Quantitative regional curvature analysis: A prospective evaluation of ventricular shape and wall motion measurements


Wall motion analysis is a fundamental prerequisite for both clinical decision-making and for evaluating the results of new therapy or interventions. Traditional methods used to measure wall motion per se can all be characterized by the need to invoke one or more assumptions about idealized geometry of the ventricle, the reference system (internal or external), the indexing system (fixed or floating), and the coordinate system (radial or perpendicular). Consequently, numerous approaches have been proposed that are all dramatically affected by translational and rotational motion within the image plane. Our laboratory has attempted to circumvent these problems by measuring ventricular shape as an indirect index of actual function. The approach is based on the hypothesis that normal and abnormal ventricles look dissimilar by virtue of differences in regional function and that clinicians use these shape cues when assessing ventricular function. Therefore a measure of shape should provide an index related to ventricular function. Our laboratory has previously established normal shape patterns, patterns of abnormality, and the performance of the shape algorithm compared to that of the centerline method. The purpose of this investigation was to reevaluate prospectively the comparative performance of these two approaches for the diagnosis of subtle abnormalities of ventricular function in a population different from the population used for initial development of the algorithms. The study also compares the degree to which each method simulates the performance of clinical observers and the prerequisites for achieving this level of performance. The ultimate goal of this line of work is to begin to develop methods for automatic analysis of ventricular function beginning with the stage of edge detection and proceeding through to the stage of generating a probabilistic interpretation within the context of utilizing artificial intelligence techniques for decision-making.

METHODOLOGY

The study group consisted of 82 patients, of which 30 had been used to establish a normal data base and the remaining 52 were new patients with normal or mildly abnormal regional ventricular function. Patients with akinesis, dyskinesis, or hyperkinesis were not included. End-diastolic and end-systolic outlines of the 52 new patients were drawn with an external reference system convention to allow application of the centerline method. These were viewed by four independent observers on two occasions. The original ventriculograms were not shown in order to present only the static outlines, thereby mandating that all clinical decisions would depend solely on shape and displacement cues and not on cues related to the coordination of motion. Two observers were familiar with the quantitative regional curvature algorithm (GBJM, SFD) and two were not (MJM, ERB). Each observer was asked to classify the anterior, apical, and inferior regions as either normal (0 points) or abnormal (1 point). Scores were collated so each segment was assigned a semiquantitative visual score ranging from 0 (all four observers felt that the segment was normal on both readings) to 8 (all four observers felt that the segment was abnormal on both readings). There were seven instances of apical abnormalities and these were invariably associated with anterior...
abnormalities. Therefore the scores for these two segments were added and then halved and the segments were considered to be anterior segments for the remainder of the study. This method provided a continuous variable for assessing the degree of abnormality. For categorical analyses, a visual score of $\geq 4$ was used to designate an abnormal segment. This grading resulted in 62 normal segments (16 anterior and 46 inferior) and 42 abnormal segments (36 anterior and 6 inferior). No attempt was made to establish a cohort with an equal distribution of normal and abnormal regions.

The outlines were then quantitated with the use of the previously detailed centerline method and the quantitative regional curvature analysis method. Based on prior experience, only the end-systolic shape was examined with the quantitative regional curvature analysis method. Quantitation of motion and shape was constrained to 50% of the segment length, as previously described. Each algorithm was applied in three different ways: (1) the minimum ("worst") value within 50% of the segment length; (2) the maximum ("best") value within 50% of the segment length; and (3) based on the clinical designation, the minimum value was quantitated when the segment was felt to be clinically abnormal and the maximum value was quantitated when the segment was felt to be clinically normal. This was called the "min/max" approach. Motion results were reported in units of standard deviations per chord and shape results were reported in units of standard deviations per point.

Each quantitative methodology was analyzed to determine the critical value that maximized performance based on sensitivity, specificity, and concordance. In the absence of a true "gold standard" for

Fig. 1. Panels A, B, and C show the results of the different quantitative applications for both the shape and wall motion algorithms. Optimal results were obtained with the "min/max" approach (panel A). Shape and motion quantification were equal in their relation to the visual scores.
Fig. 2. Panels A, B, and C show the relation between motion and shape scores. Optimal results were obtained with the "min/max" approach (panel A). Dashed lines show the critical values determined for each technique (see Table I). ANT, anterior; INF, inferior; NRM, normal; ABN, abnormal.

Regional function, the clinical designation was used as a "gold standard." This was further justified because one of the intents was to develop a system that mimics clinical performance. Accordingly, sensitivity was defined as the number of quantitatively abnormal segments divided by the total number of clinically abnormal segments. Specificity was defined as the number of quantitatively normal segments divided by the total number of clinically normal segments. Concordance was defined as the number of segments that were both clinically and quantitatively normal or abnormal divided by the total number of segments.

Linear regression analysis was used to determine the relation between visual scores and both shape and wall motion scores. This was also used to determine the relation between shape and motion scores. Categorical analyses for sensitivity, specificity, and concordance rates were analyzed with a chi square test. p values <0.05 were considered significant.

**OBSERVATIONS**

Fig. 1 shows the regression results between shape scores or wall motion scores and visual scores. Optimal correlations were obtained by means of the "min/max" approach. Both the shape and motion results correlated to a similar degree with the clinical designation, irrespective of the quantitative approach used.

Fig. 2 shows the relation between motion and shape quantification. As in the analyses shown in Fig. 1, results of this analysis were also best when the "min/max" approach was used. Notice in panel A that one inferior segment was shown to have abnormal shape but normal wall motion. The
Table 1. Critical values, sensitivity, specificity, and concordance rates for each application of the shape and wall motion algorithms

<table>
<thead>
<tr>
<th>Approach</th>
<th>Critical value</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Concordance</th>
</tr>
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<tr>
<td>&quot;Min/max&quot; 50%</td>
<td></td>
<td></td>
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<tr>
<td>Shape</td>
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<td>Motion</td>
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<td>64.3</td>
<td>82.3*</td>
<td>75.0</td>
</tr>
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</table>

Critical values are given in units of standard deviations per point (shape) and units of standard deviations per chord (motion). Results are given as percentages. See text for definition of terms.

*p < 0.01 versus shape analysis.
†p < 0.04 versus shape analysis.

quantitative output for this patient is shown in Fig. 3.

Table I shows the critical values, sensitivity, specificity, and concordance results for all three approaches. The "min/max" approach was again optimal for both techniques. In this instance, concordance was significantly better for the shape approach (99% versus 93%, p < 0.04). Sensitivity was equal (100% vs 98%, p = 0.31) and specificity was not quite significantly different (98% vs 90%, p = 0.052).

COMMENTS

This laboratory has attempted to take a radically different approach to solving the clinical problem of regional function quantitation in order to circumvent the assumptions and approximations required by traditional wall motion methodologies. The method of using shape analysis is based on the hypothesis that clinicians use shape cues to assess regional function and that normal and abnormal ventricles look different by virtue of differences in function. Accordingly, methods incorporating shape analysis should provide methodologies that mimic clinical performance and that provide quantitative parameters that reflect regional ventricular function.

This study evaluates the comparative performance of the quantitative regional curvature analysis method and the centerline method in a new population consisting primarily of patients with normal or minimally abnormal regional function. The results demonstrate that: (1) both approaches have similar overall performance but the shape analysis method mimics clinical performance somewhat better when both methods are applied to maximize the likelihood of finding normal and abnormal results (i.e., the "min/max" approach); (2) both motion and shape quantitation showed similar linear relations to the probabilistic, visual
that optimal results are achieved only when a priori
prognostically than simple measures of global or
regional function.

The results of the current study confirm previous-
ly published results obtained in a different study
population. Considering the results of the "min/
max" approach previously obtained, the correlation
between shape and motion parameters was 0.748
compared to 0.74 in the current study, the critical
value for shape analysis was −0.4 standard devia-
tions per point compared to −0.35 in the current
study, and the critical value for motion analysis was
−1.10 standard deviations per chord compared to
−1.15 in the current study. Similar concordance
rates were also previously found for shape analysis
(96.5% compared to 99.0% in this study) and
motion analysis (93.9% compared to 93.3%). In
summary, consistent performance of both methodol-
gies was demonstrated.

Aside from providing confirmatory results, this
investigation has several other important implica-
tions. First, the traditional approaches have led to
continuing controversies regarding the relative mer-
its of fixed and internal reference frames, coordinate
systems, and indexing systems but without a resultant
general consensus. All of the traditional
methods are markedly affected by translational and
rotational motion parallel to the imaging plane. The
shape analysis methodology is the first quantitative
approach that is not affected by these factors,
thereby obviating long-standing reservations about
the reliability and accuracy of traditional wall
motion methods. Second, since the quantitative
regional curvature analysis can be applied through-
out the cardiac cycle and because the results are
independent of size, the opportunity exists to
assess both systolic and diastolic function indepen-
dent of volume. Third, the visual cues used by
clinicians to make regional function interpretations
can be quantitated and therefore can be incorporat-
ed into robust methods for achieving automatic edge
detection and decision-making. Fourth, the ability
to measure shape provides a tool for serial assess-
ment of remodelling of the ventricle after myocardi-
al infarction and to assess potential alteration of this
process by drugs and therapeutic interventions.
Finally, shape analysis, perhaps through its rela-
tion to regional wall stress, may be more important	only when a priori knowledge is used to determine the specific way in which the programs are to be applied. For example, the centerline method was validated by quantitating the area of worst abnormality in zones supplied by abnormal coronary arteries and by quantitating the area of least abnormality in zones supplied by normal coronary arteries. The quantitative regional
curvature analysis also shows optimal perform-
ance when applied in a similar fashion. Further
work is necessary to free these methods of this
requirement. One approach might be to generate
automatically the probability of whether a segment
is normal or abnormal based on its shape and to
proceed with wall motion analysis based on this
information alone. This approach would be analo-
gous to template matching and might become a key
procedure for automatic wall motion interpreta-
tion.

SUMMARY

To overcome the assumptions and approxima-
tions mandated by the use of traditional wall motion
methodologies, a method was recently developed for
measuring ventricular shape based on quantitative
curvature analysis of ventricular outlines. This
study was designed to assess prospectively the per-
formance of this algorithm, to compare it to tradi-
tional wall motion measurements (centerline meth-
od), and to determine the comparative degree to
which each method mimicked the interpretation of
wall motion by clinical observers. Semiquantitative
visual grading of regional function in 52 patients was
performed by four independent observers on two
occasions. Anterior, apical, or inferior segments were
judged to be normal (0 points) or abnormal (1 point)
based on viewing nonrealigned, end-diastolic and
end-systolic ventricular silhouettes from cineventri-
culograms obtained in the 30-degree right anterior
oblique projection. Each segment was assigned a
collated score ranging from 0 (all observers felt the
region was normal on both readings) to 8 (all
observers felt the region was abnormal on both
readings). Quantitative regional curvature analysis
and wall motion analysis (centerline method) were
performed. Quantitative shape and wall motion
scores correlated equally well with the semiquanti-
tative visual scores. When a visual score of ≥4 was
used to designate an abnormal segment, both quan-
titative approaches demonstrated comparable sensi-
tivity, specificity, and concordance rates. Both
methods achieved optimal performance when maxi-
imum and minimum deviations from normal were
recorded. Under these circumstances, the shape
analysis demonstrated a greater concordance with
the clinical diagnosis than did wall motion analysis (99% vs 93%, p < 0.04). Thus new information is
provided by the shape analysis program that reflects clinical evaluations more closely and does not
require assumptions mandated by traditional wall motion methods. This confirms the value of quanti-
tative regional curvature analysis in a prospectively studied patient population with subtle wall motion
abnormalities.

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