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● *Original Contribution*

AUTOMATED, OBJECTIVE AND EXPERT-INDEPENDENT ASSESSMENT OF THE ANALYZABILITY OF STRAIN AND STRAIN RATE IN TISSUE DOPPLER IMAGES IN TERM NEONATES BY ANALYSIS OF BEAT-TO-BEAT VARIATION

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Abstract—The variation in longitudinal strain and strain rate (SR) between two consecutive heartbeats (beat-to-beat-variation, BBV) was used to evaluate the analyzability of longitudinal strain and SR in tissue Doppler images in term neonates. Strain and SR BBV analysis and visual evaluation of analyzability were performed in 2394 segments; 1739 segments (73%) were deemed to be analyzable by visual evaluation, with an intra-rater κ score of 0.87 and inter-rater κ score of 0.61 ($p < 0.001$). Compared against visual evaluation, the κ scores for identification of analyzable segments were 0.57 based on SR BBV and 0.58 based on strain BBV ($p < 0.001$). The areas under the receiver operating characteristic curves for identification of analyzable segments were 0.87 (0.85–0.88) for strain BBV and 0.87 (0.85–0.89) for SR BBV ($p < 0.001$). For both BBVs, the sensitivity for identification of analyzable segments was 77% at a specificity of 80%. Analysis of BBV can be used for automated, objective and expert-independent assessment of analyzability. (E-mail: nestaas@hotmail.com) © 2014 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Heart function, Deformation analysis, Cardiology, Infant, Myocardial function, Echocardiography, Automated analysis, Myocardial performance assessment.**

INTRODUCTION

Echocardiography is widely used in neonates. Good acoustic windows hold the potential for good image quality. In neonates, fractional shortening has been found to be less sensitive than atrioventricular plane systolic velocities (Matter et al. 2010) and deformation indices (Nestaas et al. 2011) for detection of reduced heart function between asphyxiated and non-asphyxiated neonates. Strain and strain rate have the advantage over atrioventricular plane indices in that they are normalized for ventricle size and, therefore, can be more readily compared between hearts of different sizes.

Assessment of deformation by B-mode speckle tracking is hampered by each vendor having its own variant of the technology, yielding different values in the same images (Koopman et al. 2010). In neonates, a further obstacle to the use of B-mode speckle tracking is the low frame rate, resulting in a small number of frames per heartbeat, which may result in poor tracking as well as under-sampling, especially for assessment of strain rate.

The main challenge in deformation analysis by tissue Doppler in neonates is related to the signal-to-noise ratio and the size of the segments. Deformation indices by tissue Doppler are based on assessment of difference in velocities along the strain length and, therefore, have a less favorable signal-to-noise ratio than atrioventricular plane indices, as the noise is the sum of the variation of the velocity measurements (Heimdal et al. 1998). Tissue Doppler indices have been found to have lower reproducibility than blood flow measurements both in adults (Thorstensen et al. 2010) and in neonates (Joshi et al. 2010). Deformation indices have been found to have lower reproducibility than tissue velocity measurements (Joshi et al. 2010). In smaller segments, the signal-to-noise ratio is lower; although the amount of noise for each velocity measurement within an image is independent of segment size, analysis of segments with fewer pixels (few velocity measurements) and with smaller

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velocity differences between the pixels (short strain lengths) will lower the signal-to-noise ratio. In images of low quality, more noise is present. Although there is no general agreement on what criteria should be used for deciding the analyzability of segments, clutter (in particular, stationary reverberations) and random dropouts are, in our experience, the main causes of low image quality. Deformation analysis of segments with low image quality leads to erroneous measurements, and significantly lower values have been obtained in such segments in neonates (Nestaas et al. 2009). This occurs because the autocorrelation algorithm for velocity assessment incorporates information from stationary echoes. Visual assessment of the analyzability of tissue Doppler images is expert dependent. Difficulties in evaluation of analyzability might be a significant obstacle to the use of deformation analyses by tissue Doppler in neonates, as well as in other patient groups. An objective and expert-independent tool for evaluation of the analyzability is therefore desired.

Earlier we used the variation in strain and strain rate curves between two consecutive heart cycles, the strain and strain rate beat-to-beat variations (BBVs) (Fig. 1), as measures of noise in deformation analyses by tissue Doppler (Nestaas et al. 2007, 2008). The BBV is the difference between a curve from a single cycle and the mean (compound) curve of two heart cycles, expressed as a fraction of the area under the compound cycle curve. This is the sum of the true variation and the variation caused by the noise in the analyses, from heart cycle to heart cycle.

This method quantifies random noise. The main point of using a compound cycle for reference is that the averaging of two cycles, to a large extent, averages out random noise; thus, the difference could be regarded basically as a measure of the amount of random noise in a single heart cycle. Clutter is mainly stationary echoes, which leads to reduced velocity estimates by the autocorrelation algorithm of color tissue Doppler. Alone, this effect would lead to reduced velocity and strain rate (velocity gradient) values, but not necessarily to increased beat-to-beat variation. However, the effect of the stationary noise on the velocity estimate will also depend on the relative amplitude of the tissue signal versus the clutter. As this will vary from point to point, the effect will thus be increased variability from point to point, an effect that is largely random (Sagberg et al. 2004). Thus, clutter will result in a signal with, on average, reduced velocity, but increased variability. This effect is accentuated in the strain rate calculation.

Probe type and frame rate (Nestaas et al. 2008) and settings for region of interest (ROI)) size and strain length (Nestaas et al. 2007, 2008) have effects on the noise in the analyses. We have suggested that settings with little

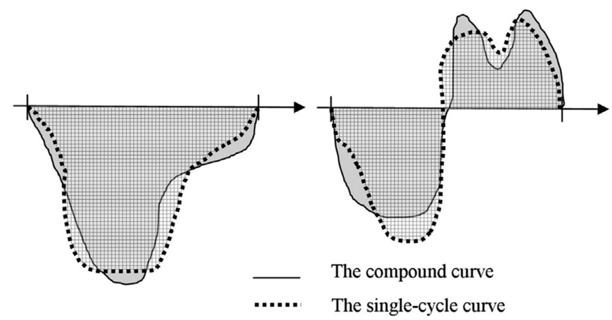

Fig. 1. Assessment of beat-to-beat variation (BBV) as depicted in examples from a strain curve (*left*) and a strain rate curve (*right*). The single-cycle curve is represented by the *dotted line*, and the area under the single-cycle curve is marked by the *square pattern*. The two-cycle compound curve is represented by the *solid line,* and the area under the compound curve is *gray*. To assess the BBV, the area between the single-cycle curve and the two-cycle compound curve is divided by the area under the compound curve (*gray area*).

variation between heartbeats should be used, and similar settings for the off-line analyses were later suggested by others (Joshi et al. 2010). Recently, suggestions for ROI size and strain length for analysis of deformation have been proposed based on quantification of noise by BBV also in premature neonates (Helfer et al. 2013).

The aim of this study was to assess the feasibility of using strain and strain rate BBVs as an automated, objective and expert-independent tool for evaluating the analyzability of longitudinal strain and strain rate in tissue Doppler images in neonates.

METHODS

Patients

Forty-eight healthy term neonates from the maternity ward at Oslo University Hospital, Ullevål, Norway, were examined on the first, second and third days of life (March–May 2005) (Table 1). Written parental consent was obtained, and the project was approved by the Norwegian South-East Regional Committee for Medical Research Ethics and by the Scientific Committee at Oslo University Hospital, Ullevål.

Table 1. Characteristics of the neonates included in the analyses

Number of neonates	48
Female:male ratio	1:1
Mean (range) gestational age, wk	41 (37–42)
Mean (SD) birth weight, kg	3.68 (0.45)
Median (range) 5-min Apgar score	9 (8–10)
Mean (SD) age at examination, h	
Day 1 (n = 47)	12.2 (4.5)
Day 2 (n = 46)	36.1 (4.7)
Day 3 (n = 45)	58.6 (4.8)

SD = standard deviation.