ESC European Society of Cardiology

European Heart Journal - Case Reports (2022) **6**(1), 1–10
https://doi.org/10.1093/ehjcr/ytab528

CASE SERIES
Cardiac imaging

Computed tomography assessment of saw-tooth cardiomyopathy: a case series

Joaquin Berarducci [1], Javier Ivan Armenta-Moreno [1], Nilda Espinola-Zavaleta [1,2]*, Roberto Cano-Zarate[3], Ana-Valentina Gutiérrez-Solana-Ossa[1], and Candace Keirns [4]

[1]Department of Nuclear Cardiology, National Institute of Cardiology Ignacio Chavez, Juan Badiano N° 1, Colonia Seccion XVI, Tlalpan, P.C-14060 Mexico City, Mexico; [2]Department of Echocardiography, ABC Medical Center I.A.P., Sur 136 N° 116, Colonia Las Americas, P.C-01120 Mexico City, Mexico; [3]Department of Magnetic Resonance Imaging, National Institute of Cardiology Ignacio Chavez, Juan Badiano N° 1, Colonia Seccion XVI, Tlalpan, P.C-14060 Mexico City, Mexico; and [4]International Medical Interpreters Association, Massachusetts General Hospital, 55 Fruit St, Boston, MA 02114, USA

Received 21 June 2021; first decision 26 August 2021; accepted 22 December 2021; online publish-ahead-of-print 27 December 2021

Background Saw-tooth cardiomyopathy (STC) is an unusual type of left ventricular dysplasia. To our knowledge, six cases have been reported in the literature. Two new cases are presented with a review of all the case reports that have been published.

Case summary Two patients with STC were examined. The first one was a 69-year-old woman with shortness of breath on mild exertion and chest pain, and the second was a 49-year-old man with a history of myocardial infarction who required stent implantation and is now asymptomatic. Both patients revealed findings of STC in the cardiac computed tomography (CT).

Discussion When analysing the cases and comparing them to the ones reported in the literature; STC is a generally benign heart disease, although the clinical spectrum can range from asymptomatic to heart failure. Imaging studies such as cardiac magnetic resonance and cardiac CT are essential for the diagnosis.

Keywords Cardiac computed tomography • Saw-tooth cardiomyopathy • Echocardiography • Crypts • Case report

ESC Curriculum 2.1 Imaging modalities • 2.2 Echocardiography • 2.4 Cardiac computed tomography • 6.2 Heart failure with reduced ejection fraction

Learning points

- Saw-tooth cardiomyopathy (STC) is a rare form of left ventricular (LV) dysplasia that may not be represented in the literature because it is underdiagnosed.
- Cardiac computed tomography is a valuable non-invasive study for the diagnosis of STC due to its capacity to rule out coronary lesions and identify this type of LV dysplasia.
- Decreased global longitudinal left ventricular strain could be an early diagnostic indicator of STC.

Introduction

Saw-tooth cardiomyopathy (STC) is a very rare pathology that presents with left ventricular (LV) dysplasia. It mainly affects the apical and middle segments of the lateral and inferior walls of the LV where multiple projections of compacted myocardium resembling crypts can be observed on MRI and cardiac computed tomography (CT).[1] Clinical courses range from asymptomatic to acute heart failure.[2]

* Corresponding author. Tel: +52 555 505 3039, Email: niesza2001@hotmail.com
Handling Editor: Davide Stolfo
Peer-reviewers: Constantinos Bakogiannis and Edin Begic
Compliance Editor: Zhiyu Liu
Supplementary Material Editor: Ameenathul Mazaya Fawzy

There are few cases published in the literature; all of them have been identified and diagnosed by transthoracic echocardiography (TTE) and cardiac magnetic resonance (CMR).[1–7] The first case was reported in Greece by Davlouros *et al.*[4] Since, at present, the aetiology and the prognosis remain unknown further studies are necessary.

The objective of our study was to present two cases of STC diagnosed with cardiac CT and compare them with previous reports.

Timeline

Patient no. 1

Day 0
- Initial presentation with chest pain and severe dyspnoea [New York Heart Association (NYHA) III].
- 12-lead electrocardiogram (ECG)
  - Sinus rhythm with no relevant findings.
- Laboratory blood test
  - N-terminal pro-B-type natriuretic peptide 2140 ng/L (normal range <170 ng/L), troponin I, creatine kinase, and C-reactive protein all within normal ranges.
- Transthoracic echocardiogram
  - Dilation of the cardiac chambers with biventricular systolic dysfunction.
  - Left ventricular end-diastolic diameter 76 mm, left ventricular end-systolic diameter 60 mm.
  - Left ventricular end-diastolic volume 127 ml/ m^2
  - Left atrial volume 53.2 ml/m^2
- Initiation of heart failure therapy and indication of a 24-h Holter ECG and a cardiac computed tomography (CT).

Day 2
- Holter ECG
  - Intermittent second degree Mobitz II atrioventricular block.
- Cardiac CT
  - It showed dilatation of the right cavities with deep crypts in the anterior and inferior walls of the left ventricle (LV), biventricular systolic dysfunction with left ventricular ejection fraction (LVEF) of 30%, tricuspid annular plane systolic excursion of 10 mm, and no epicardial coronary lesions.

Month 3
- Follow-up
  - Good adherence to medical treatment and lifestyle modifications with improvement of the dyspnoea (NYHA II).

Patient no. 2

Day 0
- 48-year-old male with past medical history of coronary artery disease and hypertension who attends for annual follow-up.

Continued

Continued

Patient no. 2

- Current treatment: aspirin 100 mg daily, atorvastatin 40 mg daily, and candesartan 8 mg daily.
- 12-lead ECG
  - First degree atrioventricular block (PR 220 ms) without sings of ischaemia or necrosis.
- Laboratory blood studies
  - All values within normal ranges.
- Transthoracic echocardiogram
  - Normal LVEF (63%), crypts in the middle and apical portions of the interventricular septum and LV inferior wall, resembling the appearance of a saw-tooth and a decreased LV global longitudinal strain (-17.3%) in the previously mentioned segments, suggesting subclinical dysfunction.
- Cardiac CT
  - Crypts in the interventricular septum, right dominance of coronary arteries with a partially calcified plaque on the left anterior descendent coronary artery, no significant stenosis with a stent placed on the middle segment. Mild anteroseptal hypokinesia of the left ventricle.

Month 3
- Follow-up
  - The patient remains asymptomatic.

Case presentation: Patient no. 1

A 69-year-old female sought medical attention in the emergency room with a chief complaint of chest pain, marked limitation of physical activity, and shortness of breath on minor exertion. The patient had a history of long-term hypertension and type II diabetes mellitus treated with enalapril, metformin, and sitagliptin with poor treatment adherence. The physical examination revealed an S3 sound over the fifth intercostal space on the medio-clavicular line and bilateral pitting malleolar oedema (++/++++). The 12-lead electrocardiogram (ECG) showed sinus rhythm with no relevant findings, and the 24-h Holter study revealed a Mobitz type II AV block (*Figure 1*). N-terminal pro-B-type natriuretic peptide (NT-ProBNP) levels of 2140 ng/Lt were obtained (normal range <170 ng/Lt). Transthoracic echocardiography showed dilated cardiac chambers with a right ventricular basal diameter of 45 mm, LV global hypokinesis with biventricular systolic dysfunction [left ventricular ejection fraction (LVEF) 28% and tricuspid annular plane systolic excursion 10 mm] and type III LV diastolic dysfunction. Heart failure was suspected based on clinical data and was confirmed by the echocardiographic findings and the NT-ProBNP levels. The cardiac CT performed with a 128 Multi-Slice Siemens Somaton (*Figures 2* and *3*) showed dilatation of the right chambers and deep crypts in the LV anterior and inferior walls with systolic dysfunction (LVEF of 30%). The main differential diagnosis was non-compacted left ventricular cardiomyopathy, which was a

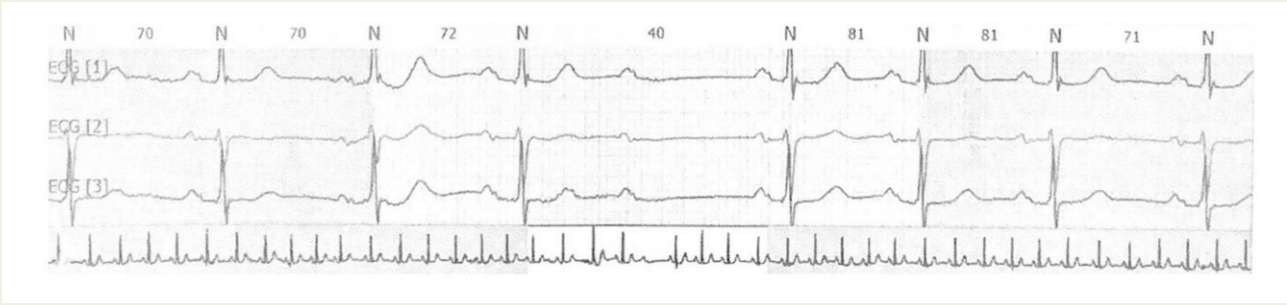

Figure 1 Twenty-four-hour Holter study. Segment of the Holter study that reveals an intermittent Mobitz II second degree atrioventricular block.

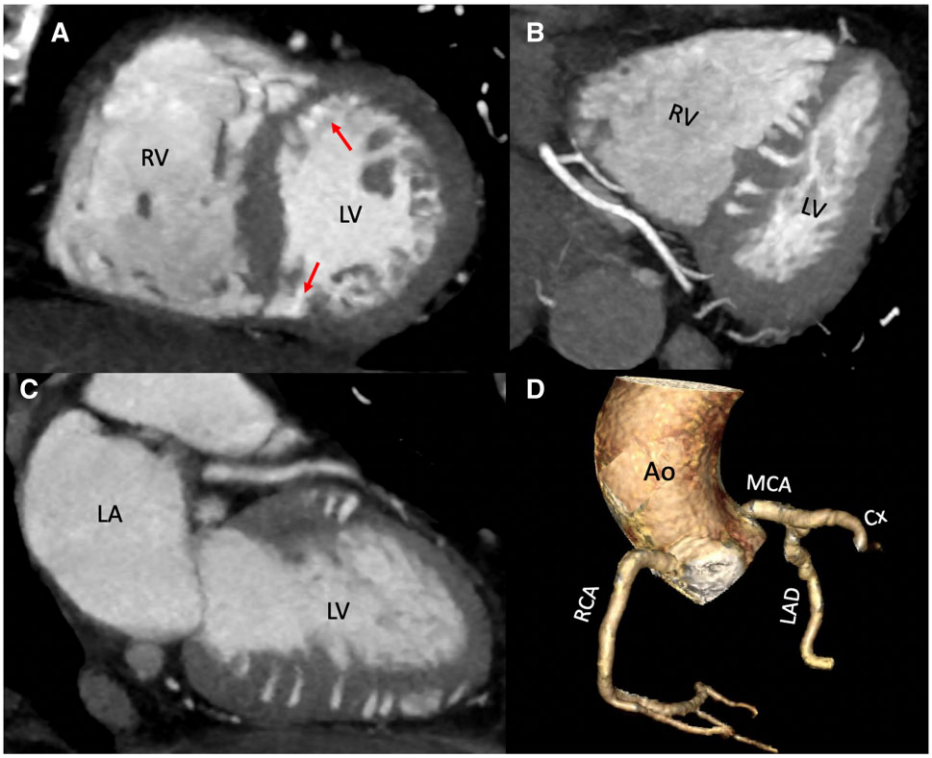

Figure 2 Cardiac computed tomography. (*A*) Short-axis view at the level of papillary muscles with crypts in the left ventricular infero-septal wall (red arrows) and dilation of the right ventricle. (*B*) Modified four-chamber view showing the crypts in the interventricular septum and enlargement of right ventricle. (*C*) Two-chamber view with crypts in the left ventricular anterior and inferior walls. (*D*) Three-dimensional rendering of the coronary arteries without lesions. Cx, circumflex; LA, left atrium; LAD, left anterior descending; LV, left ventricle; MCA, main coronary artery; RCA, right coronary artery; RV, right ventricle.

challenge due to the presence of ventricular dysplasia. Nevertheless, this was ruled out because of the absence of hyper-trabeculation, normal compaction of the LV in both TTE and cardiac CT and the presence of ventricular crypts. There was no need for a coronary angiogram due to the previously mentioned findings. The diagnosis of STC was reached by correlating the patient's structural findings with cases reported in the literature. Her treatment included 10 mg of enalapril twice daily, carvedilol 6.25 mg daily, and furosemide 20 mg daily. Initially, spironolactone (12.5 mg daily) was part of the established therapy, but after using it for 4 weeks, the patient presented hyperkalaemia, and since the risk of a fatal arrhythmia outweigh the benefits of the drug it was discontinued. The patient has limited economic resources, so the costs and the low availability of sacubitril/valsartan where she lives precluded its use. The rationale for prescribing her treatment was the clinical diagnosis of heart failure; beta-blockers were omitted due to a second-degree AV block detected in the 24-h Holter monitoring. Pacing was not considered because she had a heart rate >40 b.p.m., no sinus pauses longer than 3 s, and the clinical finding was not attributed to the AV block. Treatment was based on the 2016 ESC guidelines;[8] spironolactone

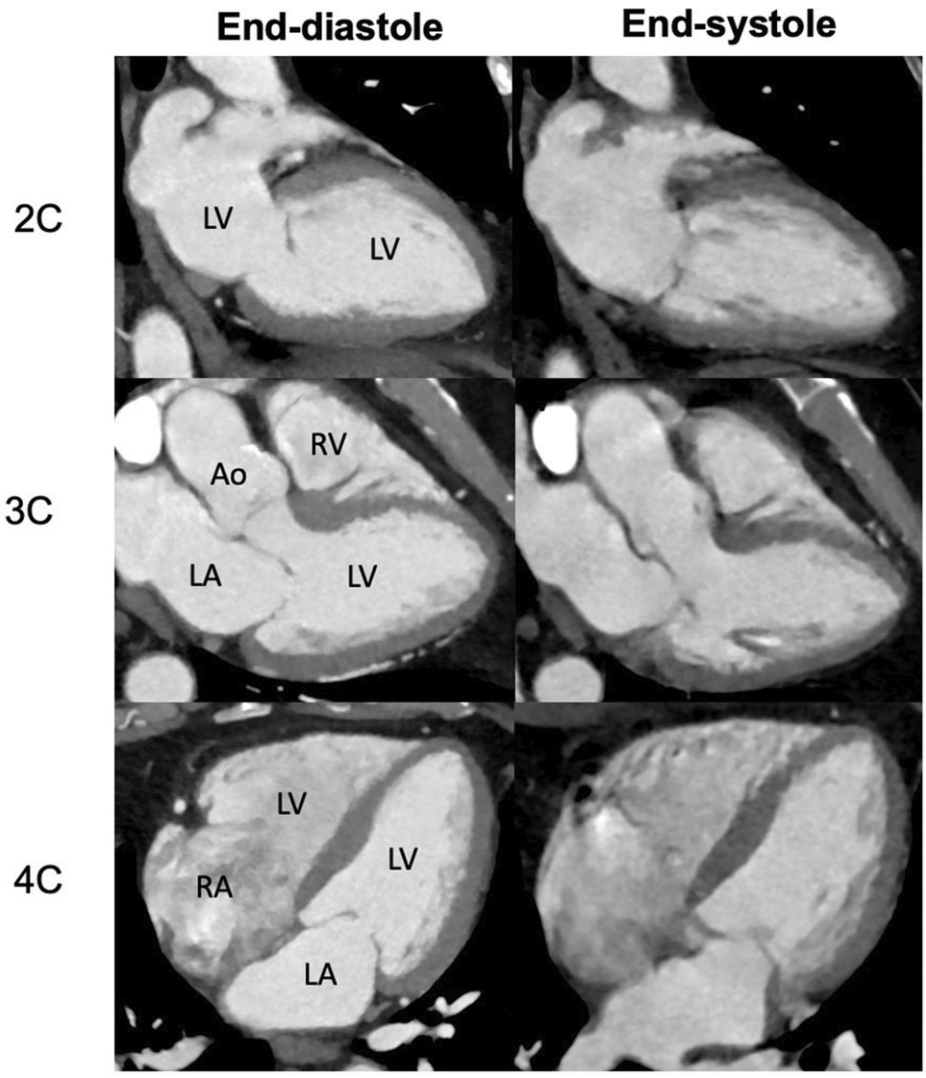

Figure 3 End diastole and end systole on cardiac computed tomography. All images are from Patient no. 1. These sequences were used to rule out the diagnosis of left ventricular non-compaction. The end-diastolic non-compaction/compaction ratio was 1.52 in >2 segments of the apical and medial segments of the left ventricle; this does not meet the criteria for left ventricular non-compaction. The characteristic morphologic changes of saw-tooth cardiomyopathy are not visible in these planes, but there is evident dilation of the right chambers observed in the four-chamber view. 2C, two-chamber; 3C, three-chamber; 4C, four-chamber.

and sacubitril/valsartan were excluded due to the combination of the side effects and the patient's economic limitations which prevented her from receiving optimal heart failure treatment. The possibility of adding a SGLT-2 was considered due to its cardiovascular benefits, but the patient rejected it because of its high cost. On the follow-up, the patient has an adequate response to medical treatment with improvement of her functional class, with moderate dyspnoea on exertion and none at rest.

Case presentation: Patient no. 2

A 48-year-old male came for an annual follow-up. He had a long-term history of hypertension and suffered a myocardial infarction 2 years ago requiring stent implantation in the left anterior descending coronary artery. His physical examination was unremarkable. Twelve-lead ECG was performed that showed sinus rhythm, QRS axis 70°, normal P-wave morphology, and Q waves in V1–V4. Transthoracic echocardiography was performed with Philips Epiq CVX Imaging equipment (Philips Medical Systems, Bothell, Washington, DC, USA), and it showed a normal LVEF of 63%, crypts in the middle and apical segments of the interventricular septum and LV inferior wall of a saw-tooth appearance (*Figure 4*). These findings correlated with decreased left ventricular global longitudinal strain (-17.7%) in the previously mentioned segments, suggesting subclinical dysfunction. Cardiac CT with a 64 Multi-Slice Philips Brilliance was performed (*Figures 5* and *6*) to assess the stent permeability and showed partially calcified plaque with no occlusion, crypts in the

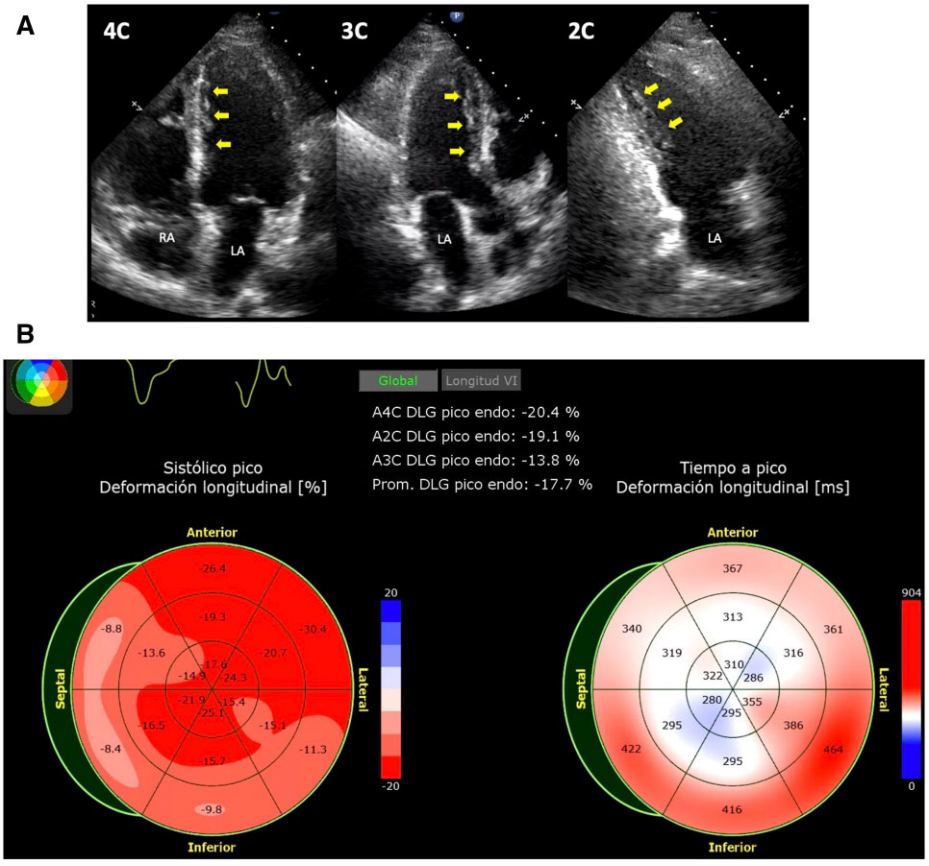

Figure 4 Conventional transthoracic and speckle tracking echocardiography. (*A*) 4C—apical four-chamber image with irregularities in the middle and apical portions of the interventricular septum (yellow arrowheads). 3C—apical three-chamber image with irregularities of the interventricular septum in its middle and apical segments (yellow arrowheads). 2C—apical two-chamber image with irregularities in the middle and apical portions of the left ventricular inferior wall (yellow arrowheads). (*B*) Decreased global longitudinal deformation by speckle tracking (-17.7%) more evident in the inferior, infero-lateral and infero-septal walls of the left ventricle. Ao, aorta; LA, left atrium; RA, right atrium; RV, right ventricle.

interventricular septum, and hypokinesis of the anteroseptal middle third of the left ventricle. Even though there was hypokinesis, the LVEF was preserved due to the heart's capability to compensate. Differential diagnosis was made with non-compacted left ventricular cardiomyopathy due to the ventricular hyperplasia but was ruled out because of the adequate compaction of the LV observed in TTE and confirmed by cardiac CT. There was no need of a coronary angiogram due to the previously mentioned findings. Treatment with 40 mg of atorvastatin o.d., 100 mg of aspirin o.d., and 8 mg of candesartan o.d. was maintained. Currently, the patient remains stable. His present treatment is based on ESC 2018 guidelines[9] which recommend lifelong antiplatelet therapy for patients with revascularization history and statins when there is a medical history of coronary artery disease. As the patient had adequate control of his hypertension with an ARB-II inhibitor, there was no need to modify this treatment. On the follow-up, the patient remains asymptomatic with an adequate response to treatment.

Genetic analysis was performed on both patients. Seventy genes commonly associated with various cardiomyopathies were sequenced, including LVNC. No pathologic mutation was found in either of the patients.

Transthoracic echocardiography was performed on the parents of both patients along with complete clinical histories, but no morphologic alterations suggesting STC were found.

Discussion

Saw-tooth cardiomyopathy is a rare pattern of left ventricular dysplasia characterized by multiple myocardial crypts resembling a 'saw tooth' in non-invasive imaging.[1] So far, there have only been six cases reported in the literature: one female, two male newborns and three male adults.[1–7] Transthoracic echocardiography CMR, and cardiac CT are valuable non-invasive tools for the diagnosis of this pathology. Two investigators conducted independent searches using the key words 'saw-tooth cardiomyopathy', 'tiger heart', and 'variant of left ventricular non-compaction' published in the past 20 years (2000–20).

Our first case is the oldest female patient diagnosed with STC in the literature. She had clinical manifestations of heart failure like most

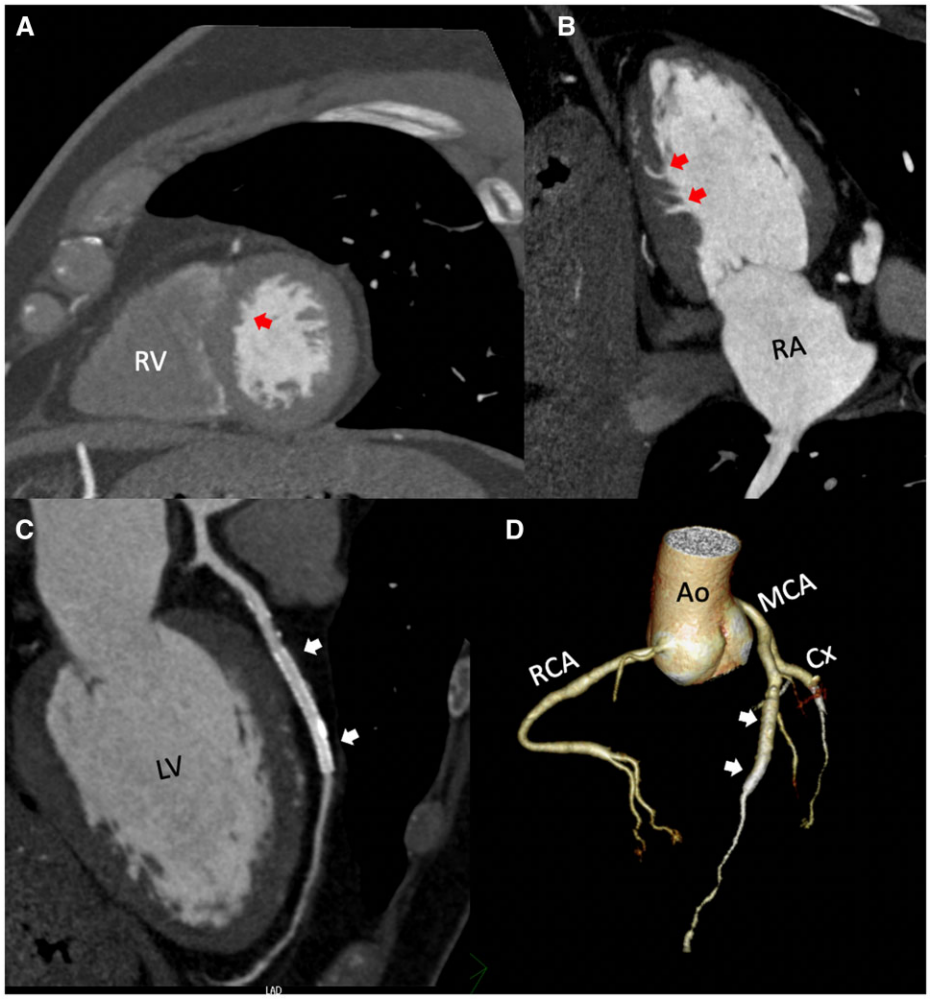

Figure 5 Cardiac computed tomography. (*A*) Short-axis view at the middle third with irregularities in the left ventricular septal surface (red arrowhead). (*B*) Two chamber view of the left chambers with crypts in the left ventricular inferior wall (red arrowhead). (*C*) A stent in the middle segment of left anterior descending artery without lesions (white arrowhead). (*D*) Three-dimensional rendering of the coronary arteries without lesions with a stent in the middle segment of left anterior descending (white arrowheads). Ao, aorta; Cx, circumflex; LV, left ventricle; MCA, main coronary artery; RA, right atrium; RCA, right coronary artery; RV, right ventricle.

of the patients in our review of the literature[1,6,7] (*Table 1*). Her echocardiographic findings were consistent with the most common findings in STC, including hypokinesis and reduced LVEF, although crypts were not evident in this study. The cardiac CT findings were consistent with those described in CMR as a saw-tooth appearance of the anterior and inferior LV myocardial walls and interventricular septum. The evolution of this patient was satisfactory with conservative therapy, a trend following the current case reports in the literature.

The second case is the first male patient with a history of myocardial infarction in the literature. Like the other two cases, he was asymptomatic, thus the diagnosis of STC was incidental. In this patient, TTE did not show classical suggestive signs of STC, but cardiac CT findings did correlate with those previously reported. Transthoracic echocardiography revealed subclinical dysfunction with decreased global longitudinal strain predominantly of the left infero-septal ventricular wall without correlation with the area of myocardial infarction. The sparing of the previously affected cardiac walls due to ischaemia could be explained because the patient was successfully treated with percutaneous intervention following the ESC guidelines.[10]

In contrast to the other case reports, our patients were the first ones diagnosed using cardiac CT. It has been proposed that cardiac CT has similar specificity and sensitivity to CMR in the diagnosis of structural heart conditions.[11–13] Also, cardiac CT has the advantage over CMR that it can rule out the presence of coronary artery disease, which is very important for the diagnosis. The main differential diagnosis in our two patients was LV non-compaction, which was excluded because of normal compaction of the ventricular wall, the absence of hypertrabeculation, and the presence of ventricular crypts. Another important differential diagnosis was multiple ventricular septal defects, but no such defects were documented.

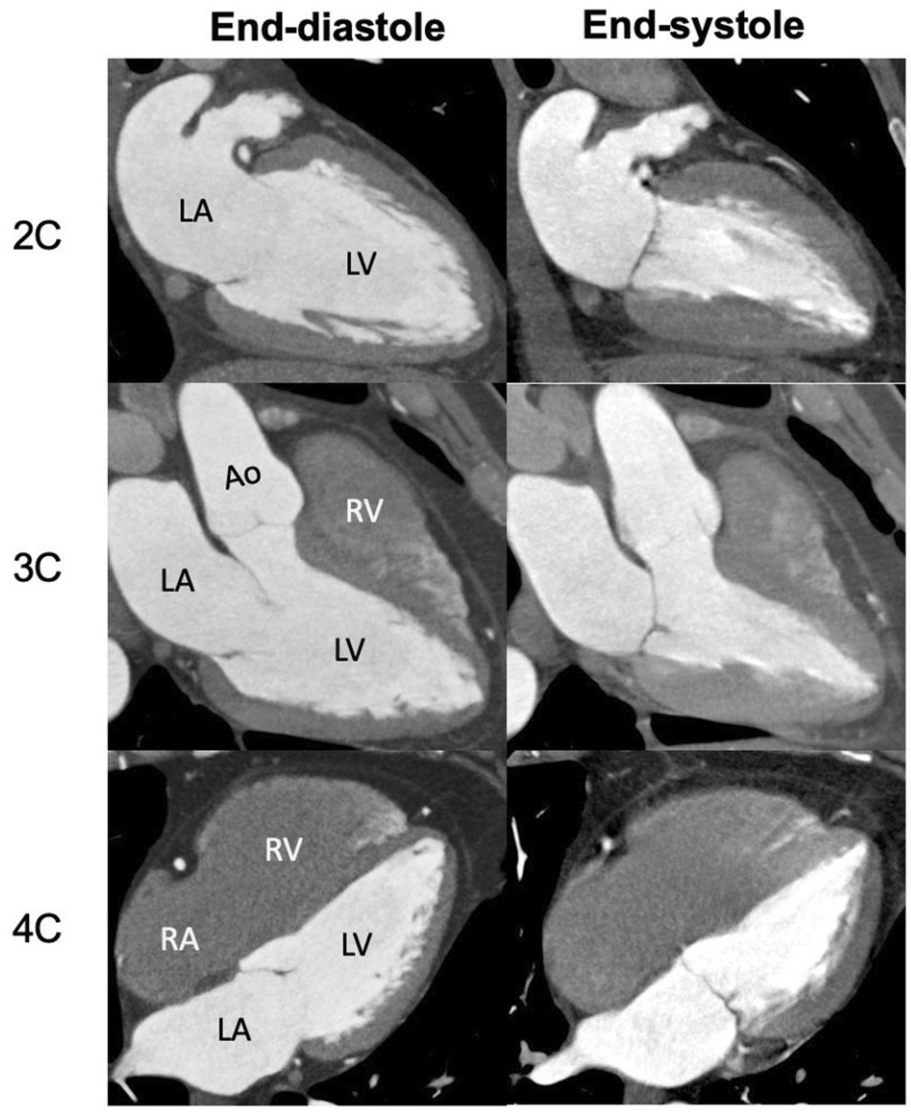

Figure 6 End-diastole and end-systole on cardiac computed tomography. All images are from Patient no. 2. These sequences were used to rule out left ventricular non-compaction. The end-diastolic non-compaction/compaction ratio was 0.3 in >2 segments of the apical and medial portions of the left ventricle; this does not meet the criteria for left ventricular non-compaction. The characteristic morphologic changes of saw-tooth cardiomyopathy are not visible in these planes. 2C, two-chamber; 3C, three-chamber; 4C, four-chamber.

There is no consensus that establishes cardiac CT diagnostic criteria for STC. To diagnose our patients, we combined previous morphologic descriptions[1,2,5–9] and ruled out left ventricular non-compaction (LVNC). For the latter, we used CT criteria for LVNC:[14–16] end-diastolic non-compaction/compaction ratio >2.3 in ≥2 myocardial segments with typical morphologic findings (trabeculations in medial and apical portions). Neither of our patients fulfilled the diagnostic criteria for LVNC, so it was ruled out.

Our review of the literature indicates that the prevalence of this disease is higher in males than in females. The distribution is not limited to any age group, and most patients have compromised ventricular function with low LVEF. There were no evident risk factors evident from the review since most patients did not have histories of cardiovascular disease. The most common symptom was shortness of breath followed by oppressive chest pain, although some patients were asymptomatic. However, because the reported population is so small no generalizations can be established: the cases studied shared similar phenotypic appearances and perhaps nothing else.

One of the greatest limitations in this country is the lack of economic resources that led the patients to decline CMR because of its high cost, arguing that they had already undergone cardiac CT. Nevertheless, the non-invasive studies performed do rule out ventricular hypertrophy, which is the most common presentation of sarcomeric cardiomyopathies. Another limitation to this study is that the pandemic has interrupted the follow-up of the patients, making it impossible to retrieve more useful data.

The underlying mechanisms of this disease are currently unknown; further molecular studies must be pursued to identify these

Table 1 Review of cases with saw-tooth cardiomyopathy

Authors	Country	Gender	Age	Symptoms	Comorbidities	LVEF	Mitral regurgitation	ECHO/CMR/Cardiac CT	Diastolic dysfunction	Systolic Dysfunction
Bailly and Vasile	France	Male	75 years	Transient ischaemic attack with monocular amaurosis	Hypertension, dyslipidaemia, obesity	57%	Yes	CMR: Crypts at the inter-ventricular septum and left ventricular inferior wall	No	No
Rafiq *et al.*	United Kingdom	Male	37 years	Chest pain, left bundle branch block	No	Not specified	No	ECHO: Hypertrophic crypts at the inter-ventricular septum CMR: Muscular bands in the inferoseptal region	No	No
De Pinho Cardoso *et al.*	Portugal	Male	1 month	Congestive heart failure	No	Not specified	No	ECHO and CMR: Left ventricular dilation and apical and septal hypokinesia. Numerous projections of apparently compacted myocardium originating in the LV inferior and lateral walls and on the left surface of the inter-ventricular septum	Not specified	Mild
Chenaghlou *et al.*	Iran	Male	32 years	Congestive heart failure	No	35% without treatment, 45% post-treatment	Yes	ECHO: Left ventricular enlargement. CMR: Saw-tooth appearance of myocardium in basal inferolateral and basal to mid lateral segments. Normal right ventricular function (RVEF-48%). Cardiac CT: No coronary lesions, muscle bridge segment at the mid portion of LAD	Mild	Severe
Davlouros *et al.*	Greece	Male	2 months	No Systolic murmur grade I	No	47%	No	ECHO: Septal hypokinesia, LV apical aneurysm and saw-tooth morphology of the inferior, septal and lateral walls.	No	Mild

Continued

Table 1 *Continued*

Authors	Country	Gender	Age	Symptoms	Comorbidities	LVEF	Mitral regurgitation	ECHO/CMR/Cardiac CT	Diastolic dysfunction	Systolic Dysfunction
								CMR: Numerous cross bridging muscular projections in the LV inferior and lateral walls and inferior inter-ventricular septum		
Halioui *et al.*	Italy	Female	16 years	No	No	68%	Yes	CMR: Left ventricular dilation, ridges extending from the inferolateral to the inferior and inferoseptal wall.	Not specify	No
Espinola *et al.*	Mexico	Female	69	Chest pain, Congestive heart failure	HT, Diabetes	30%	No	Cardiac CT: Biventricular systolic dysfunction, no epicardial coronary lesions	No	Yes
Espinola *et al.*	Mexico	Male	48	No	History of myocardial infarction	63%	No	Cardiac CT: anteroseptal middle third hypokinesia, partial calcified plaque without significant coronary obstruction.	No	No

Cardiac CT, cardiac computed tomography; CMR, cardiac magnetic resonance; ECHO, echocardiography; HT, hypertension; LAD, left anterior descending; LV, left ventricle; LVEF, left ventricular ejection fraction; RVEF, right ventricular ejection fraction.

mechanisms. From this review of the literature and the findings of these cases, it is reasonable to assume that this is not a variant of LVNC, as it was stated in the first case reports more than 10 years ago. The morphologic findings are different and there is no evidence of 'non-compaction' in STC; the diagnostic criteria for LVNC were not met in any of our patients. Moreover, the genetic testing (whole-exome sequencing) included the genes described in the literature for LVNC and none of them revealed mutations. Image studies suggest that the crypts of STC involve the endocardium and mesocardium while the trabeculations of LVNC involve only the endocardium. These statements were based on mere hypotheses, and no definitive pathophysiological asseveration could be made from this type of study.

Conclusion

Due to the very low incidence of this condition, the substantial amount of information required to reach any conclusions regarding the prognosis of these patients is lacking. Saw-tooth cardiomyopathy should be suspected in patients with signs and symptoms of heart failure without apparent aetiology although it can be an asymptomatic disease. A review of the current literature on this disease is included here, but the small number of reports suggests that this is a highly underdiagnosed condition that warrants further exploration. Non-invasive imaging studies proved to be essential in the diagnostic assessment of these patients. Cardiac CT was the key imaging study to establish the diagnosis of STC. This is the first published case series using cardiac CT, and it broadens the diagnostic tools available for these patients. Decreased global longitudinal strain could be a subtle marker for early STC and an indication for CMR or cardiac CT for a more accurate evaluation. More studies focusing on this parameter are required to reach a conclusion.

Lead author biography

Joaquin Berarducci was born in Buenos Aires Argentina, studied medicine in Mexico City, currently finishing my year of social service. Interests in internal medicine, nephrology, and cardiology.

Supplementary material

Supplementary material is available at *European Heart Journal - Case Reports* online.

Slide sets: A fully edited slide set detailing these cases and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written consent for submission and publication of this case series including images and associated text has been obtained from both patient's families in line with COPE guidance.

Conflict of interest: None declared.

Funding: None declared.

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