Quantification of Myocardial Area at Risk: Validation of Coronary Angiographic Scores With Cardiovascular Magnetic Resonance Methods

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A B S T R A C T

Introduction and objectives: Quantification of myocardial area-at-risk after acute myocardial infarction has major clinical implications and can be determined by cardiovascular magnetic resonance. The Bypass Angioplasty Revascularization Investigation Myocardial Jeopardy Index (BARI) and Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease (APPROACH) angiographic scores have been widely used for rapid myocardial area-at-risk estimation but have not been directly validated. Our objective was to compare the myocardial area-at-risk estimated by BARI and APPROACH angiographic scores with those determined by cardiovascular magnetic resonance.

Methods: In a prospective study, cardiovascular magnetic resonance was performed in 70 patients with a first successfully-reperfused ST-segment elevation acute myocardial infarction in the first week after percutaneous coronary intervention. Myocardial area-at-risk was obtained both by analysis of T2-short tau inversion recovery sequences and calculation of infarct endocardial surface area with late enhancement sequences. These results were compared with those of BARI and APPROACH scores.

Results: BARI and APPROACH showed a statistically significant correlation with T2-short tau inversion recovery for myocardial area-at-risk estimation (BARI, intraclass correlation coefficient=0.72; P<.001; APPROACH, intraclass correlation coefficient=0.69; P<.001). Better correlations were observed for anterior acute myocardial infarction than for other locations (BARI, intraclass correlation coefficient=0.73 vs 0.63; APPROACH, intraclass correlation coefficient=0.68 vs 0.50). Infarct endocardial surface area showed a good correlation with both angiographic scores (BARI, intraclass correlation coefficient=0.72; P<.001; APPROACH, intraclass correlation coefficient=0.70; P<.001).

Conclusions: BARI and APPROACH angiographic scores allow reliable estimation of myocardial area-at-risk in current clinical practice, particularly in anterior infarctions.

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Cuantificación del área miocárdica en riesgo: validación de puntuaciones angiográficas coronarias con métodos de resonancia magnética cardiovascular

R E S U M E N

Introducción y objetivos: La cuantificación del área miocárdica en riesgo tras el infarto agudo de miocardio tiene repercusiones clínicas importantes y puede determinarse mediante resonancia magnética cardiovascular. Las puntuaciones angiográficas Bypass Angioplasty Revascularization Investigation Myocardial Jeopardy Index (BARI) y Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease (APPROACH) se han utilizado ampliamente para la estimación rápida del área miocárdica en riesgo, pero no han sido validadas de manera directa. Nuestro objetivo es comparar el área miocárdica en riesgo estimada mediante las puntuaciones angiográficas BARI y APPROACH con la determinada mediante resonancia magnética cardiovascular.

Métodos: En un estudio prospectivo, en la primera semana siguiente a la intervención coronaria percutánea, se realizaron exploraciones de resonancia magnética cardiovascular a 70 pacientes con un primer infarto agudo de miocardio con elevación del segmento ST reperfundido con éxito. El área miocárdica en riesgo se determinó mediante el análisis de secuencias T2-short tau inversion recovery y el cálculo del área endocardica con infarto utilizando secuencias de contraste tardío. Estos resultados se compararon con los de las puntuaciones BARI y APPROACH.

Resultados: Las puntuaciones BARI y APPROACH mostraron una correlación estadísticamente significativa con el T2-short tau inversion recovery para la estimación del área miocárdica en riesgo (BARI, coeficiente de correlación intraclass = 0.72; p < 0.001; APPROACH, coeficiente de correlación intraclass = 0.68; p < 0.001). Se observaron correlaciones mejores para el infarto agudo de miocardio de cara anterior que para otras localizaciones (BARI, coeficiente de correlación intraclassa, 0.73 frente a 0.63;
INTRODUCCIÓN

El área de ataque-riesgo (AAR) es definido como el área de hipoperfusión miocárdica durante la conversión aguda en ausencia de circulación alterada.1-3 Este parámetro permite la extensión del área salvada miocárdica a ser calculado si el neocárdio miocárdico es substratificado. Ambos parámetros son de utilidad, no solo respecto a la eficacia de los tratamientos reperfusión, sino también como factores predictivos en pacientes con AMI.4,5

T2-short tau inversion recovery (STIR) secuencias, por su parte, han sido validadas por microsfera inyección en animales, el método de referencia para estimar AAR en estudios experimentales,6 y han sido ampliamente utilizados en el campo clínico para estimar el AAR en pacientes con AMI. En casos de imágenes de baja calidad obtenidas con secuencias T2-STIR, la superficie de la infartada (Infarct-ESA), obtenida por las secuencias de incremento de contraste,10,11 constituye un método alternativo.

El estudio angiográfico Bypass Angioplasty Revascularization Investigation Myocardial Jeopardy Index (BARI) y el Project for Outcome Assessment in Coronary Heart Disease (APPROACH) han sido propuestos como métodos de referencia para la estimación de AAR durante la angioanatomía coronaria, y sólo se ha aplicado en estudios clínicos de pacientes no evaluados por CMR.12-14

El objetivo fue determinar la reproducibilidad y la exactitud del método que se propone en comparación con el método de referencia STIR, considerando la segmentación de Infarct-ESA.

MÉTODOS

Pacientes

Desde octubre de 2008 a junio de 2010, 75 consecutivos pacientes con retroceso en el segmento ST pudieron ser reperfusos con éxito mediante PCI y fueron evaluados por ambos métodos de estudio. El área de superficie endocárdica con infarto mostró correlación con ambas puntuaciones angiográficas (con BARI, coeficiente de correlación intraclass = 0,72; p < 0,001; con APPROACH, coeficiente de correlación intraclass = 0,70; p < 0,001).

CONCLUSIÓN

Las puntuaciones angiográficas BARI y APPROACH permiten una estimación fiable del área miocárdica en riesgo en la práctica clínica actual, sobre todo en los infartos de cara anterior.

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**Abbreviations**

- AAR: área-at-risk
- AMI: infarto agudo de miocardio
- CMR: cardiovascular magnetic resonance
- Infarct-ESA: infarto endocárdico superficie área
- PCI: procedimiento intervencionista coronario percutáneo
- STIR: cortex corto inverción recupero tau

**Cardiovascular Magnetic Resonance**

Todos los estudios se realizaron con equipo 1.5 T (Siemens Avanto). Las imágenes se obtuvieron en sincronización con el electrocardiograma y con la apnea. Vista corta de la circunferencia se realizó para cuantificar los volúmenes y la fracción de eje (SSFP secuencias; corte: 8 mm; espacio entre corte 20%; matriz: 256 x 256; campo de visión: 300-370 mm; resolución temporal: 50 ms). Para evaluar la disección, STIR secuencias se utilizan en la misma vista que las secuencias cines, en todos los casos de infarto agudo de miocardio (corte: 8 mm; espacio entre corte 20%; matrix: 256 x 256; FOV: 300-370 mm; temporal: 50 ms; tiempo de repeticion: 2 R-R; tiempo de eco: 100 ms; tiempo de inversión: 170 ms; ángulo: 160°; ancho de banda, 781 Hz/píxel). Finalmente, las secuencias de incremento de contraste se utilizaron para calcular el volumen del área de AMI y se obtuvo en 15 min después de la administración intravenosa de 0,2 mmol/l de gadoantipetate-Magnevist® (corte: 8 mm; espacio entre corte 20%; matrix: 256 x 256: campo de visión: 300-370 mm; tiempo de inversión: 500 ms; espectro de supresión del fóneto miocárdico).

**Image Analysis**

Los estudios se realizaron en una estación (QMARS MR 2.1, Medis Medical Imaging Systems, The Netherlands) por dos radiólogos especializados en imagen y evaluados de forma ciega por los mismos y los angioanatómicos. En el caso de las imágenes, los bordes endocárdicos y epicárdicos fueron delineados en end-systole y end-diastole con el método de retroceso aproximado a cuantificar los volúmenes, funciones y masa de la válvula mitral (LV). El AAR se cuantificó en T2-STIR secuencias delineando las áreas de intensidad, más 2 desviaciones estándar por encima de la media, obtenida de la región no infartada, y normalizada por la LV. La intensidad de señal se obtuvo en la región de edém y la ratio de señal a ruido y la ratio de contraste a ruido. Hipointensas áreas dentro de regiones hipointensas fueron consideradas como áreas de infarto del miocardio y de la región no infartada.15,16
Quantification of the infarcted myocardium was assessed by delineating the enhanced areas in the late enhancement sequences with 5 standard deviations above average, obtained from the remote healthy myocardium, and normalized by the LV mass. The hypoenhanced areas, suggesting microvascular obstruction, were included in the infarct volume. In case of poor quality of T2-STIR sequences, the quantification of AAR was performed with the help of delayed enhancement images to improve the reproducibility of the method. In these cases, the consensus between both cardiologists specialized in cardiac imaging was required. The infarct-ESA was calculated as: \( \text{summed endocardial hyperenhancement infarct length/total LV endocardial length} \times 100 \). The salvaged myocardium was calculated as the difference in AAR, obtained by quantitative analysis of the T2-STIR sequences, minus the size of the necrosis obtained through late enhancement sequences.

### Coronary Angiography

All patients underwent coronary angiography according to the protocol established by the catheterization laboratory. All were implanted with at least one stent depending on the characteristics of the lesion. Collateral flow was evaluated before performing the PCI and according to Rentrop’s classification, where 0 stands for total absence of collateral circulation and 3 for complete retrograde filling of the ischemic territory until occlusion. Anterograde flow in the infarct-related artery prior to the PCI was characterized using the TIMI (Thrombolysis in Myocardial Infarction) system. The AAR was established using the BARI and modified APPROACH scores.

### Bypass Angioplasty Revascularization Investigation Myocardial Jeopardy Index Score

This system assigns a score to all terminal arteries (terminal portion of the left anterior descending, left circumflex, and right coronary artery, as well as the ramus, diagonals, obtuse marginals, posterior descending and posterolateral branches) based on their length and caliber according to specific criteria. A value of 0 represents an almost insignificant vessel size, whereas a value of 3 defines a large-size artery with a length of two thirds the distance between the base and cardiac apex. Right ventricular marginals and posterior descending artery septal branches are not taken into account. The final score is obtained by dividing the resulting value from the infarct-related artery by the overall score of all arteries supplying the LV, which finally permits estimation of the percentage of myocardial muscle at risk (Fig. 2). Stenosed arteries in noninfarced areas are not added to the AAR.

### Modified Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease Score

This score is based on the division of the LV into regions in accordance with anatomopathological studies in humans, which evaluate the relative proportion of the myocardium perfused by
each artery. The modified APPROACH score provides the AAR value, taking into account the location of the culprit lesion and dominance and size of the secondary branches (Fig. 3). As with the BARI score, stenosed arteries in noninfarcted areas are not added to the AAR.

### Interobserver Variability

Each AAR calculation method was assessed with the evaluator blinded to the results of other techniques. All studies, both angiographic and CMR, were evaluated separately by 2 cardiologists specialized in cardiac imaging and 2 interventional cardiologists who were unaware of previous results, to obtain the interobserver variability of each AAR estimation method.

### Statistical Analysis

Continuous variables were expressed as mean (standard deviation [SD]) and categorical variables as percentages. The Kolmogorov-Smirnov test was applied to evaluate the normal distribution of variables. The interobserver variability and correlation between methods were calculated using the coefficient of intraclass correlation (ICC), which describes how strongly units in the same group resemble one other. Finally, Student’s t-test was used in cases of normal distribution and the Mann-Whitney U test in the opposite case to calculate the difference between groups for continuous parameters. P values < .05 were considered statistically significant. Data plotting used in analyzing the agreement between the different methods was made with Bland-Altman analysis. The SPSS version 13.0 (Chicago, Illinois, United States) software was used for the statistical analysis.

### RESULTS

The clinical, CMR and angiographic characteristics of the population are shown in Table 1. The descending anterior artery was responsible for the AMI in 30 patients (43%). The mean time from symptom onset to achievement of TIMI flow grade 3 during PCI was 227 (69) min (range: 97-380 min). Although 44.3% of patients showed multivessel coronary artery disease, none of nonresponsible lesions showed a chronic total occlusion.

CMR was performed 4.3 (1.5) days (range: 2-7 days) after PCI. In all cases, increased signal intensity was detected in T2-STIR as well as in late enhancement sequences. The signal-to-noise ratio of the edematous myocardium vs healthy myocardium was: 11.3 (3.2) vs 5.6 (2.7), respectively (P<.001). The contrast-to-noise ratio of the edematous myocardium vs healthy myocardium was 5.7 (2.1). However, in 4 cases (5.7%) the T2-STIR images were of low quality, and required a consensus between both cardiologists specialized in cardiac imaging.

### Comparison Between Infarcted Area and the Different Myocardial Area-at-Risk Estimation Scores

The AAR calculated through T2-STIR analysis varied between 14% and 79.7% of total LV mass (mean [SD]: 36.9 [14.3%]). The AAR measured by T2-STIR sequences was significantly higher than the necrosis size calculation, which varied between 1.1% and 69.7% of total LV mass (mean [SD]: 24.2 [13.5%]) (Table 2). Interobserver variability for infarct size calculation was good (Table 3). The mass of the salvaged myocardium, defined as the difference between AAR obtained by T2-STIR sequences and the necrotic mass assessed through late enhancement sequences, was 16 (11.5 g) (range: 1.1-56 g) and the myocardial salvaged index was 12.8 (8.6%).

### Comparison Between Angiographic Scores

There was an excellent correlation between the BARI and APPROACH scores (Table 4), and both showed very low interobserver variability (ICC=0.91 and ICC=0.92, respectively) (Table 3).
Nonetheless, such (0.51-0.94) correlation was poor. Table 1 shows comparison of Jeopardy Data Inversion of APPROACH, Disease; TIMI, Dyslipidemia 193, BARI, Smokers 245, Diabetes mellitus 10 (14.3), Family history of ischemic heart disease 9 (12.9) LVEDV, mL 161.5±37.5 LVEF, % 49±10.5 Left ventricular mass, g 127±28.1 Infarct size, g 31.7±21.7 Renin: 1 60 (85.7)

Comparison Between Quantitative Analysis of T2-short tau inversion recovery and Angiographic Scores

Both BARI and APPROACH showed a good correlation when AAR was obtained through T2-STIR analysis (Table 4 and Fig. 4). Nevertheless, the correlations were dependent on infarct location. In anterior infarctions, ICC were 0.73 (0.13-0.89; P<.001) and 0.68 (0.10-0.87; P<.001) for BARI and APPROACH, respectively, whereas in other territories, ICC were 0.63 (0.32-0.81; P<.001) and 0.50 (0.09-0.75; P=.004), respectively.

Table 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ICC (SD)</th>
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<tr>
<td>Infarct size</td>
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<tr>
<td>T2-STIR</td>
<td>0.81 (0.70-0.89)</td>
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<tr>
<td>BARI</td>
<td>0.91 (0.82-0.96)</td>
</tr>
<tr>
<td>APPROACH</td>
<td>0.92 (0.83-0.97)</td>
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<td>Infarct-ESA</td>
<td>0.86 (0.78-0.90)</td>
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Table 3

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<th>Parameters</th>
<th>Infarct-ESA</th>
<th>APPROACH</th>
<th>BARI</th>
</tr>
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<tr>
<td>Infarct-ESA</td>
<td>0.87 (0.51-0.94)</td>
<td>0.72 (0.58-0.81)</td>
<td>0.70 (0.56-0.80)</td>
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<tr>
<td>APPROACH</td>
<td>0.69 (0.35-0.84)</td>
<td>0.91 (0.83-0.97)</td>
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Comparison Between Quantitative Analysis of T2-STIR and Infarct Endocardial Surface Area

Infarct-ESA showed a good correlation with AAR obtained through T2-STIR sequences (Table 4 and Fig. 5). In addition, the interobserver variability of both scores was very small, particularly infarct-ESA (Table 3).

DISCUSSION

The present study shows a good correlation between AAR defined through angiographic scores and CMR STIR sequences in patients with ST-segment elevation myocardial infarction receiving primary PCI. The correlation was better in anterior infarctions, and both angiographic scores had low interobserver variability. These results demonstrate that angiographic scores provide clinically useful estimation of AAR, particularly in anterior infarctions. This finding is relevant to clinical practice since AAR is an important variable in patients with ST-segment elevation AMI and CMR is not universally available. Several methods have been proposed to estimate AAR.less method (0.10-0.87; P<.001) for BARI and APPROACH, respectively, whereas in other territories, ICC were 0.63 (0.32-0.81; P<.001) and 0.50 (0.09-0.75; P=.004), respectively.

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Inferior ischemic area of myocardial at risk (0.51-0.94) correlation was poor. Table 1 shows comparison of Jeopardy Data Inversion of APPROACH, Disease; TIMI, Dyslipidemia 193, BARI, Smokers 245, Diabetes mellitus 10 (14.3), Family history of ischemic heart disease 9 (12.9) LVEDV, mL 161.5±37.5 LVEF, % 49±10.5 Left ventricular mass, g 127±28.1 Infarct size, g 31.7±21.7 Renin: 1 60 (85.7)

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estimation. Several studies have shown that T2-weighted sequences performed after AMI permit retrospective identification of AAR both in animals and humans.6,23

Correlation Between Angiographic Scores and Myocardial Area-at-risk Calculation Through Cardiovascular Magnetic Resonance

Although angiographic scores have been partially compared to other reference methods for AAR calculation,10,11,14 BARI has not been directly validated by any of the reference methods (T2-STIR sequences or myocardial SPECT), and only one study with significant limitations has evaluated the correlation between APPROACH and T2-STIR. Wright et al.11 had shown a moderate correlation between BARI and infarct-ESA (r=0.42), which in turn showed a good correlation with T2-STIR (r=0.77). Nevertheless, no direct data on the correlation between BARI and T2-STIR were provided. Previously, Ortiz-Perez et al.10 had provided a comparison between both angiographic scores and infarct-ESA, obtaining an excellent correlation (r=0.9 for BARI and r=0.87 for APPROACH), although none of the methods had been validated previously. Another recently published study provided data on the correlation between AAR using T2-STIR sequences and APPROACH, with very good results (r=0.78). Nonetheless, some features of that study might limit the general validity of its conclusions: 24% of the 50 included patients had an acute coronary syndrome without ST-segment elevation, up to 20% had a previous history of AMI and up to 26% showed collateral circulation with a value of >1 on the Rentrop scale.14

Our study shows the good correlation between both angiographic scores and all CMR-derived indices in a homogeneous sample. The better results in our series as compared with that of Wright et al., may stem from the fact that all our CMR studies were performed 2-7 days after AMI, while this period of time was up to 20 days in Wright’s study.

Cardiovascular Magnetic Resonance Scores for Myocardial Area-at-risk Calculation

Owing to the limitations for exact AAR delineation of T2-STIR,7-9 alternative scores are sometimes required for its estimation. Different methods validated through pathological anatomy, similar to infarct-ESA, have been used in animal samples with the same goal and good results.24,25 As the calculation of infarct-ESA does not require T2-STIR sequences, and late enhancement sequences do not show as many limitations when high resolution images are obtained, it can constitute an excellent alternative. This could be one of the main reasons why infarct-ESA shows a better interobserver correlation (ICC=0.86) than AAR calculation with T2-STIR (ICC=0.81). Moreover, the correlation between angiographic scores and infarct-ESA is as good as T2-STIR.

Influence of Acute Myocardial Infarction Location on the Correlation Between the Different Scores

Wright et al.11 noted that one possible explanation for the discrepancies between T2-STIR and infarct-ESA with regard to the BARI score when compared with the results obtained by Ortiz-Perez et al.,10 might be that inferior wall infarctions occasionally extend to the right ventricle,24 an area not evaluated by the first 2 methods but partially evaluated by the third. However, on the basis of data obtained in our study, although this explanation could be applied for the BARI score, it cannot be valid for the APPROACH score, which considers solely the LV. A possible

Figure 4. Bland-Altman analysis comparing T2-STIR with BARI (A), and T2-STIR with APPROACH (B). APPROACH, Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease; BARI, Bypass Angioplasty Revascularization Investigation Myocardial Jeopardy Index; LV: left ventricle; T2-STIR, T2-short tau inversion recovery.

Figure 5. Bland-Altman analysis comparing T2-STIR with infarct endocardial surface area. APPROACH, Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease; Infarct-ESA, infarct endocardial surface area; LV: left ventricle; T2-STIR, T2-short tau inversion recovery.
reason could be the normal anatomical variability of the coronary arteries. The source of the most frequent variation is the posterior descending artery, which basically defines the irradiation predominance of the inferior territory at the expense of the right coronary artery, dominant in 70% of patients, or the circumflex artery. Furthermore, other terminal branches, such as the posterolateral arteries, which supply a variable area of the inferior and lateral wall, can originate from both arteries, which explains why these areas are subject to wide anatomical variability in irradiation. Perea Valdés et al. found wide variability in the inferior and lateral walls using cardiac perfusion scintigraphy to calculate the area irrigated by each of the coronary arteries compared to the standardized 17-segment model. Although there are differences in results depending on AMI location, the correlation between angiographic scores and CMR methods in anterior and nonanterior infarctions is statistically significant for each one separately. Therefore, the usefulness of BARI and APPROACH scores for both territories seems consistent.

Clinical Significance of our Study

Larger AAR are associated with greater infarct size, lesser ejection fraction, a higher number of hypoperfused segments and greater microvascular obstruction. Moreover, measurement of AAR and comparison with infarct size allows estimation of salvaged myocardium, which adds clinically valuable information compared with infarct size alone. Myocardial infarctions with little or no salvaged myocardium are more likely to be transmural, exhibit more risk of cardiovascular events and trigger adverse remodelling than infarcts of similar size but surrounded by an important mass of salvaged myocardium. Measurement of AAR is also an essential research tool to evaluate reperfusion strategies and to maximize salvaged myocardium in patients with ST-segment elevation AMI, offering a much needed therapeutic approach.

Limitations

The inclusion of patients with ST-segment elevation AMI only, and no other, implies that our results may not be extrapolated to all types of acute coronary syndromes.

CONCLUSIONS

The concordance between the methods used to evaluate the AAR through CMR and angiography is good and they represent an excellent alternative for clinical practice, particularly in anterior myocardial infarction. The infarct-ESA score constitutes an interesting alternative for AAR calculation, particularly in patients whose myocardial signal is hard to delineate in T2-STIR sequences.

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CONFLICTS OF INTEREST

None declared.

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