissue Doppler and spectral tissue Doppler differ, and are not interchangeable.\(^8\) Color tissue Doppler values based on this material and automated analysis are published recently.\(^{24}\)

### 4.1 Limitations

The HUNT study is among the largest normal studies but is limited by the lack of ethnic and geographical differences. This limits the generalizability of the normal values. However, for the main issue of comparing GLSR and \(S'\) with relation to BSA and age, this is less important. As the conventional LV dimensions and FS in this material are in line with other M-mode studies,\(^{25,26}\) the population seems to be fairly representative.

As this is a cross-sectional study, the age differences are between cohorts and not true aging. However, it reflects the age relations as seen today.

The present study only discusses the variability of the indices within normal ranges. In conditions with reduced regional function, the diagnostic performance of global strain rate may still be better than \(S'\), although this needs to be established in studies by direct comparison.

### 5 Conclusion

Systolic annular velocity shows similar biological variation as global strain rate in normal adults, despite global strain rate are normalized for LV length. Further, the normalization for LV length actually increases the body size dependence. Age is the main determinant of LV shortening. Thus, it is dubious that strain rate adds diagnostic information about global function, compared to mitral annular peak velocity, although strain rate being important for assessing regional function.

### Acknowledgments

The study was fully sponsored by the Norwegian University of Science and Technology, as a PhD grant, as well as the HUNT Study providing the infrastructure for the Echocardiography in HUNT sub-study. There was no relation to industry.

### Conflict of Interest

The authors have no conflicts of interest.

### ORCID

Asbjorn Støylen https://orcid.org/0000-0002-2245-7066

### References

1. Gulati VK, Katz WE, Follansbee WP, Gorcsan J 3rd. Mitral annular descent velocity by tissue Doppler echocardiography as an index of global left ventricular function. *Am J Cardiol*. 1996;77: 979-984.
2. Vinereanu D, Florescu N, Sculthorpe N, Tweddle AC, Stephens MR, Fraser AG. Differentiation between pathologic and physiologic left ventricular hypertrophy by tissue Doppler assessment of long-axis function in patients with hypertrophic cardiomyopathy or systemic hypertension and in athletes. *Am J Cardiol*. 2001;88:53-58.
3. Nagueh SF, Bachinski LL, Meyer D, et al. Tissue Doppler imaging consistently detects myocardial abnormalities in patients with hypertrophic cardiomyopathy and provides a novel means for an early diagnosis before and independently of hypertrophy. *Circulation*. 2001;104:128-130.
4. Støylen A, Skjæerpe T. Systolic long axis function of the left ventricle. Global and regional information. *Scand Cardiovasc J*. 2003;37:253-258.
5. Vinereanu D, Nicolaides E, Tweddle AC, Fraser AG. “Pure” diastolic dysfunction is associated with long-axis systolic dysfunction. Implications for the diagnosis and classification of heart failure. *Eur J Heart Fail*. 2005;7:820-828.

6. Yip G, Wang M, Zhang Y, Fung JW, Ho PY, Sanderson JE. Left ventricular long axis function in diastolic heart failure is reduced in both diastole and systole: time for a redefinition? *Heart*. 2002;87:121-125.

7. Elnoamany MF, Abdelhameed AK. Mitral annular motion as a surrogate for left ventricular function: correlation with brain natriuretic peptide levels. *Eur J Echocardiogr*. 2006;7:187-198.

8. Ballo P, Barone D, Bocelli A, Motto A, Mondillo S. Left ventricular longitudinal systolic dysfunction is an independent marker of cardiovascular risk in patients with hypertension. *Am J Hypertens*. 2008;21:1047-1054.

9. Dalen H, Thorstensen A, Vatten LJ, Aase SA, Stoylen A. Reference values and distribution of conventional echocardiographic Doppler measures and longitudinal tissue Doppler velocities in a population free from cardiovascular disease. *Circ Cardiovasc Imaging*. 2010;3:614-622.

10. Thorstensen A, Dalen H, Amundsen BH, Aase SA, Stoylen A. Reproducibility in echocardiographic assessment of the left ventricular global and regional function, the HUNT study. *Eur J Echocardiogr*. 2010;11:149-156.

11. Mondillo S, Galderisi M, Ballo P, Marino PN. Left ventricular systolic longitudinal function: comparison among simple M-mode, pulsed, and M-mode color tissue Doppler of mitral annulus in healthy individuals. *J Am Soc Echocardiogr*. 2006;19:1085-1091.

12. Heimdal A, Stoylen A, Torp H, Skjaerpe T. Real-time strain rate imaging of the left ventricle by ultrasound. *J Am Soc Echocardiogr*. 1998;11:1013-1019.

13. Urheim S, Edvardsen T, Torp H, Angelsen B, Smiseth OA. Myocardial strain by Doppler echocardiography. Validation of a new method to quantify regional myocardial function. *Circulation*. 2000;102:1158-1164.

14. Stoylen A, Heimdal A, Bjornstad K, Torp HG, Skjaerpe T. Strain rate imaging by ultrasound in the diagnosis of regional dysfunction of the left ventricle. *Echocardiography*. 1999;16:321-329.

15. Stoylen A, Heimdal A, Bjornstad K, et al. Strain rate imaging by ultrasonography in the diagnosis of coronary artery disease. *J Am Soc Echocardiogr*. 2000;13:1053-1064.

16. Stoylen A, Molmen HE, Dalen H. Relation between mitral annular plane systolic excursion and global longitudinal strain in normal subjects: the HUNT study. *Echocardiography*. 2018;35:603-610.

17. Dalen H, Thorstensen A, Aase SA, et al. Segmental and global longitudinal strain and strain rate based on echocardiography of 1266 healthy individuals: the HUNT study in Norway. *Eur J Echocardiogr*. 2010;11:176-183.

18. Støylen A, Molmen HE, Dalen H. Importance of length and external diameter in left ventricular geometry. Normal values from the HUNT Study. *Open Heart*. 2016;3:e000465.

19. Dalen H, Thorstensen A, Romundstad PR, Aase SA, Stoylen A, Vatten LJ. Cardiovascular risk factors and systolic and diastolic cardiac function: a tissue Doppler and speckle tracking echocardiographic study. *J Am Soc Echocardiogr*. 2011;24(3):322-332.e6.

20. Inglul CB, Torp H, Aase SA, Berg S, Støylen A, Slordahl SA. Automated analysis of strain rate and strain: feasibility and clinical implications. *J Am Soc Echocardiogr*. 2005;18:411-418.

21. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American society of echocardiography and the European association of cardiovascular imaging. *J Am Soc Echocardiogr*. 2015;28:1-39.e14.

22. Carlsson M, Ugander M, Mosen H, Buhre T, Arheden H. Atroventricular plane displacement is the major contributor to left ventricular pumping in healthy adults, athletes, and patients with dilated cardiomyopathy. *Am J Physiol Heart Circ Physiol*. 2007;292:H1452-H1459.

23. Lervig LCN, Brekke B, Aase SA, et al. Myocardial strain rate by anatomic Doppler spectrum: first clinical experience using retrospective spectral tissue Doppler from ultra-high frame rate imaging. *Ultrasound Med Biol*. 2017;43:1919-1929.

24. Grue JF, Sturve S, Stoylen A, et al. Normal ranges for automatic measurements of tissue Doppler indices of mitral annular motion by echocardiography. Data from the HUNT3 Study. *Echocardiography*. 2019;36(9):1646-1655.

25. Ganau A, Saba PS, Roman MJ, de Simone G, Realdi G, Devereux RB. Ageing induces left ventricular concentric remodelling in normotensive subjects. *J Hypertens*. 1995;13:1818-1822.

26. Knutsen KM, Stugaard M, Michelsen S, Otterstad JE. M-mode echocardiographic findings in apparently healthy, non-athletic Norwegians aged 20–70 years. Influence of age, sex and body surface area. *J Intern Med*. 1989;225:111-115.

How to cite this article: Støylen A, Molmen HE, Dalen H. Over all variability of mitral annular plane peak systolic velocity and peak global longitudinal strain rate in relation to age, body size, and sex: The HUNT Study. *Echocardiography*. 2020;37:578–585. [https://doi.org/10.1111/echo.14630](https://doi.org/10.1111/echo.14630)