In Vitro Measurement of Enzymatic Markers as a Tool to Detect Mouse Cardiomyocytes Injury

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**Primary cultures of cardiomyocytes represent a useful model for analyzing cardiac cell biology as well as pathogenesis of several cardiovascular disorders. Our aim was to standardize protocols for determining the damage of cardiac cells cultured in vitro by measuring the creatine kinase and its cardiac isotype and lactate dehydrogenase activities in the supernatants of mice cardiomyocytes submitted to different protocols of cell lysis. Our data showed that due to its higher specificity, the cardiac isotype creatine kinase was the most sensitive as compared to the others studied enzymatic markers, and can be used to monitor and evaluate cardiac damage in in vitro assays.

Key words: creatine kinase - in vitro assays - cardiac damage

The cellular damage of heart cells plays an important role in the pathogenesis of several cardiovascular disorders. It is accepted that the non-invasive identification and localization of myocardial lesions helps in the diagnosis of these disorders, as well as in prognosis and assessment of treatment response (Flotats & Carrio 2003). Initial attempts to directly visualize the area of myocardial injury were based on the recognition of myocardial infarction with hot spot imaging agents (Botvinic 1990). Biochemical methods represent an important tool for the diagnostic of cardiac injury. Among the commercially available markers, the most used non-enzymatic markers are the myoglobin, the troponin T, and troponin I molecules. While myoglobin is a non-specific indicator of myocardial damage, its diagnostic value relies on its early appearance in the blood (Bhayana & Henderson 1995). The high sensitivity and specificity of the cardiac troponins make them one of the most used biochemical non-enzymatic markers for diagnosing the myocardial damage (Amit et al. 2003). However, troponin measurements appear to have an equivalent diagnostic accuracy compared to the creatine kinase cardiac isoenzyme (CK-MB) marker for diagnosing myocardial necrosis such as reported in patients with cocaine-associated chest pain and suspected infarction (Kontos et al. 2002). Creatine kinase (CK; EC 2.7.3.2) is a meaningful enzyme regulator of high-energy phosphate production and utilization in contractile tissues (Takagi et al. 2001). CK can be found in brain, in striated and smooth muscles, and their serum levels have been largely used as indicator of tissue injury especially in the skeletal and cardiac tissues. CK has three cytoplasmatic isozymes (CK-MM, CK-MB, and CK-BB) and due to its specific localization in the tissues (skeletal muscle, cardiac muscle, and brain, respectively), CK measurements provide substantial information concerning cellular injury in acute skeletal muscle diseases, myocardial infarction, brain damage, and malignant tumor of the gastrointestinal tract (Takagi et al. 2001). CK-MB activity can be measured either by enzyme activity or mass concentration. Other markers with enzymatic activity that can be assayed include the lactate dehydrogenase (LDH) (Zhang et al. 2000) and its isoforms, and the aspartate aminotransferase (Nishimura & Yazaki 1995), which offer the lower costs. However, both are supplanted by the CK detection (together isoenzymes and isoforms) due to aforementioned superior tissue specificity. The biochemical detection of CK-MB plasma levels has been used to monitor the occurrence of experimental chagasic myocarditis as the kinetic of the necrotic heart lesions found in the histopathological sections were clearly related to the increase of CK-MB in the plasma (de Souza et al. 2000).

Since feasible enzymatic biochemical markers are pivotal for detecting cellular injury in cardiac cells grown in culture, our present aim was to standardize protocols for determining creatine kinase, its cardiac isoenzyme, and lactate dehydrogenase activities in the supernatants of primary cultures of cardiomyocytes submitted to different protocols of cell lysis.

MATERIALS AND METHODS

Cell cultures - Primary cultures of mice embryonic cardiomyocytes (CM) were obtained as previously described (Meirelles et al. 1986). Briefly, heart from 18-day-old Swiss mice embryos were isolated and the ventricular muscle cut into small pieces before submitting to a series of enzymatic dissociation steps employing 0.01% collagenase 0.025% trypsin diluted in phosphate-buffered sa-
line, pH 7.0 (PBS). Enzyme inactivation was achieved by adding 20% fetal calf serum and the released cells were centrifuged for 7 min at 650 g. The resulted pellet was resuspended in Dulbecco’s modified medium (DMEM) supplemented with 10% horse serum, 5% fetal bovine serum, 2.5 mM CaCl2, 1 mM L-glutamine, and 2% chicken embryo extract. The purified heart cells were then plated for 20 min in 0.01% gelatin-coated culture flasks to allow the adherence of fibroblasts. Next, the cellular density of the cardiomyocyte-enriched supernatant was established and the cells seeded at different cell densities per well into 96-well culture plates previously coated with 0.01% gelatin. Cultures were maintained at 37°C in an atmosphere of 5% CO2 in DMEM supplemented as above discriminated. Peritoneal mouse resident macrophages were cultivated as described elsewhere (Ararú-Jorge et al. 1989) and were used as negative controls for CK-MB measurements. All assays described here were run 3 to 5 times at least in triplicate. All procedures were carried out in accordance with the guidelines established by the Fiocruz Committee of Ethics for the Use of Animals, resolution 242/99.

Fluorescent analysis - The CM were fixed for 20 min with 4% paraformaldehyde, permeabilized with 0.2% Triton-X-100 in PBS for 2 to 3 min, incubated with phalloidin-FITC and DAPI for actin staining and DNA respectively. The samples were then mounted with DABCO to prevent fading and analyzed at Zeiss photomicroscope equipped with epifluorescence.

Ultrastructural analysis - For transmission electron microscopy procedure, the CM were fixed for 1 h at 4°C with 2.5% GA in 0.01 M Na cacodylate buffer, pH 7.2, rinsed in the same buffer. The CM were then post-fixed with 1% O2, dehydrated in acetone and embedded in Epon. Thin sections were stained with uranyl acetate and lead citrate and examined in an EM 10C Zeiss microscope.

Cell lysis - For the initial standardization, 7.5x10^4 uninfected CM plated for 48 h at 37°C, were washed three times with 0.01M PBS to remove the medium and serum sources. Then the monolayers were treated for 20 min at room temperature (RT) with agents (50 µl/well) to induce cellular damage: deionized H2O and different concentrations of Triton X-100. All the employed protocols lead to the release of CK-MB into the culture supernatant, changing from 0.3 to 63 the mean OD differences observed every minute, confirming the cardiac lysis (Table I). The damage could also be detected by light microscopy using the trypan blue dye exclusion assay that revealed the total loss of the cardiac cell viability (data not shown). Among the protocols, the treatment for 20 min with the detergent 2% Triton X-100 was the most effective, reaching mean levels of 63 ΔOD/min x 10-3. As expected, the incubation of the cells only with PBS did not result in any release of the enzymatic activity (Table I). To assay the sensitivity of the methodology, different densities of CM were seeded and submitted to T2 incubation. We found a reliable and positive correlation between the cell density and CK-MB activity: ΔOD/min values increased according to the crescent number of cardiomyocytes (Table II) showing a correspondence between the injury level and the amount of released molecules. However, since the amount of CK-MB activity was almost undetectable when concentrations of CM were low as 1.2x10^4 (Table II), we wonder if the centrifugation pro-
procedure during the incubation with the detergent could enhance the release of the marker to the extracellular medium by improving the cellular damage caused by T2. The detergent treatment along with the centrifugation procedure released higher amounts of CK-MB as compared to correspondent non-centrifuged CM samples (Table II).

The addition of the centrifugation step enhanced the sensitivity of the method for measuring the CK-MB activity even employing very low densities of CM such as $0.3 \times 10^4$, reaching $\Delta OD/min \times 10^{-3}$ mean readings of 57, which was previously undetectable when only the detergent was used, while the centrifugation step alone in the absence

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**Fig. 1:** cell morphology (A–C) of primary cultures of mice cardiac myocytes. A and B: fluorescent micrographs of cardiomyocytes (CM) showing sarcomeres labeled with phalloidin-FITC (A, arrows) and the respective nuclei stained with DAPI (B); C: transmission electron microscopy image of typical cardiac myocytes showing myofibrils (→), caveolae (cv), and mitochondria (mit); D and E: evaluation of cellular damage in CM through enzymatic markers; D: CK, CK-MB, and LDH activities in the supernatant of $7.5 \times 10^4$ cultured cells upon 2% Triton-X 100 treatment. Note the higher specificity of CK-MB activity with higher $\Delta OD/min$ values. The PBS represents the measurements in the absence of any enzyme substrate; E: measurements of CK-MB activities employing different supernatants volumes of $7.5 \times 10^4$ cultured cardiomyocytes submitted to treatment with 2% Triton-X 100.
of T2 did not induce detectable CK-MB release (Table II). To assess the specificity of the CK-MB release methodology, we performed similar assays using peritoneal macrophages. As expected due to the CK-MB cardiac localization, CK-MB release was negligible in the supernatant of lysed macrophages as compared to the CM, even when the double of the maximum cellular density were used (Table II). As other enzymatic markers have been used in clinical trials for detecting tissue damage, we next compared the use of different markers for measuring cardiomyocytes injury. Our data show that we successfully detected all the enzymatic activities into the CM supernatant after incubation for 20 min with T2, reaching mean values of 114, 90, and 76 \( \Delta \text{OD/min x 10}^{-3} \) for CK-MB, CK, and LDH, respectively (Fig. 1 D). Since the former enzyme are only expressed by cardiac muscle cells, our assays confirmed the higher specificity and sensitivity for CK-MB activity, which reached the higher \( \Delta \text{OD/min} \) levels in CM but was undetectable in the supernatant of lysed macrophage cultures, which have been used as negative controls (Table II). We finally tested the correlation between supernatant volume and amount of the enzyme substrate that was offered and found that increasing the supernatant volume lead to higher \( \Delta \text{OD/min} \) levels (Fig. 2E).

**DISCUSSION**

The choice of a biochemical marker for detecting cellular damage of the cardiomyocytes depends on (i) its specificity towards the myocardial cells, (ii) its fast release after cell injury, (iii) the linear correspondence between the injury level and the amount of released molecules, (iv) its easy measurement by automatic methods, and finally (v) its low cost. The measurements of the CK-MB levels in the CM supernatant as described here is a rapid, low cost and easy methodology, presenting reliable correspondence between the cell density and the marker release. This isoenzyme still represents one of the first choices for detecting the cardiac cells injury in the plasma analysis of patients displaying different types of heart diseases (Tietz 1980). We found that this method also presents a high specificity towards cardiac cells cultured in vitro since undetectable levels were consistently found when other cell types were used such as peritoneal macrophages. The parallel analysis of the CM morphological by light microscopy along with the trypan blue exclusion analysis showed a good correlation between cell viability and CK-MB detection. In an ex-vivo study, it has been demonstrated a clear correlation of CK release and impaired cardiomyocytes necrosis but not apoptosis after verapamil treatment of rat hearts submitted to ischemia and reperfusion procedures (Di Napoli et al. 2002). Besides, it has been suggested that CK isoenzymes could be employed as the index for the infection and necrosis of the muscle in electrical injured patients due to its high specificity and sensitivity (Liu & Xie 2002). Literature data show that in vitro models can provide a rapid, precise and relevant tool to reduce and replace some in vivo studies (Person 1986). Cell injury in cultured cells has been approached by several methodologies including morphological and functional assays (Civiale et al. 2003), the measurement of lactate dehydrogenase leakage, and the reduction of the tetrazolium salt to formazan by mitochondrial metabolic activity (Huhtala et al. 2002). Our study described a sensitive method for detecting cellular damage in the supernatant of primary cultures of cardiac myocytes. Among the markers that we tested, LDH, CK, and its cardiac isoenzyme CK-MB, the latter proved to be the most specific and assured methodology for detecting cardiac injury in vitro. Cytotoxicity studies employing culture systems have been performed and some employ detergents such as triton X-100 to induce cellular mem-

**TABLE I**

<table>
<thead>
<tr>
<th>Agent of cell lysis</th>
<th>( \Delta \text{OD/min x 10}^{-3} )</th>
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<tbody>
<tr>
<td>PBS</td>
<td>0.3 ± 1</td>
</tr>
<tr>
<td>H2O</td>
<td>19 ± 4</td>
</tr>
<tr>
<td>0.25% T</td>
<td>50 ± 6</td>
</tr>
<tr>
<td>1% T</td>
<td>56 ± 3</td>
</tr>
<tr>
<td>2% T</td>
<td>63 ± 3</td>
</tr>
</tbody>
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T: Triton X-100

**TABLE II**

Effect of centrifugation procedure (430 g) and correlation between the cell density of cardiac myocyte and the corresponding CK-MB release after 2% triton treatment for 20 min

<table>
<thead>
<tr>
<th>Cell density (10^4)</th>
<th>Cardiomyocyte</th>
<th>Macrophage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not centrifuged</td>
<td>Centrifuged</td>
</tr>
<tr>
<td>0.3</td>
<td>0</td>
<td>57 ± 3</td>
</tr>
<tr>
<td>0.6</td>
<td>1 ± 1</td>
<td>62 ± 5</td>
</tr>
<tr>
<td>1.2</td>
<td>2 ± 0</td>
<td>66 ± 5</td>
</tr>
<tr>
<td>2.5</td>
<td>8 ± 3</td>
<td>71 ± 4</td>
</tr>
<tr>
<td>5</td>
<td>19± 3</td>
<td>92 ± 2</td>
</tr>
<tr>
<td>7.2</td>
<td>63 ± 3</td>
<td>114 ± 6</td>
</tr>
<tr>
<td>10</td>
<td>85 ± 10</td>
<td>170 ± 2</td>
</tr>
<tr>
<td>20</td>
<td>nd</td>
<td>nd</td>
</tr>
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nd: not done
brane disruption and rapid lysis of the cultured cells (Dias et al. 2003). Presently, we describe a simple method for detecting cellular damage in CM indicated by the release of CK-MB, CK, and LDH in the cell culture supernatant upon the use of the non-ionic surfactant agent Triton X-100. This methodology that identifies the loss of cardiac myocyte viability can be used in several in vitro approaches such as the assessment of irritant and corrosive properties of chemicals, during cytotoxicity assays employing heterotypic interaction of cardiomyocytes with immune effector cells as well during the analysis of pathological damage caused by pathogens.

REFERENCES


