Holes in the heart: an atlas of intracardiac injuries following penetrating trauma

Darshan Reddy* and David J.J. Muckartb

a Department of Cardiothoracic Surgery, University of KwaZulu Natal, Inkosi Albert Luthuli Central Hospital, Durban, South Africa
b Trauma Unit and Trauma Intensive Care, Inkosi Albert Luthuli Central Hospital, Durban, South Africa

* Corresponding author. Department of Cardiothoracic Surgery, University of KwaZulu Natal, Inkosi Albert Luthuli Central Hospital, Private Bag X03, Mayville, Durban 4058, South Africa. Tel: +27-0312401000; fax: +27-0312402113; e-mail: darshanredd@ialch.co.za (D. Reddy).

Received 30 October 2013; received in revised form 11 February 2014; accepted 25 February 2014

Abstract

OBJECTIVES: The extraordinarily high rate of penetrating heart injuries in South Africa provides a substantial denominator from which we derive a subset of patients with intracardiac lesions as a result of these injuries. The surgical literature, which consists largely of case reports and case series, describing various patterns of injury is dated and a review of management in the era of modern imaging and surgical techniques is warranted.

METHODS: A retrospective observational chart review of all patients with intracardiac injuries following penetrating trauma who were referred to the Department of Cardiothoracic Surgery at Inkosi Albert Luthuli Central Hospital in Durban, South Africa, during the 10-year period between July 2003 and July 2013 was performed. The spectrum of pathology encountered included ventricular septal defects, valve apparatus lacerations, intracardiac fistulae, ventricular aneurysms and retained intracardiac missiles.

RESULTS: Of the 17 patients, 10 required operative repair of the intracardiac lesions using cardiopulmonary bypass, with no early mortality noted. Seven patients were treated non-operatively, for reasons that varied from insignificant haemodynamic shunts to advanced human immunodeficiency virus (HIV) infection. The in-hospital mortality in this group consisted of 1 patient, who was moribund at presentation.

CONCLUSIONS: The referral of patients for the repair of intracardiac injuries following penetrating cardiac trauma is often delayed. Symptoms of cardiac failure should be optimized medically prior to undertaking definitive surgical repair, thereby also allowing for detailed preoperative imaging to guide appropriate intervention. Utilizing standard principles of intracardiac shunt repair, as well as contemporary valve repair techniques, favourable surgical outcomes may be reproduced. Percutaneous catheter device techniques may prove useful in patients deemed unsuitable for surgical repair, such as patients with sternal wound sepsis.

Keywords: Trauma (penetrating) • Echocardiography • Septal defects • Heart valves • Ventricular aneurysms

INTRODUCTION

While the surgical and trauma literature abounds with reports of penetrating cardiac injuries, the body of knowledge regarding intracardiac lesions resulting from these injuries consists of a largely dated collection of case reports and small case series. This contribution, a retrospective institutional review from a trauma epicentre, represents a contemporary view of the subject, focusing on preoperative imaging and surgical repair techniques.

PATIENTS AND METHODS

The Department of Cardiothoracic Surgery at Inkosi Albert Luthuli Central Hospital in Durban, South Africa, serves as the sole provider of cardiac surgical care for the province of KwaZulu Natal and the Eastern seaboard of South Africa, serving an estimated population of 14 million people. The case records of all patients with intracardiac lesions resulting from penetrating trauma presenting to the department between July 2003 and July 2013 were reviewed. Data were gathered from electronic patient records (including demographics), computerized imaging undertaken [plain chest radiography, echocardiography, computed tomography angiography (CTA) and conventional catheter angiography (CCA)] and intraoperative photographic images.

The indications for surgery of intracardiac shunts and valve apparatus injuries included symptoms related to the haemodynamic abnormality (congestive cardiac failure, failure to wean from ventilation and persistent hypoxemia) or the presence of a ventricular aneurysm with potential for rupture. All patients underwent preoperative clinical cardiological review and transthoracic echocardiography (TEE). CTA was used to further delineate ventricular aneurysms and retained intracardiac foreign bodies, whereas CCA was used to obtain haemodynamic, oximetry and angiography data in patients with intracardiac shunts and fistulae to estimate the shunt fraction and localize lesions. Intraoperative transoesophageal echocardiography (TEE) was used to evaluate repairs when available. Definitive repairs were undertaken via median sternotomy, employing conventional techniques of cardiopulmonary bypass. Repair techniques utilized included ventricular septal defect (VSD) closure; aortic, mitral, tricuspid and pulmonary valve repair;
intracardiac fistulae repair and ventricular aneurysm repair. Postoperative intensive care was undertaken in the cardiothoracic surgical intensive care unit (ICU), with follow-up undertaken jointly by the Departments of Cardiothoracic Surgery and Cardiology. Outcomes measured included early mortality and morbidity (including reoperation). The lack of follow-up data limited the consistent measurement of late outcomes.

This study was approved by the Biomedical Ethics Review Committee at the University of KwaZulu-Natal (BE303/12).

RESULTS

Over the study period, a total of 17 patients (16 males) with documented intracardiac injuries following penetrating thoracic trauma were referred to our institution. The age at presentation ranged from 13 to 52 years, and all patients were initially treated at a local health-care facility, where the primary surgical care included tube thoracostomy for the treatment of a haemothorax in 6 patients, emergency sternotomy or thoracotomy for the relief of cardiac tamponade in 3 patients and pericardial drainage in 2 patients. Upon arrival at our institution, all patients were reviewed by a cardiologist and underwent TTE imaging, with CTA and CCA used selectively as outlined above in the study methods. All patients in congestive cardiac failure underwent a period of in-hospital diuresis prior to definitive surgery, to optimize their condition at surgery and reduce the duration of the postoperative ICU course. Owing to the heterogeneous patient population and injury pattern, details of the 17 cases are tabulated, with definitive management classified as operative and non-operative in Tables 1 and 2, respectively.

In the group that underwent surgical correction, 5 of the 10 patients presented with haemodynamically significant VSDs, of which 3 were associated with mitral or tricuspid valve lesions (Fig. 1). These defects were repaired on cardiopulmonary bypass via the tricuspid valve, using various repair techniques appropriate to the configuration of the defect. Circular defects were closed with a double velour Dacron patch and interrupted pledged sutures (Fig. 2), whereas linear defects were closed using a direct suture technique buttressed with teflon strips or felt pledgets. None of the patients developed heart block following VSD closure, while 1 patient had a residual VSD shunt necessitating reoperation (described later). Two intracardiac fistulae were encountered; an aortic root to right ventricular outflow tract fistula associated with aortic and mitral valve injuries, and a right main pulmonary artery to left atrial fistula. Fistulae were closed at both ends using a direct polypropylene suture technique, with felt pledgets for additional support. Two patients presented with false aneurysms of the left ventricle; at surgical exploration, one had resolved (Fig. 3) while the other required repair by plication of the communication with the left ventricle using teflon strips (Fig. 4). One patient presented 33 years after injury with an aneurysm of the right ventricular outflow tract involving the pulmonary valve, which was regurgitant due to distortion and leaflet perforation. The aneurysm neck was plicated, and the pulmonary valve leaflets reconstructed with bovine pericardium and commissures resuspended. Three patients required more than one surgical procedure. Patient 4 presented with a VSD and underwent emergency surgical repair due to associated cardiac tamponade. He required reoperation 5 months later for a residual VSD shunt and the presence of severe mitral regurgitation, which was not detected prior to the first surgery. The VSD repair, previously undertaken using interrupted pledged sutures, was reinforced with felt strips. Following an unsuccessful attempt at mitral valve repair, the valve was replaced using a 27/29 On-X mechanical prosthesis (On-X Life Technologies, Inc., Austin, TX, USA). This patient returned in acute pulmonary oedema 17 months later with a thrombosed mechanical prosthesis, necessitating emergency reoperation. Patient 5 presented with a wooden spike penetrating the pericardium and traversing the right pulmonary artery and left atrium (Fig. 5). The spike was extracted via right thoracotomy, followed by further imaging which illustrated a right pulmonary artery to left atrial fistula. This was repaired via median thoracotomy 3 days later. Patient 6 underwent surgical repair of the aorto-right ventricular fistula, with concomitant aortic and mitral valve repair using a direct suture closure of the perforations (Fig. 6). Early postoperative echo demonstrated residual moderate mitral regurgitation, which progressed to severe regurgitation necessitating mitral valve repair 11 months later. At reoperation, the residual anterior mitral leaflet perforation was closed using a bovine pericardial patch, and the repair secured with a Cosgrove–Edwards mitral valve annuloplasty ring (Edwards Lifesciences Corp., Irvine, CA, USA). No residual mitral regurgitation was noted.

No early mortality was noted in patients undergoing operative correction. One patient was lost to follow-up after discharge, and the remaining patients were asymptomatic with satisfactory echocardiographic findings at their last hospital visit, which varied from 1 to 14 months post-discharge.

In the group of patients managed non-surgically, 2 patients had undergone prior emergency median sternotomy. Patient 12 presented to his primary care facility in cardiac tamponade, necessitating emergency median sternotomy and cardiography of a right ventricular wound, and upon referral to our institution had anuric renal failure and hypoxic brain injury. Echocardiography confirmed a muscular VSD, with severe mitral regurgitation and tricuspid regurgitation, and he demised within 48 h of admission to our institution. Patient 16 similarly underwent emergency sternotomy at his local health-care facility for cardiac tamponade and repair of a right ventricular injury, complicated by bleeding from an intercostal artery necessitating reoperation. The sternal wound subsequently dehisced 7 days later, with deep sepsis evident. Following admission to our centre, the wound was treated by sternal debridement and application of a vacuum-assisted closure device (KCI, Inc., San Antonio, TX, USA). Echocardiography illustrated a restrictive muscular VSD, which was deemed haemodynamically insignificant. The sternal wound improved and at the last follow-up the patient was systemically well with chronic osteitis of the sternum. Patients 11 and 17 presented with restrictive VSDs and advanced human immunodeficiency virus (HIV) infection, with acquired immunodeficiency syndrome (AIDS) defining criteria of a CD4 count of <200. As both these patients were highly active antiretroviral therapy (HAART) naive with no significant haemodynamic abnormality, surgery was not undertaken, and both patients were treated with diuretics and referred for HAART initiation. At the last follow-up, both patients were well, with Patient 11 having achieved suppression of the viral load to lower-than-detectable limits. Patients 13 and 15 required no surgical intervention due to isolated moderate-to-severe tricuspid regurgitation and a restrictive VSD, respectively, and both received diuretic therapy with clinical and echocardiographic surveillance.

In both the operative and the non-operative groups, although follow-up data were sparse, all patients who did return for review were well and required no surgical intervention.
<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/ gender</th>
<th>Mode of injury</th>
<th>Primary intervention</th>
<th>Presentation</th>
<th>Investigations</th>
<th>Diagnosis</th>
<th>Definitive management</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22 M</td>
<td>Precordial stab</td>
<td>None</td>
<td>7 days post-injury Pansystolic murmur</td>
<td>CXR TTE</td>
<td>Inlet VSD, severe TR due to transected septal leaflet chordae</td>
<td>VSD closure and TV repair</td>
<td>Asymptomatic at the follow-up 1 month later</td>
</tr>
<tr>
<td>2</td>
<td>19 M</td>
<td>Precordial stab</td>
<td>Pericardiocentesis. Tube thoracotomy</td>
<td>3 weeks post-injury Cardiac failure</td>
<td>CXR TTE</td>
<td>Outlet VSD, severe eccentric MR due to chordal rupture</td>
<td>VSD closure and MV repair</td>
<td>Asymptomatic at the follow-up 3 months later</td>
</tr>
<tr>
<td>3</td>
<td>28 M</td>
<td>Precordial stab</td>
<td>Left anterolateral thoracotomy and RV injury repair</td>
<td>3 weeks post-injury Cardiac failure</td>
<td>CXR TTE</td>
<td>Mid-muscular VSD</td>
<td>VSD closure</td>
<td>Asymptomatic on discharge Lost to follow-up</td>
</tr>
<tr>
<td>4</td>
<td>16 M</td>
<td>Precordial stab</td>
<td>None</td>
<td>6 days post-injury Incipient tamponade</td>
<td>CXR TTE</td>
<td>Mid-muscular VSD, cardiac tamponade</td>
<td>VSD closure</td>
<td>Closure of residual VSD and MVR 5 months later Thrombosed prosthesis—emergency redo MVR 17 months later Well at the last follow-up 1 month later Asymptomatic at the last follow-up 1 year later</td>
</tr>
<tr>
<td>5</td>
<td>13 M</td>
<td>Right supraclavicular impaling injury with wooden rod</td>
<td>None</td>
<td>On the day of injury Odynophagia, elevated central venous pressure, persistent hypoxemia</td>
<td>CXR Contrast swallow CT scan TTE</td>
<td>RPA to LA fistula, LA thrombus</td>
<td>Right thoracotomy and removal of wooden rod 3 days later—median sternotomy and repair of RPA to LA fistula</td>
<td>Persistent severe MR—redo MV repair 11 months later Asymptomatic at the follow-up 9 months later</td>
</tr>
<tr>
<td>6</td>
<td>17 M</td>
<td>Precordial stab</td>
<td>None</td>
<td>3 weeks post-injury Cardiac failure</td>
<td>CXR TTE CCA</td>
<td>Aorto-RV fistula with severe AR and severe MR</td>
<td>Closure of aorto-RV fistula, aortic and mitral valve repair</td>
<td>Persistent severe MR—redo MV repair 11 months later Asymptomatic at the follow-up 9 months later</td>
</tr>
<tr>
<td>7</td>
<td>20 M</td>
<td>Precordial stab</td>
<td>Tube thoracotomy</td>
<td>4 weeks post-injury Cardiac failure HIV-positive CD4 900</td>
<td>CXR TTE</td>
<td>Outlet VSD, severe TR due to septal leaflet laceration</td>
<td>VSD closure and tricuspid valve repair</td>
<td>Asymptomatic at the follow-up 14 months later</td>
</tr>
<tr>
<td>8</td>
<td>25 M</td>
<td>Precordial stab</td>
<td>None</td>
<td>2 weeks post-injury Cardiac failure</td>
<td>CXR CT scan TTE</td>
<td>LV false aneurysm, moderate MR</td>
<td>Median sternotomy 4 weeks post-injury—spontaneous resolution of aneurysm Plication of LV false aneurysm</td>
<td>Asymptomatic at the follow-up 14 months later Moderate MR</td>
</tr>
<tr>
<td>9</td>
<td>17 M</td>
<td>Precordial stab</td>
<td>Tube thoracotomy</td>
<td>8 weeks post-injury Cardiac failure</td>
<td>CXR TTE CT scan</td>
<td>LV false aneurysm</td>
<td>VSD closure and TV repair</td>
<td>Asymptomatic at the last follow-up 6 weeks later</td>
</tr>
<tr>
<td>10</td>
<td>52 M</td>
<td>Precordial and abdominal stabs</td>
<td>Laparotomy</td>
<td>33 years post-injury Cardiac failure</td>
<td>CXR TTE CT scan</td>
<td>False aneurysm of RVOT involving PV annulus with severe PR</td>
<td>RVOT aneurysm repair, PV leaflet reconstruction</td>
<td>Asymptomatic at the follow-up 6 weeks later</td>
</tr>
</tbody>
</table>

AR: aortic regurgitation; CCA: conventional catheter angiography; CXR: plain chest radiograph; HAART: highly active antiretroviral therapy; HIV: human immunodeficiency virus; LA: left atrium; LV: left ventricular; MR: mitral regurgitation; MV: mitral valve; MVR: mitral valve replacement; PR: pulmonary regurgitation; PV: pulmonary valve; RPA: right pulmonary artery; RV: right ventricle; RVOT: right ventricular outflow tract; TR: tricuspid regurgitation; TTE: transthoracic echocardiogram; VSD: ventricular septal defect; TV: tricuspid valve.
Table 2: Non-operative cases

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/Gender</th>
<th>Mode of injury</th>
<th>Primary intervention</th>
<th>Presentation</th>
<th>Investigations</th>
<th>Diagnosis</th>
<th>Definitive management</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>31 F</td>
<td>Precordial stab</td>
<td>None</td>
<td>8 months post-injury in cardiac failure. HIV-positive CD4 211 (HAART naïve)</td>
<td>CXR TTE CCA</td>
<td>Restrictive outlet VSD</td>
<td>Medical therapy, HAART</td>
<td>Asymptomatic at the last follow-up 7 years later. Suppression of HIV VL to LDL</td>
</tr>
<tr>
<td>12</td>
<td>23 M</td>
<td>Precordial stab</td>
<td>Median sternotomy and repair of RV injury. Intraoperative cardiac arrest and coagulopathy</td>
<td>6 days post-injury with anuric renal failure and hypoxic brain injury. HIV-positive, CD4 unknown (HAART naïve)</td>
<td>CXR TTE</td>
<td>Muscular VSD, severe MR, severe TR</td>
<td>Supportive intensive care</td>
<td>Demised 8 days after initial injury</td>
</tr>
<tr>
<td>13</td>
<td>29 M</td>
<td>Precordial stab</td>
<td>Tube thoracostomy</td>
<td>17 days post-injury in cardiac failure</td>
<td>CXR TTE</td>
<td>Moderate-to-severe TR due to tear in anterior leaflet</td>
<td>Medical therapy</td>
<td>Asymptomatic at the follow-up 2 months later</td>
</tr>
<tr>
<td>14</td>
<td>40 M</td>
<td>Precordial stab</td>
<td>Tube thoracostomy</td>
<td>1 day post-injury Asymptomatic</td>
<td>CXR TTE CT scan</td>
<td>Bullet shrapnel in ventricular septum on CT</td>
<td>Medical therapy</td>
<td>Asymptomatic at discharge Lost to follow-up</td>
</tr>
<tr>
<td>15</td>
<td>34 M</td>
<td>Precordial stab</td>
<td>Tube thoracostomy</td>
<td>1 week post-injury Asymptomatic with murmur</td>
<td>CXR TTE</td>
<td>Restrictive outlet VSD</td>
<td>Medical therapy</td>
<td>Asymptomatic at the follow-up 1 month later</td>
</tr>
<tr>
<td>16</td>
<td>26 M</td>
<td>Precordial stab</td>
<td>Median sternotomy and repair of RV injury. Reopened for bleeding</td>
<td>8 days post-injury with sternal wound dehiscence and sepsis</td>
<td>CXR TTE</td>
<td>Restrictive muscular VSD</td>
<td>Sternal wound debridement. Vacuum dressing</td>
<td>Chronic sternal osteitis with draining sinus Systemically well at the follow-up 8 months later</td>
</tr>
<tr>
<td>17</td>
<td>23 M</td>
<td>Precordial stab</td>
<td>None</td>
<td>5 years later with pansystolic murmur CD4 80 (HAART naïve)</td>
<td>CXR TTE</td>
<td>Restrictive outlet VSD, moderate–severe MR</td>
<td>Medical therapy, HAART</td>
<td>Asymptomatic at the last follow-up 4 months later</td>
</tr>
</tbody>
</table>

CCA: conventional catheter angiography; CXR: plain chest radiograph; HAART: highly active antiretroviral therapy; HIV: human immunodeficiency virus; LDL: lower than detectable limits; TTE: transthoracic echocardiogram; VL: viral load; VSD: ventricular septal defect.
DISCUSSION

The high prevalence of penetrating cardiac injuries in the South African context has been well documented. In a 3-year review of 1198 cases of penetrating cardiac trauma in Durban, 94% of victims were direct mortuary transfers, while 50% of patients who reached hospital died [1]. Cardiac gunshot wounds were uniformly fatal in this series, reflecting the observations made by others in the region [2]. While some trauma centres report the use median sternotomy as the preferred approach to the repair of cardiac wounds in the emergency context [3], others undertake left anterolateral thoracotomy and median sternotomy with equal frequency [2] to access these injuries. Median sternotomy undoubtedly provides optimal exposure of the heart and great vessels, yet the risk of sternal wound sepsis may complicate the further treatment of intracardiac injuries. It has been suggested that the absence of a pleural breech may improve survival following a penetrating cardiac injury, favouring cardiac tamponade over exsanguination [1].

While basic echocardiography facilities are available at local hospitals, the use of echo screening following penetrating cardiac trauma is inconsistent in the local environment. Mattox et al. [4] were among the earliest to advocate the use of two-dimensional echo as a tool to investigate symptomatic patients after cardiac injury. The need for routine repeat outpatient echocardiography following a normal discharge echo has been debated [4, 5], with the poor follow-up and low yield cited as limiting the feasibility of this approach [3, 6]. Nevertheless, echocardiogram undertaken early after injury may miss intracardiac lesions due to the presence of cardiac oedema, occluding coagulin plugs and non-dilated cardiac chambers [7–10]. In the weeks following the injury, the fibrous retraction of defect margins and resultant cardiac chamber enlargement unmask lesions previously not evident echocardiographically [11], and likely correlate with the appearance of gross clinical symptoms.

Preoperative TEE is an attractive option when TTE is hindered by the presence of extensive surgical emphysema, pneumothoraces...
and the presence of bulky thoracotomy wound dressings. The concomitant use of TEE improves the detection of valve leaflet perforations coexisting with traumatic VSDs [12]. We consider intraoperative TEE mandatory, as surgery is generally undertaken under elective conditions and experienced cardiology expertise is available to interpret the study.

CTA proved especially useful in the evaluation of the left ventricular aneurysms encountered, and for the localization of missile fragments in the heart. CTA may also delineate associated lung or vascular injuries.

Conventional catheter studies are used in select cases when the anatomical localization of the shunt on echo was suboptimal (usually VSDs), or when quantification of the shunt fraction was required. The percutaneous transcatheter closure of posttraumatic VSDs has been described in the literature [13, 14], noting the difficulties associated with VSD device sizing due to the ill-defined defect margins early after injury, and the risk of perforation and haemolysis associated with use of the larger atrial septal defect closure devices [14]. In our series, haemodynamically significant VSDs frequently coexisted with valve injuries, favouring surgical closure and concomitant valve repair. In contrast to VSDs following blunt chest trauma, penetrating cardiac trauma is usually an

Figure 4: (A) A coronal CTA image illustrates a false aneurysm arising from the anterolateral left ventricular free wall, following a cardiac stab injury. (B) The reconstructed CTA image confirms the large calibre of the aneurysm neck, and demonstrates its relation to the anterior interventricular groove and left anterior descending artery. This was treated by surgical plication of the aneurysm neck. CTA: computed tomography angiography.

Figure 5: (A) A coronal CTA image demonstrates the impaling object – a wooden rod – transfixing the right pulmonary artery and the left atrium. (B) CTA undertaken after extraction of the rod defines the presence of a fistula between the right pulmonary artery and left atrium. CTA: computed tomography angiography.
isolated injury and thus cardiopulmonary bypass and heparinization is generally uneventful. In this group, percutaneous catheter device closure may be a suitable option in patients not amenable to surgical closure, such as in the presence of sternal wound sepsis.

This review reflects the spectrum of intracardiac injuries previously classified by Symbas as shunts, valvular lesions, aneurysms and retained foreign bodies [15]. Posttraumatic VSDs are the commonest lesion encountered in most series [10, 16, 17], while aorto-right ventricular fistulae (with or without aortic valve injury) are also frequently identified [18–21]. Posttraumatic LV aneurysms following penetrating trauma have been described [22], as have isolated valve injuries [8].

Traditional indications for closure of traumatic VSDs include persistent symptoms despite optimal medical therapy, a pulmonary-to-systemic flow ratio of >2 and elevated right ventricular and pulmonary artery pressures, and an associated valve injury [16]. The propensity for small posttraumatic muscular VSDs to close spontaneously has been well documented [10, 13].

In contrast, the spontaneous closure of aorto-right ventricular fistulae is uncommon due to the location of the injury in the membranous ventricular septum [18]. Furthermore, the frequent association of this injury with aortic valve disruption often mandates surgical repair [19].

The presence of a left ventricular aneurysm following penetrating cardiac trauma is considered an indication for surgical intervention due to the risk of rupture. Our series contained two examples, with spontaneous resolution noted in the first, while the second required repair. Factors predicting the spontaneous resolution of these aneurysms have not been described following penetrating trauma and are likely to be related to the calibre of the ventricular breach.

The indications for extraction of retained missile fragments in the heart include shrapnel in a cardiac chamber (with the potential for systemic or pulmonary embolization), or missiles in the pericardial space resulting in features of pericarditis [23]. The fragment retained in our asymptomatic patient was embedded within the interventricular septum, with surgical interference deemed hazardous.

The primary treatment of penetrating cardiac wounds—for cardiac tamponade or haemorrhage—should be dealt with independently of the treatment of coexisting intracardiac injuries, generally by a trauma surgical service [24]. It is recommended that, following initial resuscitative surgery, stabilization and the requisite cardiac imaging be obtained prior to definitive intracardiac repair by a cardiac surgical service [19, 21]. The absence of early clinical symptoms and high rate of missed diagnosis on early echocardiogram support this approach [21]. Furthermore, the evolving pathology of muscular defects may result in the spontaneous closure of VSDs and left ventricular aneurysms, while persisting lesions develop fibrous margins, thereby enhancing the integrity of subsequent surgical repair. Premature repair in Patient 4 may account for the need for reoperation, as significant mitral regurgitation was not observed on the early echocardiogram, and secure closure of the muscular VSD was likely compromised by poor tissue quality. Patient 8 emphasizes the importance of repeat imaging during the surveillance period prior to exploration, in order to detect spontaneous resolution and therefore avoid unnecessary exploration.

The technical aspects of posttraumatic VSD closure have been established previously [16], including the use of prosthetic patches to close defects and felt strips to reinforce ventricular septum suture lines, essentially immobilizing the segment of compromised muscle. While right ventriculotomy has been traditionally used to close posttraumatic VSDs, experience with congenital defects
makes right atriectomy the current preferred approach. In contrast to congenital muscular VSDs, which are often obscured by ventricular trabeculae, posttraumatic muscular VSDs are readily visualized due to the fibrous rim and transected overlying trabeculae.

The repair of intracardiac fistulae includes opening both chambers/vessels involved and securing the repair at both ends, using a direct suture closure technique with polypropylene reinforced with felt pledgets [19].

In treating valve injuries, intraoperative echocardiographic imaging and contemporary techniques of valve repair compel us to attempt repair when feasible. Patient 4 emphasizes the unsatisfactory alternative of implating a mechanical valve in a young, previously healthy patient with a high-risk lifestyle who does not consider himself chronically ill and is therefore non-compliant with anticoagulation. Direct suture closure of valve leaflet perforations may yield satisfactory results, particularly with right-sided valve injuries. In delayed repair when perforation edges are distracted, or in cases of tissue loss, the use of a patch closure technique is more durable and is recommended for left-sided perforations. With mitral valve repairs, transected chordae may be reimplanted or neochordae created, while use of an annuloplasty ring may improve durability.

Left ventricular false aneurysms are treated using traditional principles of aneurysm repair—by obliterating the communication with the ventricle and excising the aneurysmal wall. The aneurysm neck may be in close proximity to the left anterior descending artery that may be injured during plication, especially if obscured by adhesions or inflammation following haemopericardium.

In dealing with impaling injuries, the removal of the retained object prior to further imaging may be useful to visualize intracardiac shunts. The two-stage approach utilized in treating Patient 5 appears to confer no additional morbidity [25].

In summary, intracardiac injuries following penetrating trauma may be dealt with semi-electively in most cases, allowing for direct suture closure technique with polypropylene reinforced with felt pledgets [19].

In our experience, percutaneous catheter techniques have a limited role at present due to the common coexistence of valve injuries associated with VSDs, necessitating surgical repair.

ACKNOWLEDGEMENTS

The authors thank the medical staff and administration at the Inkosi Albert Luthuli Central Hospital for their participation and permission to undertake this study.

Conflict of interest: none declared.

REFERENCES