Customizing the Bull's-Eye to Improve the Clinician's Diagnostic Intuition

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Abstract

The standard "bull's-eye" plot is a synthetic planar representation of left ventricular (LV) myocardium pathologies, as studied in all imaging modalities. The graphical display of a three-dimensional solid on a two-dimensional plane implies distorted or partial representation of the LV, affecting evaluation of the extent of a variety of pathological processes. This study, after having estimated the entity of the divergence of visual assessment of myocardial infarct extension from reality, proposes to upgrade the bull's eye plot in order to provide a more likely information, so to improve the clinician's perception of the heart. The presented alternatives keep the accepted 17 segments architecture, eventually tailored on real LV of each patient.

1. Introduction

In order to provide a compact planar representation of the left ventricular (LV) myocardium, as clinically studied on tomographic medical imaging, the classical "bull's eye" plot was defined as a standard in 2002 by the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association [1]. This model, after having previously set up in nuclear medicine [2-5], was largely accepted by the scientific community, and, in the definitive display of the 17-segment model, became a consensus standard for LV description by tomographic imaging with all imaging modalities [6-9]. The three circular crowns of the bull's eye correspond to the three main LV slices (basal, mid-cavity, and distal). For the imaging modalities with a good spatial resolution (e.g. cardiac magnetic resonance, CMR), the basal slice is the myocardium included between the mitral valve plane and the base of the papillary muscles; the mid-cavity slice is the myocardium that corresponds to the entire length of papillary muscles, and the distal slice is the myocardium included between the tip of the papillary muscles and the end of the LV cavity. The apex, often referred to as apical cup, is the part of myocardium distal to the end of LV cavity, visualized in the horizontal and vertical long-axis views. The bull's eye includes 17 segments: the basal and mid-cavity slices are divided into 6 equiangular and equiradial segments each, the distal slice into 4 equiangular and equiradial segments, while the inner circle represents the apex.

Displaying a three-dimensional structure on a two-dimensional plane implies geometrical distortion, affecting the cardiologist's acknowledgement of a variety of pathological processes (e.g., myocardial perfusion deficits, wall motion abnormalities, LV hypertrophy or post-infarctions cars).

The aim of this study was to evaluate if the bull's eye plot affects the visual estimate of the volume of myocardial segments, and of myocardial infarct (MI) size at late gadolinium enhanced (LGE) acquisitions; subsequently, some enhancements of the plot are proposed to provide a more reliable information at visual inspection.

2. Methods

2.1. Patients

A group of 38 patients (26 men, age 65.6 ± 10.1 years), with previous MI documented by clinical records and referred to CMR for clinical purposes, was retrospectively selected (with approval by the institutional review committee, and after patients' informed consent). Patients with suboptimal image quality at CMR were excluded, as well as those showing moderate valve disease or irregular heart rhythm.

2.2. CMR Data Acquisition

CMR was performed using a 1.5T whole body scanner (GE Signa, Milwaukee, WI, USA). An 8-channel cardiac phased-array receiver surface coil was used for signal reception. A breath-hold steady-state free-precession ECG-triggered sequence was used to evaluate global LV function. In each patient, a set of contiguous short-axis views from the mitral valve plane to the apex and two long-axis views (one vertical and one horizontal) were acquired. A minimum of 30 cine frames for each slice were acquired with the following parameters: slice thickness 8 mm, no gap, eight views per segment, NEX 1, field of view 40 cm, phase field of view 1, matrix 224 × 224, reconstruction matrix 256 × 256, flip angle 45°, TR/TE 3.5/1.5, and bandwidth 125 KHz.

Late gadolinium enhancement images were obtained 8–10 min after bolus injection of gadolinium derivates (Omniscan®, Amersham, GE Medical System or Magnevist®, Shering). The same projections were used as for cine CMR. The fast Gradient Echo Inversion Recovery sequence was utilized with the following parameters: repetition time 4.2 ms, echo time minimum, flip angle 208, matrix 224 x 224, number of excitations 1.00, field of view 36 mm, slice thickness 8 mm, no inter-slice gap. The inversion time was optimized to null signal from the normal myocardium.

2.3. CMR Data Analysis

A semiautomatic, previously validated software [10] quantified the myocardial mass and the extent of LGE areas. In each LGE contrast-enhanced short-axis image the LV endocardial and epicardial borders were manually drawn. The areas of delayed contrast-enhancement inside LV boundaries were automatically identified by a fuzzy clustering method able to classify each pixel as belonging to the non-infarcted myocardium or to LGE areas, on the basis of its intensity. When needed, manual correction was applied.

After manual identification of the anterior septal insertion of the right ventricle as reference point, the myocardium of each short-axis image was automatically divided into 6 equiangular segments for the basal and mid-cavity slices, and into 4 equiangular segments for the distal slice. In each image the areas of myocardium and LGE regions were automatically measured for each segment and multiplied by the slide thickness. The volume of the 16 myocardial and LGE regions was obtained by summing the values of the corresponding segments. To evaluate the myocardial volume of the apex in the LGE images, the apex was assimilated to a semi-ellipsoid, whose axis a, b, and c were manually measured on the two-chamber and four-chamber image views, to apply: $V_{apex} = \frac{2}{3}\pi abc$. The extent of delayed enhancement in the apical segment was manually measured.

Thus, the analysis of CMR images provided the volume of myocardium and of LGE areas for each segment, as well as global MI size. The values were expressed both in absolute terms and as percent of entire LV myocardium.

2.4. Geometric Analysis of the bull’s eye

From the consensus document [1], retrieved in PDF format, its Figure 4, representing the 17 myocardial segments on a circumferential polar plot, two independent observers extracted and measured the radii of the different circles of the polar plot; the values were averaged and expressed as percent of the radius of the larger, external circle.

2.5. Modified and Personalized Bull's Eye

The design of the new bull’s eye plot aimed to provide to the cardiologist, used to the standard one, something familiar but enhanced in the related information. So, we kept unaltered both the circular shape for the apex, around which each modified plot develops, as well as the equiangular architecture and subdivision of the other 16 segments.

Modified bull’s eyes.

Knowing the volume of the different segments in the study patients, the first modified bull's eye plot shows that the areas of the slices and of the apex (expressed as percent of the entire plot area) proportional to the volume of each slice and of the apex (expressed as percent of the entire LV myocardial volume). At first, mean volume values were obtained from the study population (Modified bulls' eye # 1). To be closer to the individual characteristics, volume values were those evaluated for each study patient (Modified bulls' eye # 2).

Personalized bull's eye.

For the personalized bull's eye plot, the area of each segment (as % of the entire plot area) corresponded to the volume of that segment (as % of the LV myocardial volume) in each individual patient; it is necessary to act on the radius of the circular sector to which each segment belongs, avoiding overlapping of segments as well as empty spaces.

In order to indicate the MI extent in each segment, we assigned to each segment a different gray shade, going from white (no contrast enhancement) to four different gray shades corresponding to <25%, 26-50%, 51-75%, and >75% of MI extent in that segment. Of course, an alternative look-up table can be chosen.

2.6. Statistical analysis

All data were analyzed using the statistical package R [11]. Continuous variables were expressed as mean ± standard deviation, categorical variables as percentages. One-way repeated measures analysis of variance (ANOVA) was used to evaluate whether there was a significant divergence between different volume measurements in CMR data. The difference between the percent area of myocardial segments displayed in the bull's eye plot and the percent volume of myocardial segments in CMR images was tested by a one-sample Student's t test. A $p < 0.05$ was considered statistically significant.

3. Results

The areas of the 17 myocardial segments displayed in the standard bull's eye plot widely differed from each other in the basal, mid-cavity, distal segments and in the apex (Table 1).

	Area	Volume	
Seg 1-6	7.40	5.83 ± 1.36	$p<0.05$
Seg 7-12	5.63	6.47 ± 1.00	$p<0.05$
Seg 13-16	4.19	6.07 ± 1.46	$p<0.05$
Seg 17	5.08	1.96 ± 1.36	$p<0.05$

Table 1 - Comparison of conventional bull's eye area sizes versus measured volumes expressed in % units.

For what concerns the study population, ANOVA analysis confirmed that the segmental volumes of the myocardium as measured at CMR and expressed as percent of LV myocardium significantly differed from each other ($p < 0.001$). The percent displayed area and the percent measured volume of the corresponding segments widely differed ($p < 0.001$). Specifically, the displayed area overestimated the volume by 22 and 63% in the basal segments and in the apex, while it underestimated the volume by 15 and 45% in the middle-cavity and distal segments (Table 1), respectively.

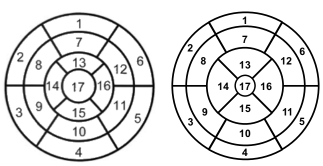

Fig. 1 – Conventional (left) vs. modified (right) bull's eye.

By considering the mean volume values in the study population, (Fig. 1), compared to the standard plot, the apex is smaller and the basal crown shows a smaller thickness, while a larger thickness of the mid and distal crowns are remarkable.

Taking into account the features of each individual patient, the subsequently modified bull's eye shows analogous behavior as the modified one based on the global population, but close to individual measurements. Finally, the personalized bull's eye plot is no more regular, as the percent area of each segment corresponds to its percent volume in each individual patient. Examples of both subject-related plots of LV myocardium infarction scars areas are shown in Fig 2.

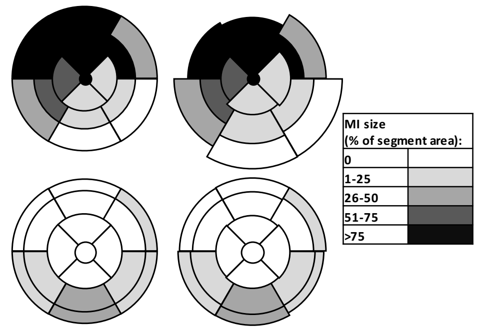

Fig. 2 – Modified (left) and personalized (right) bull's eye plots, both based on individual measurements, for anterior (top) and inferior (bottom) MIs.

The global extent of MI, as measured in our sample population, was 15.0 ± 9.7% of LV myocardial volume; the corresponding extent of the displayed MI (13.7 ± 9.0% of LV myocardial area) significantly differed ($p = 0.001$), the mean difference being 8%.

4. Discussion

The standard bull's eye display of the LV appears to affect the visual estimate of the volume of myocardial segments and MI size. Both volume and infarct size in the outer segments and in the apex are overestimated, while the plot allow to underestimate the volume and infarct size in the middle and distal segments. Taking into consideration the large consensus and application of the bull's eye display in medical imaging, the proposed modifications provide a better intuitive evaluation of real physiological conditions, notwithstanding the limitations related to the representation of a three-dimensional structure on a plane.

The first modified display is based on the volume of the segments measured for each slice in a reference population. This approach is simple and intuitive, but it is related to the sample population to derive the slice volume. To validate this approach, the sample population should be larger and should include a wider variety of patients and normal subjects.

The second modified display can be easily implemented, and, while keeping the architecture of the standard bull's eye, is closer to the individual physiology.

The personalized display requires the computation of the area of each of the 17 segments of each individual patient; simple computer graphics algorithms can provide the plot, without any interaction with the operator, once implemented in the medical equipments and analysis tools. Because of its irregular shape, this display is, at first sight, less intuitive for the cardiologist familiar with the standard display. Though, it could give some more information about the cardiac physiology after the MI. For instance, by observing the anterior and the inferior MI plots in Fig. 2, besides the extension and entity of the pathologic event, the operator could have a qualitative idea of the myocardial efficiency.

The apex is usually not included in the calculation of LV mass and infarct size, although this segment is frequently involved in ischemic heart disease. The great variability of the volume of the apex largely depends on the degree of apical remodeling, which is different in the case of pressure or volume overload, and varies according to the etiology of LV dysfunction. Its approximation, in the present study, to a semi-ellipsoid is quite good because it does not require time consuming operations, and allows to get an acceptable esteem of its contribution to the LV physiopathologic behavior.

The actual study is affected by limitations, in particular for what concern the first type of modified bull's eye. The number of enrolled patients is small, likely enough for proving the principle, but certainly not enough for building-up a new data base of normalcy and pathology. More, to assess the volume of myocardial segments, normal segments have been mixed with infarction segments. On the other hand, the personalized bull's eye plot does not yield the circular shapes, that cardiologists are used to see.

In conclusion, this study shows that changes in the planar compact display of tomographic images of the LV could be introduced and implemented in medical imaging instrumentation to make image interpretation more intuitive for the cardiologist and closer to the reality of individual patients.

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