Cell Therapy in Chagas Cardiomyopathy (Chagas Arm of the Multicenter Randomized Trial of Cell Therapy in Cardiopathies Study)  
A Multicenter Randomized Trial

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Background—Previous studies suggested that transplantation of autologous bone marrow–derived mononuclear cells (BMNCs) improves heart function in chronic chagasic cardiomyopathy. We report the results of the first randomized trial of BMNC therapy in chronic chagasic cardiomyopathy.

Methods and Results—Patients 18 to 75 years of age with chronic chagasic cardiomyopathy, New York Heart Association class II to IV heart failure, left ventricular ejection fraction (LVEF) <35%, and optimized therapy were randomized to intracoronary injection of autologous BMNCs or placebo. The primary end point was the difference in LVEF from baseline to 6 and 12 months after treatment between groups. Analysis was by intention to treat and powered to detect an absolute between-group difference of 5%. Between July 2005 and October 2009, 234 patients were enrolled. Two patients abandoned the study and 49 were excluded because of protocol violation. The remaining 183 patients, 93 in the placebo group and 90 in the BMNC group, had a trimmed mean age of 52.4 years (range, 50.8–54.0 years) and LVEF of 26.1% (range, 25.1%–27.1%) at baseline. Median number of injected BMNCs was $2.20 \times 10^8$ (range, $1.40 \times 10^8$–$3.50 \times 10^8$). Change in LVEF did not differ significantly between treatment groups: trimmed mean change in LVEF at 6 months, 3.0 (1.3–4.8) for BMNCs and 2.5 (0.6–4.5) for placebo ($P=0.519$); change in LVEF at 12 months, 3.5 (1.5–5.5) for BMNCs and 3.7 (1.5–6.0) for placebo ($P=0.850$). Left ventricular systolic and diastolic volumes, New York Heart Association functional class, Minnesota quality-of-life questionnaire, brain natriuretic peptide concentrations, and 6-minute walking test did also not differ between groups.

Conclusion—Intracoronary injection of autologous BMNCs does not improve left ventricular function or quality of life in patients with chronic chagasic cardiomyopathy.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT00349271.  
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Key Words: cardiomyopathies ■ Chagas cardiomyopathy ■ stem cells ■ tissue therapy

Chagasic cardiomyopathy, which affects ~1.6 to 2.4 million people and results in an estimated 12,500 deaths every year, is a leading cause of heart failure in Latin America.\(^1\) The disease is caused by infection with the parasite Trypanosoma cruzi, which is transmitted to humans mainly by triatomine insects or occasionally by nonvectorial mechanisms such as blood transfusion and vertically from mother to infant.\(^2\) Cardiac manifestations, which appear 10 to 30 years after primary infection during the chronic phase of the disease, are attributed to multifactorial causes, including parasite persistence, vascular impairment, destruction of ganglia of the autonomic nervous system, and autoimmunity.\(^3\) Cardiomyopathy is characterized by focal or disseminated inflammatory infiltrates, myocyte apoptosis, myo-
necrosis, and progressive fibrosis, resulting in damage to the extracellular matrix and replacement of cardiac myocytes and vascular cells by fibrous tissue, with remodeling of the myocardium and vasculature.4,5

**Clinical Perspective on p 2461**

Chronic chagasic cardiomyopathy (CCC) is treated like all other heart failure syndromes; therapy usually includes β-blockers, diuretics, angiotensin-converting enzyme inhibitors (or angiotensin receptor blockers), and spironolactone. CCC has also been reported to be the main prognostic factor of mortality in patients with heart failure of different causes.6 When disease progresses, heart transplantation remains one of the few valuable therapeutic options. However, this option is limited by the small number of donors and the complications of immunosuppressive therapy, including parasite reactivation. New therapeutic interventions are clearly needed, and cell transplantation has emerged as an adjunct to standard therapy. Pioneering studies by Soares and colleagues7 in a mouse model of CCC and by Vilas-Boas et al8,9 to assess safety in patients with CCC proved intracoronary injection of autologous bone marrow–derived mononuclear cells (BMNCs) to be safe and feasible.

We performed a multicenter, double-blind, placebo-controlled randomized trial to assess the efficacy of BMNC therapy for improvement of left ventricular ejection fraction (LVEF) in patients with CCC and severe heart failure. We targeted this population because it was the focus of the safety study and because BMNC has been shown to be an independent predictor of mortality in patients with chronic heart failure secondary to chagasic cardiomyopathy.10

**Methods**

Patients

The study sample was selected consecutively from CCC patients who attended outpatient clinics in 11 specialized centers in Brazil. Patients meeting all of the following criteria were eligible for the study: previous diagnosis of heart failure according to the Framingham criteria receiving active and regular follow-up at a cardiac center with an etiologic diagnosis of Chagas disease confirmed by 2 serological tests using distinct methods, age of 18 to 75 years, New York Heart Association (NYHA) functional class II to IV heart failure, and echocardiogram showing LVEF of <35% by the Simpson rule. Women also had to have a negative serum pregnancy test during the screening phase, had to have been postmenopausal for at least 1 year, or had to be surgically sterile (bilateral tubal ligation, bilateral oophorectomy, or hysterectomy).

Patients meeting any of the following criteria were ineligible for the study: valvular heart disease except for functional mitral or tricuspid regurgitation; coronary angiography showing a clinically significant lesion (>50% lumen obstruction in 1 or more coronary arteries); sustained ventricular tachycardia episodes diagnosed previously; alcohol or drug abuse; serum creatinine of >221 μmol/L or previous dialysis therapy; evidence of acute systemic infection; valvular heart disease (severe aortic stenosis, gradient of left ventricle to aorta >50 mm Hg, mean stenosis <1.5 cm², or aortic or mitral regurgitation); chronic obstructive pulmonary disease with continuous use of steroids or bronchodilators; liver, blood, and neoplastic diseases or hemostasis disorders; chronic inflammatory or infectious diseases; other diseases that could affect life expectancy; or any other comorbidity affecting 2-year survival.

All patients enrolled in the study provided signed informed consent. The study was approved by the national and local ethics committees.

**Procedures**

Figure 1 shows the progression of patients through the study. For at least 6 weeks before the eligibility assessment, pharmacological therapy was optimized for all patients by identification of maximum tolerated doses of each drug. Unless required, optimal doses were not altered during the study. Appropriate drug treatment for heart failure in CCC was defined as the use, whenever possible, of the following drugs: digoxin (0.125–0.25 mg/d); spironolactone (25 mg/d); hydrochlorothiazide (12.5–50 mg/d) and/or furosemide (minimum of 40 mg/d); enalapril (5–40 mg/d) or captopril (37.5–150 mg/d); losartan (50–150 mg/d); hydralazine (75 mg/d) with isosorbide mononitrate (20 mg/d) for patients intolerant of angiotensin-converting enzyme inhibitors or angiotensin receptor blockers; carvedilol (6.25–50 mg/d); and amiodarone (200–400 mg/d). All drugs were dispensed free of charge to enrolled patients.

After the eligibility assessment but before randomization, all patients had bone marrow aspiration and catheterization to allow exclusion of patients with coronary artery disease and to ensure that masking was maintained once treatments were assigned. Bone marrow content (100 mL) was aspirated under sedation and local anesthesia by iliac crest puncture. An enriched BMNC fraction was obtained by Ficoll Hystopaque gradient centrifugation (GE Healthcare, Uppsala, Sweden) and resuspended in sterile 5% glucose saline solution. This procedure was repeated twice, after which the BMNCs were resuspended in saline solution containing 5% autologous serum. BMNC populations were characterized by flow cytometry by
use of a FACSCan
ty core laboratory at the National Cardiology
Institute (Rio de Janeiro, Brazil). Cells were counted in a hemocy-
tometer (Coulter, Miami, FL) and then labeled with a panel of 23
antibodies (Table 1 in the online-only Data Supplement) to charac-
terize cell populations present in the BMNC fraction.

Within 2.5 to 3 hours of bone marrow aspiration, a syringe
containing the randomly assigned treatment was sent to the catheter
laboratory for intracoronary injection, thereby avoiding the need for
a second catheterization. Saline with 5% autologous serum was used as
the placebo treatment. In the BMNC group, a minimum target of
10^6 BMNCs diluted in 20 mL saline solution was slowly injected
into all coronary arteries with an angioplasty catheter without
balloon inflation over a period of 10 minutes: 10 mL in the anterior
descending artery, 5 mL in right coronary artery, and 5 mL in the
circumflex artery in case of right dominance; and 10 mL in the
descending artery, 5 mL in right coronary artery, and 5 mL in the
right coronary artery in case of left dominance. Twenty-five
days after BMNC infusion, 5 μg/kg per day filgrastim (granulocyte
colony-stimulating factor) or its placebo was administered for 5
days. After catheterization, all patients stayed for 24 hours in the
intensive care unit and then for 72 hours in the hospital ward. If no
complications ensued, patients were discharged from hospital. Dur-
ing their stay in the intensive care unit, concentrations of creatinine,
kidney–MB and troponin I were measured at 6 and 12 hours after

Outcomes
Assessments done at baseline and at 6 and 12 months of follow-up
consisted of clinical examination, chest radiography, ECG, biochem-
istry and hematology, brain natriuretic peptide (BNP) concentration,
echocardiography, 6-minute walk test, and 24-hour Holter monitor-
ing. Clinical assessments included physical examination, blood
pressure, Minnesota quality-of-life questionnaire, and NYHA func-
tional class. ECG was recorded as 12-lead conventional ECG.
Biochemistry assessments included electrolyte, urea, creatinine,
glucose, aspartate and alanine aminotransferases, glutamyl trans-
ferase, and total and fraction of bilirubin. Hematology assessments
included hematocrit, hemoglobin, and coagulation. We assessed BNP
concentration with chemiluminescence using the TRIAGE test (Bio-
site, San Diego, CA). Echocardiography was done according to the
American Society of Echocardiography guidelines, and the Simpson
rule was used to calculate LVEF.

All examinations were done in each participating center, and the
values were entered directly in the electronic case report form and
immediately stored in 2 independent servers located at the National
Cardiology Institute and at the Federal University of Rio de Janeiro
(Rio de Janeiro, Brazil). Three investigators in each center were
allowed to enter data using usernames and passwords attributed by
the data coordinating center located at the National Cardiology
Institute. These investigators were the hematologist who did bone
marrow aspiration and BMNC processing, the interventional cardiol-
ologist who did catheterization for BMNC or placebo injection, and
the cardiologist who followed up the patients during the study. Data
were collected for the sequential phases of the study (Figure 1); data
entry depended on completion of previous case report forms, without
which the system was blocked, allowing remote monitoring of the
study. A core laboratory at the National Cardiology Institute vali-
dated these values on the basis of random sampling of recorded
examinations sent to the core laboratory.

The primary end point was the difference between groups in
LVEF (expressed as trimmed mean and 95% confidence interval)
from baseline to 6 and 12 months in patients receiving optimized
therapy for dilated chagasic cardiomyopathy. Secondary end points
recorded at 6 and 12 months were differences between groups in
NYHA functional class, mortality, physical capacity (by 6-minute
walk test), quality of life (Minnesota questionnaire), and BNP
concentrations.

The Data and Safety Monitoring Board was chosen among
investigators of the other arms of the MiHeart Study. Meetings
occurred every 2 months, and all changes in study protocol had to be
approved by the independent Data and Safety Monitoring Board.

Randomization and Masking
Patients were randomly assigned (1:1 ratio) to receive autologous
BMNC therapy or placebo. The randomization sequence was com-
puter generated with R software (version 1.9.0). To ensure compa-
ribility between the treatment groups throughout the study, block
randomization was used with block sizes of 2, 4, 6, or 8 patients. To
ensure allocation concealment, we used an automated, Web-based
randomization system situated at and managed by the coordinating
center at the National Cardiology Institute in Rio de Janeiro, where
randomization was generated by the Biostatistics Division. Patients,
study staff, and investigators were masked to treatment assignment;
the hematologist preparing the assigned treatment in each participat-
ing center was the only person who knew the randomization code.
Identical 10-mL syringes wrapped in dark plastic film to conceal
contents were used to mask treatment assignment. The same strategy
was used for the filgrastim injections.

Sample Size and Statistical Analysis
From analysis of data for patients with NYHA functional class II to
IV heart failure who were treated in the National Cardiology Institute
in the past 2 years, we concluded that LVEF followed an approxi-
mate gaussian distribution with a mean of 25% (SD, 10%). Thus, for
a 5% absolute difference in LVEF to be detected with a 95% confi-
dence level, 80% statistical power, and a standard deviation of
15% (allowing for the multicenter design of the trial), a sample size
of 142 patients per treatment group was needed. With a 2.5% loss to
follow-up in 12 months, we calculated that we needed a sample size
of 150 patients per treatment group.

Two assessments were scheduled: an interim analysis when the
first 150 patients completed their 6-month follow-up and a final
analysis when all 300 patients completed the 12-month follow-up.
The O’Brien-Fleming stopping rule was followed: ie, for an overall
α level of 0.05, we used an α of 0.005 in the interim analysis and of
0.049 in the final analysis. The interim analysis showed a smaller
dispersion than was expected, in fact a standard deviation of 8
instead of 15. Therefore, under the same assumptions, the necessary
sample size was reduced from 142 to 41 patients per treatment group.

BNP data were log transformed. If the patient died before an end
point was measured, we imputed a fixed value for the variable that
was worse than the worst value recorded for that variable. All
imputed values correspond to deaths occurring during follow-up. We
imputed 8 values for cell group at 6 months and 17 at 12 months.
For the placebo group, we imputed 10 and 18 values at 6 and 12 months,
respectively. Because the imputation of values for deaths renders the
distribution of the variables nongaussian, we used robust statistical
methods based on 10% trimmed distributions in all numeric variables
analyses. Categorical data are presented as count (percentages) and
numeric data as trimmed means; 95% confidence intervals were
calculated for point estimates. Differences in numeric variables
between groups were analyzed with the Yuen-Welch test11 (a robust
analog of the t test). Differences in NYHA functional class were
analyzed with the χ^2 test for trend. A secondary analysis of LVEF
data was performed with the use of a robust repeated measures
model.12 All analyses were performed on an intention-to-treat basis.
Statistical analyses were done with R software (version 2.1.2), and we
judged values of P<0.05 to be significant.

This trial is registered with http://www.clinicaltrials.gov (unique
identifier: NCT00349271).

Results

Enrollment and Characteristics of Patients
Three of the 11 participating centers were excluded by the
Data and Safety Monitoring Board after onsite monitoring
showed protocol violations. Of the 464 patients assessed for
eligibility, 224 did not meet inclusion criteria and 6 declined
to participate. Thus, 234 patients were enrolled and random-
ized between July 2005 and October 2009, but 49 were not included in the analysis because they were enrolled by the 3 excluded centers, and 2 did not return for assessment even after active searching (Figure 2). The remaining 183 patients, 90 in the BMNC group and 93 in the placebo group, were treated and followed up between July 2005 and October 2010. The 2 treatment groups were well matched with respect to characteristics at baseline (Table 1); 126 (69%) were men, the mean age was 52.4 years (50.8–54.0 years), and the LVEF was 26.1% (25.1%–27.1%). No patients examined had exclusion criteria for coronary artery disease. Thirty-five patients died during follow-up, but they were included in the intention-to-treat analysis.

Cell Characterization
Trimmed mean number of BMNCs did not differ between treatment groups. In the BMNC group, 2.5×10^8 BMNCs had a mean cell viability of 97.5; in the placebo group, 2.6×10^8 had a median cell viability of 98.2. The percentages of CD34+, CD133+, and CD105+ cells also did not differ significantly between treatment groups, as shown in Table 2.

Outcomes
No serious adverse events that could be directly related to the cell injection procedure were recorded during the trial. Continuous ECG monitoring during the 48 hours in the intensive care unit did not detect an increase in life-threatening arrhythmias. Trimmed mean creatinine kinase-MB enzyme levels at 0 (just before), 12, and 24 hours after the catheterization procedure were 8.7, 8.8, and 8.8 mg/dL for the BMC group and 10.8, 8.7, and 8.5 mg/dL for the placebo group (P=0.114, P=0.981, and P=0.841, respectively). Edema, pain, and swelling were the most common complaints after bone marrow aspiration and catheterization.

Although this trial was not powered to detect between-group differences in mortality, mortality was similar: 18 (19.4%) in the placebo group, and 17 (18.9%) in the BMNC group. In analysis of the primary end point in the BMNC group, trimmed mean LVEF increased from 26.1% at baseline to 28.9% at 6 months and 29.6% at 12 months (Table 3). In the placebo group, LVEF increased from 26.1% at baseline to 29.8% at 6 months and 31.3% at 12 months (Table 3). However, change in LVEF from baseline to 12 months did not differ significantly between treatment groups (Table 3). Notably, 35 patients (37.6%) in the placebo groupequivocally received 5 days of filgrastim injections at 25 days after intracoronary saline injection. Because analysis was by intention to treat, these patients were still included in the final analysis. However, to exclude the possibility that filgrastim injections improved LVEF in the placebo group, thus masking a positive effect of BMNC therapy, we reanalyzed the data with robust 2-way ANOVA model. For 6-month data, P=0.801 for the BMNC effect, P=0.777 for the filgrastim effect, and P=0.385 for the interaction between them. For 12-month data, P=0.677, P=0.815, and P=0.793, respectively. Again, statistical analysis showed no between-group difference. Additionally, exclusion of the randomization blocks containing the patients who received filgrastim in the placebo group resulted in an analysis population of 58 patients per group, which provided sufficient statistical power to analyze the efficacy of the therapy. Even under these conditions, we recorded no significant between-group differences for any of the variables analyzed.

Left ventricular diastolic and systolic volumes at baseline and the 6- and 12-month follow-up are presented in Table 4.
Table 1. Baseline Characteristics of Patients

<table>
<thead>
<tr>
<th></th>
<th>Placebo Group (n=93)</th>
<th>BMNC Group (n=90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>52.4 (50.1–54.7)</td>
<td>52.4 (50.3–54.5)</td>
</tr>
<tr>
<td>Men, n (%)</td>
<td>68 (73.1)</td>
<td>58 (64.4)</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>26.1 (24.7–27.6)</td>
<td>26.1 (24.8–27.3)</td>
</tr>
<tr>
<td>LVdV, mL</td>
<td>253.3 (236.7–269.9)</td>
<td>247.7 (227.5–267.8)</td>
</tr>
<tr>
<td>LVsv, mL</td>
<td>171.1 (156.3–185.9)</td>
<td>162.0 (144.8–179.1)</td>
</tr>
<tr>
<td>6-min walking distance, m</td>
<td>370.2 (348.8–391.7)</td>
<td>363.5 (330.0–396.4)</td>
</tr>
<tr>
<td>MLOQ score</td>
<td>44.5 (40.0–49.1)</td>
<td>46.3 (40.9–51.8)</td>
</tr>
<tr>
<td>lnBNP, pg/mL</td>
<td>3.5 (2.9–4.0)</td>
<td>3.1 (2.5–3.7)</td>
</tr>
<tr>
<td>ACEi, %</td>
<td>65.9</td>
<td>66.0</td>
</tr>
<tr>
<td>ARB, %</td>
<td>24.2</td>
<td>22.3</td>
</tr>
<tr>
<td>Hydrochlorothiazide, %</td>
<td>8.8</td>
<td>91.5</td>
</tr>
<tr>
<td>Furosemide, %</td>
<td>89.0</td>
<td>92.6</td>
</tr>
<tr>
<td>Spironolactone, %</td>
<td>86.8</td>
<td>91.5</td>
</tr>
<tr>
<td>Digoxin, %</td>
<td>72.5</td>
<td>62.8</td>
</tr>
<tr>
<td>Amiodarone, %</td>
<td>48.4</td>
<td>57.4</td>
</tr>
<tr>
<td>Carvedilol, %</td>
<td>65.9</td>
<td>69.1</td>
</tr>
<tr>
<td>Other β-blockers, %</td>
<td>6.6</td>
<td>3.2</td>
</tr>
</tbody>
</table>

BMNC indicates bone marrow–derived mononuclear cell; LVEF, left ventricular ejection fraction; LVdV, left ventricular diastolic diameter; LVsv, left ventricular systolic diameter; MLOQ, Minnesota quality-of-life questionnaire; lnBNP, natural logarithm of BNP concentrations; ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker. Data are trimmed mean (95% confidence interval), number (%), or percentage of patients taking medication as appropriate.

Table 2. Cell Characteristics of the Bone Marrow–Derived Mononuclear Cell and Placebo Groups

<table>
<thead>
<tr>
<th></th>
<th>BMNC Group</th>
<th>Placebo Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cells, ×10⁶</td>
<td>2.5 (1.9–3.1)</td>
<td>2.6 (1.9–3.3)</td>
</tr>
<tr>
<td>Viability by trypan blue exclusion</td>
<td>97.5 (97.0–98.1)</td>
<td>98.2 (97.7–98.6)</td>
</tr>
<tr>
<td>CD34 cells, %</td>
<td>2.0 (1.3)*</td>
<td>2.2 (1.7)†</td>
</tr>
<tr>
<td>CD133 cells, %</td>
<td>1.4 (1.6)*</td>
<td>1.7 (1.8)†</td>
</tr>
<tr>
<td>CD105 cells, %</td>
<td>1.3 (0.9)*</td>
<td>1.6 (1.0)†</td>
</tr>
</tbody>
</table>

BMNC indicates bone marrow–derived mononuclear cell. Values are trimmed mean (95% confidence interval for the first 2 rows or SD for the last 3 rows). There are no significant differences between groups.

*Nineteen patients declined participation or had insufficient product for analysis.
†Ten patients declined participation.

Table 3. Left Ventricular Ejection Fraction Values at Baseline and at the 6- and 12-Month Follow-Up

<table>
<thead>
<tr>
<th></th>
<th>Placebo Group (n=93)</th>
<th>BMNC Group (n=90)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline, %</td>
<td>26.1 (24.7–27.6)</td>
<td>26.1 (24.8–27.3)</td>
<td>0.985</td>
</tr>
<tr>
<td>At 6 mo, %</td>
<td>29.6 (27.6–31.7)</td>
<td>29.3 (27.4–31.1)</td>
<td>0.780</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>2.5 (0.6–4.5)</td>
<td>3.0 (1.3–4.8)</td>
<td>0.519</td>
</tr>
<tr>
<td>P</td>
<td>0.0125</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>At 12 mo, %</td>
<td>31.1 (28.7–33.6)</td>
<td>30.2 (27.9–32.4)</td>
<td>0.599</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>3.7 (1.5–6.0)</td>
<td>3.5 (1.5–5.5)</td>
<td>0.850</td>
</tr>
<tr>
<td>P</td>
<td>0.0002</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

BMNC indicates bone marrow–derived mononuclear cell. Data are trimmed mean (95% confidence interval).

Table 4. Left Ventricular Diastolic and Systolic Volumes at Baseline and at the 6- and 12-Month Follow-Up

<table>
<thead>
<tr>
<th></th>
<th>Placebo Group (n=93)</th>
<th>BMNC Group (n=90)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVdV, mL</td>
<td>253.3 (236.7–269.9)</td>
<td>247.7 (227.5–267.8)</td>
<td>0.665</td>
</tr>
<tr>
<td>At 6 mo, %</td>
<td>246.2 (227.2–265.1)</td>
<td>248.8 (226.1–270.1)</td>
<td>0.894</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>2.4 (−15.9 to 11.2)</td>
<td>0.7 (−12.8 to 14.1)</td>
<td>0.882</td>
</tr>
<tr>
<td>P</td>
<td>0.729</td>
<td>0.920</td>
<td></td>
</tr>
<tr>
<td>At 12 mo, %</td>
<td>251.2 (230.9–271.6)</td>
<td>250.8 (229.5–272.1)</td>
<td>0.975</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>10.4 (−8.0 to 28.7)</td>
<td>7.8 (−7.6 to 28.7)</td>
<td>0.801</td>
</tr>
<tr>
<td>P</td>
<td>0.261</td>
<td>0.296</td>
<td></td>
</tr>
<tr>
<td>LVsv, mL</td>
<td>171.1 (156.3–185.9)</td>
<td>162.0 (144.8–179.1)</td>
<td>0.422</td>
</tr>
<tr>
<td>At 6 mo, %</td>
<td>171.3 (154.4–181.1)</td>
<td>164.0 (145.2–182.7)</td>
<td>0.552</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>7.2 (−5.4 to 19.7)</td>
<td>2.6 (−10.2 to 15.5)</td>
<td>0.889</td>
</tr>
<tr>
<td>P</td>
<td>0.258</td>
<td>0.685</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>167.2 (150.6–183.8)</td>
<td>162.8 (145.0–180.5)</td>
<td>0.712</td>
</tr>
<tr>
<td>Difference from baseline, %</td>
<td>9.8 (−3.1 to 22.7)</td>
<td>6.4 (−8.9 to 21.7)</td>
<td>0.734</td>
</tr>
<tr>
<td>P</td>
<td>0.135</td>
<td>0.406</td>
<td></td>
</tr>
</tbody>
</table>

BMNC indicates bone marrow–derived mononuclear cell; LVdV, left ventricular diastolic volume; LVsv, left ventricular systolic volume. Data are trimmed mean (95% confidence interval).
Repeated measures analysis of the primary end point (LVEF) also did not detect significant differences between the 2 treatment groups \( (P \text{ of the BMNC effect}) = 0.521) \).

**Discussion**

The findings of our study show that intracoronary injection of BMNCs in patients with CCC does not lead to further improvement in LVEF or other indicators of disease compared with standard therapy. However, our study adds to the notion that intracoronary BMNC therapy is safe in these patients, as previously reported by Vilas-Boas et al.\(^8,9\) BMNC therapy has been used in various cardiopathies with an almost unanimous safety profile (for a review, see the work by Martin-Rendon and colleagues\(^13\)). In the few instances when safety issues were raised,\(^14\) additional studies did not confirm the reported adverse events.\(^15,16\) In our study, no serious adverse events related to the procedure were recorded in the 90 patients analyzed in the BMNC group, even though our study population had very poor health.

Although LVEF significantly increased from baseline to 6 and 12 months in the BMNC group, this improvement was also seen in the placebo group. The 4% absolute increase in LVEF recorded 6 months after BMNC therapy in our study is similar to that reported by Vilas-Boas et al.\(^8\) in their pioneering study and highlights the need for placebo-controlled randomized trials to assess the efficacy of cell-based therapies. Although the Vilas-Boas et al. study was performed in a population with lower baseline LVEF (20% versus 26% in our study), we do not think that a 6% absolute difference in LVEF at baseline could influence the results, even more when we are comparing a safety trial with an efficacy trial. At any rate, a linear regression using the change in LVEF compared with baseline LVEF does not show significant correlation \( (R^2 = 0.000001, P = 0.989) \).

The statistically significant increase in LVEF in both groups in our trial indicates that this study population deserves improved medical attention; even though we did at least 6 weeks of pharmacological optimization, this period was clearly not long enough to achieve the patients’ best cardiac performance. Most patients with CCC belong in the lower socioeconomic stratum of the population; therefore, privileged access to medical services and free drug prescriptions would, unsurprisingly, lead to improvement in health.

The lack of benefit of BMNC therapy in CCC might stem from the complex and multivariate pathological basis of this disease. CCC is known to involve cycles of parasitic eclosion, resulting in inflammatory invasion and destruction of cardiomyocytes\(^17\) and autoimmune and microvascular disorders\(^18\) that compromise the working myocardium and conduction system. Although BMNC therapy significantly decreases cardiac inflammation and fibrosis in a mouse model of chronic chagasic infection,\(^7\) left ventricular

**Table 5. Six-Minute Walking Distance at Baseline and at the 6- and 12-Month Follow-Up**

<table>
<thead>
<tr>
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<th>Placebo Group</th>
<th>BMNC Group</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>370.2 (348.8–391.7)</td>
<td>363.5 (330.0–396.9)</td>
<td>0.735</td>
</tr>
<tr>
<td>At 6 mo</td>
<td>416.6 (388.1–445.1)</td>
<td>422.7 (387.9–457.4)</td>
<td>0.782</td>
</tr>
<tr>
<td>Difference from baseline</td>
<td>46.9 (15.9–78.0)</td>
<td>56.0 (24.6–87.4)</td>
<td>0.756</td>
</tr>
<tr>
<td>( P )</td>
<td>0.003</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>At 12 mo</td>
<td>416.0 (326.6–455.3)</td>
<td>427.8 (388.7–467.1)</td>
<td>0.663</td>
</tr>
<tr>
<td>Difference from baseline</td>
<td>41.9 (2.2–81.6)</td>
<td>63.4 (33.5–93.4)</td>
<td>0.870</td>
</tr>
<tr>
<td>( P )</td>
<td>0.039</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

BMNC indicates bone marrow–derived mononuclear cell. Data are trimmed mean (95% confidence interval).
dysfunction has not been described in this model. In fact, Goldenberg and colleagues\(^\text{19}\) showed only a dilatation of right ventricular chamber in this mouse model, raising doubts about the validity of the model to represent human cardiac dysfunction.

Another plausible explanation for the lack of benefit is that BMNCs might not be able to induce cardiomyogenesis. CCC involves destruction of cardiomyocytes, which means that a clear benefit, especially if LVEF is used as a surrogate end point, would ensue only if BMNC therapy regenerates lost cardiomyocytes. Although randomized trials of BMNC therapy in acute ischemic heart disease have reported a significant gain in LVEF,\(^\text{20,21}\) even if temporary, or a reduction in infarct area,\(^\text{22}\) this result is probably caused by increased angiogenesis stimulated by BMNC therapy, not by cardiomyogenesis. In Chagas heart disease, cell homing occurs in well-perfused areas after intracoronary cell injection\(^\text{23}\); therefore, the angiogenic effect of BMNCs might not be available where it is most needed in CCC.

This study has limitations imposed by the infrastructure of the collaborating centers; very few centers were equipped with magnetic resonance imaging, and we had to evaluate LVEF by echocardiography. Furthermore, the validation of the echocardiograms by sampling in the core laboratory is another study limitation. Cell processing at each collaborating center might be considered another limitation, but we reasoned that a centralized cell processing laboratory would require freeze/thawing of the cells given the distances between participating centers, a much greater limitation for cell quality in our view. The use of granulocyte colony-stimulating factor in a percentage of the patients of the placebo group could have limited the validity of our study. However, as mentioned earlier, even after exclusion of all randomization blocks containing these patients, we still had statistical power to analyze the data.

Intracoronary BMNC therapy does not have additional benefits over standard therapy for CCC in patients with severe heart failure. However, this finding should not deter researchers from testing new cell types, injection routes, and time windows for the start of therapy because this intractable disease leaves patients with end-stage heart failure with no treatment option other than heart transplantation.

Acknowledgments

We would like to thank Dr Timothy Henry for his role as an international consultant to this study.

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Disclosures

None.

References


**CLINICAL PERSPECTIVE**

Heart failure is a common cause of death in patients with chronic chagasic cardiomyopathy. Current therapies are limited and, with the exception of heart transplantation, only delay disease progression. Cell therapy using bone marrow–derived cells has been a promising (albeit inconsistent) approach to the treatment of cardiovascular diseases. Experimental evidence in animal models and feasibility studies in patients with chronic chagasic cardiomyopathy have suggested that bone marrow mononuclear cell transplantation may improve cardiac function. This study reports the results of a multicenter, double-blind, randomized, placebo-controlled trial evaluating the efficacy of bone marrow mononuclear cells on left ventricular ejection fraction in 183 patients with chronic chagasic cardiomyopathy. Although both the placebo and cell-therapy groups showed a significant increase in left ventricular ejection fraction at 6 and 12 months of follow-up, this study failed to document a significant difference in change in left ventricular ejection fraction between the 2 groups. Intracoronary injection of bone marrow mononuclear cells was not associated with adverse clinical events. We conclude that with the methods used, no additional benefit of intracoronary mononuclear cell injection was found in patients with chronic chagasic cardiomyopathy and a left ventricular ejection fraction <35%. Nonetheless, cell-based therapies may still hold promise for chronic chagasic cardiomyopathy patients. Larger clinical trials focusing on hard clinical end points, new cell types, methods of delivery, dosage schemes, and disease stages are warranted to further test the efficacy of this novel therapeutic approach.
Cell Therapy in Chagas Cardiomyopathy (Chagas Arm of the Multicenter Randomized Trial of Cell Therapy in Cardiopathies Study): A Multicenter Randomized Trial

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Supplemental Material

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Supplemental Table

The antibody panel used for cell characterization is shown in the Table. For determination of CD34+ cell content we used the ISHAGE protocol.

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