

# Artificial Neochordae for Tricuspid Valve Repair in Adults: A Review

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## Abstract

Expanded polytetrafluoroethylene (ePTFE) neochordae are predominantly used for mitral valve repair (MVR), while the frequency of their employment in tricuspid valve surgery is not well assessed. We have performed a review of the available literature to verify incidence, indications, techniques, and outcomes of the use of artificial neochordae in a variety of tricuspid valve pathologies. We found a total of 57 articles reporting the use of ePTFE sutures in patients in whom tricuspid valve repair (TVr) was performed. From such articles, adequate information on the basic disease, surgical techniques, and outcomes could be obtained in 45 patients in whom the indication to the use of neochordae was posttraumatic tricuspid regurgitation ( $n=24$ ), infective endocarditis ( $n=8$ ), congenital valvular disease ( $n=6$ ), valve injury during cardiac neoplasm excision ( $n=3$ ) or following repeated endomyocardial biopsies after heart transplantation ( $n=3$ ), and tricuspid valve prolapse ( $n=1$ ). Implant techniques generally replicated those currently employed for MVR using artificial neochordae. There were no reported hospital deaths with stability of repair in most cases at follow-up controls. TVr using ePTFE neochordae has been reported so far in a limited number of patients. Nevertheless, it appears a feasible and reproducible technique to be added routinely to the surgical armamentarium during TVr.

## Keywords

- ▶ tricuspid valve repair
- ▶ artificial neochordae
- ▶ expanded polytetrafluoroethylene

## Introduction

The feasibility of using expanded polytetrafluoroethylene (ePTFE) neochordae (Gore-Tex, WL Gore and Associates, Inc., Flagstaff, Arizona, United States) for mitral valve repair (MVR) has been demonstrated experimentally, favoring its introduction in the clinical setting, by the group of Albert Einstein College of Medicine in New York, United States, under the leadership of Robert WM Frater.<sup>1</sup> Subsequently, ePTFE neochordae have been used with increasing frequency, isolated or combined with other repair techniques, in MVR procedures. The excellent long-term results have demonstrated that this technique is reproducible and provides durable and

stable repairs becoming an almost essential tool in the surgical armamentarium in standard, mini-invasive or robotic MVR.<sup>2-4</sup>

However, despite their current widespread use for MVR, employment of ePTFE neochordae to correct tricuspid regurgitation (TR) has been much less frequently reported, most likely since tricuspid valve surgery is performed in the vast majority of patients for secondary TR disease that can be treated with annuloplasty only. Therefore, the present review aims to evaluate incidence, indications, techniques, and outcomes of tricuspid valve repair (TVr) using ePTFE neochordae.

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## Methods

We have performed a search to identify pertinent articles from Medline, PubMed, Google Scholar, and archives of CTSNet website journals, which included articles published starting from 1986, when clinical use of ePTFE neochordae was first reported.<sup>5</sup> All papers in the English literature were screened; for others, the English abstract was considered, when available, only if it reported adequate data. Meeting abstracts or discussions, videos, and textbook chapters were excluded as well as articles reporting case series where patients could not be clearly identified or from which scarce information could be obtained. Articles reporting the use of artificial chordae not obtained from ePTFE sutures or the use of ePTFE neochordae in the pediatric population ( $\leq 18$  years) were also not considered.

The literature search was performed using a selection of keywords, isolated or in combination, which included mainly the type of tricuspid valve pathology, use of ePTFE neochordae for TVR, and the early and late results of TVR using artificial neochordae.

For this study, approval by local ethical committees was not required as well as informed consent, since patient data were treated anonymously.

## Results

### Posttraumatic Tricuspid Regurgitation

#### Case Reports

We have found 24 articles reporting 25 patients with post-traumatic TR repaired with ePTFE neochordae<sup>6–29</sup> (→ **Table 1**). Only one article reported two patients,<sup>10</sup> while all others were single-case reports; 22 patients (88%) were males and 3 (12%) females with a mean age of 40 years (19–86 years). In most patients, TR was caused by close chest trauma during traffic accidents occurring 1 week to >40 years before diagnosis or operation. The surgical approach used a standard sternotomy in 10 cases,<sup>6–12,15,17,21</sup> a right anterolateral minithoracotomy in one<sup>16</sup> and using port-access method in one<sup>20</sup>; in the remaining cases, the approach was not available. A variable number of neochordae was implanted, generally from 2 to 6, and in almost all cases, they were attached to the anterior leaflet associated in one case to insertion on the posterior leaflet.<sup>14</sup> In one patient, ePTFE sutures were used to reattach the septal and in one the posterior papillary muscle<sup>9,20</sup>; in one case, TVR was performed using the loop technique.<sup>16</sup> The size of neochordae was mostly 4/0 to 5/0, and 6/0 only in one case.<sup>12</sup> In all cases, TVR was completed with an annuloplasty ring except in four in whom a de Vega annuloplasty was preferred.<sup>6,11,12,21</sup>

#### Patient Series

TVR for traumatic TR was reported by Maisano et al in 1986 in six patients.<sup>30</sup> In four of them, aged 18, 24, 30, and 30 years, 5/0 ePTFE neochordae were used. In all cases, rupture of the chordae to the anterior tricuspid leaflet was observed. Repair was completed with the creation of a double-orifice tricuspid

valve in one patient and with annuloplasty in three. A series of 13 patients undergoing surgical treatment for traumatic TR was reported by Ma et al.<sup>31</sup> All patients had TVR using a variety of techniques which included the use of autologous pericardium, leaflet plication, and de Vega or ring annuloplasty. In four of them, chordal replacement was performed with 5/0 ePTFE sutures. Zhang et al reported 10 patients with posttraumatic TR<sup>32</sup>; mean age was 49 years, all but one were males and the mean interval from trauma to treatment was 74 months. Among these, four underwent TVR using 4/0 and 5/0 ePTFE chordae to replace ruptured native chordae to the anterior leaflet associated with a ring annuloplasty.

### Tricuspid Valve Repair with Expanded Polytetrafluoroethylene Neochordae in Tricuspid Infective Endocarditis

#### Case Reports

→ **Table 2** summarizes nine cases of TR due to IE in whom TVR was achieved using ePTFE neochordae.<sup>33–41</sup> There were five males and four females, aged 19 to 77 years (mean, 40 years); pathological features consisted predominantly in vegetations of the anterior tricuspid leaflet causing leaflet perforation or destruction in two patients,<sup>34,41</sup> associated with a right ventricular abscess in another.<sup>36</sup> *Staphylococcus* was the most frequent responsible agent,<sup>33,35,36,40,41</sup> followed by *Pseudomonas* in two patients<sup>34,39</sup> and *Enterococcus*<sup>37</sup> and *Candida*<sup>34</sup> in one each. Repair consisted in patch reconstruction of tricuspid leaflets after generous debridement and vegetectomy, using autologous pericardium<sup>34–37</sup> and bovine<sup>39,41</sup> or equine<sup>40</sup> pericardium. Tricuspid annuloplasty was added to TVR in five cases, using a prosthetic ring in three<sup>38,39,41</sup> and a strip of autologous pericardium in other two.<sup>35,40</sup> The neochordae were generally attached to the reconstructed anterior tricuspid leaflet; their size was 4/0 and 5/0 but it was not always specified as the number of chords utilized.<sup>34,40</sup>

#### Patient Series

Dawood et al reported 56 patients with tricuspid IE in whom the use of ePTFE chordae was considered among various reconstructive strategies<sup>42</sup>; unfortunately, details on this particular aspect of TVR were not available. Hosseini et al described TVR for complex IE with periannular involvement in nine drug addicts, six males, and three females with a mean age of 28 years, in whom leaflet reconstruction with autologous untreated pericardium and ePTFE neochordae were used.<sup>43</sup> At a mean follow-up of 16 months, two patients were lost and two died, while among four survivors one had severe and five mild or moderate residual TR. Yong and colleagues reviewing the surgical management of tricuspid IE in the current era mentioned the possibility of using ePTFE neochordae for TVR in this setting.<sup>44</sup> Recently, Charkiewicz-Szeremeta et al reported seven patients in whom the tricuspid valve was excised and replaced with a cylinder of autologous or bovine pericardium secured to the heads of the posterior and septal papillary muscles using 5/0 Gore-Tex sutures.<sup>45</sup> Early failure of the repair occurred in three cases due to cylinder degeneration but not to neochordae malfunction.

**Table 1** Artificial neochordae for posttraumatic tricuspid regurgitation

Author, year	Age, sex	Cause and timing	Surgical approach	Operation	F-U
Sugita et al 1997 <sup>6</sup>	70,F	Car crash, 6 y	MS	Neochordae (4/0) to ATL, de Vega TAP	3 mo
Hachiro et al 2001 <sup>7</sup>	34,M	Blunt chest trauma, 13 y	MS	2 neochordae (5/0) to ATL, TAP	NA
Baufreton et al 2004 <sup>8</sup>	29,M	Motorcycle accident, 10 y		Neochordae (4/0) to ATL, TAP	6 mo
Knobloch et al 2004 <sup>9</sup>	29,F	Horse kick, 1 y	MS	Neochordae to SPM, TAP	NA
Fujiwara et al 2005 <sup>10</sup>	29,M 52,M	Motorcycle accident, 11 y Baseball bat chest hit, >40 y	MS MS	4 neochordae (5/0) to ATL, TAP 6 neochordae to ATL, TAP	4 y 2 y
Tatebe et al 2005 <sup>11</sup>	22,M	Horse kick, 2 y	MS	2 neochordae (5/0) to ATL, de Vega TAP	6 mo
Turkoz et al 2007 <sup>12</sup>	27,M	Car crash, 4 y	MS	6 neochordae (6/0) to ATL, de Vega TAP	11 mo
Khurana et al 2009 <sup>13</sup>	42,M	Motor vehicle accident, 3 wk	NA	Neochordae, TAP	6 mo
Nishimura et al 2010 <sup>14</sup>	19,M	Motor vehicle accident, 3 mo	NA	Neochordae to ATL, PTL (5/0), TAP	NA
Emmert et al 2011 <sup>15</sup>	29,M	Blunt chest trauma, 11 y	MS	6 neochordae to ATL, TAP	3 mo
Furukawa et al 2011 <sup>16</sup>	20,M	Traffic accident, 4 mo	RALM	Neochordae to ATL (loop technique), TAP	2 y
Abbasi et al 2012 <sup>17</sup>	28,M	Traffic accident, 1 y	MS	2 neochordae (5/0) to ATL, TAP	NA
Thekkudan et al 2012 <sup>18</sup>	58,M	Motorcycle crash, 9 mo	NA	Neochordae (5/0) to ATL, TAP	2 y
Avegliano et al 2014 <sup>19</sup>	39,M	Motor vehicle accident, 3 y	NA	2 neochordae to ATL, TAP	NA
Óz et al 2024 <sup>20</sup>	52,M	Fall from horse, 6 mo	PA	Neochordae to PPM, TAP	NA
Hirao et al 2016 <sup>21</sup>	45,F	Motor vehicle accident, 16 y	MS	4 neochordae (5/0), ATL, de Vega TAP	NA
Karaca et al 2016 <sup>22</sup>	19,M	Motorbike accident, 1 wk	NA	Neochordae to ATL, TAP	NA
Cheng et al 2017 <sup>23</sup>	57,M	Accidental chest trauma, 2 mo	NA	Neochordae to ATL, TAP	3 mo
Konstantinidou and Moat 2017 <sup>24</sup>	26,M	Blunt chest trauma, 1 y	NA	Neochordae, <sup>a</sup> TAP	2 y
Benhassen and Smerup 2018 <sup>25</sup>	44,M	Chest trauma, 28 y	NA	Neochordae (5/0) to ATL, TAP	2 y
Hatani et al 2018 <sup>26</sup>	86,M	Accidental chest trauma, 2 d	NA	Neochordae to ATL, TAP, PFO closure	NA
Moradian and Ghiasi 2021 <sup>27</sup>	26,M	Blunt chest trauma, 15 y	NA	Neochordae to ATL, TAP	NA
Shiraiwa et al 2018 <sup>28</sup>	62,M	Motorbike accident, 45 y	NA	4 neochordae (5/0) to ATL, TAP, Maze procedure	NA
Eranksi et al 2022 <sup>29</sup>	62,M	Car crash, 1 mo	NA	2 neochordae to ATL, TAP	NA

Abbreviations: ATL, anterior tricuspid leaflet; ePTFE, expanded polytetrafluoroethylene; F-U, follow-up; MS, median sternotomy; NA, not available; PA, port access; PFO, patent foramen ovale; PPM, posterior papillary muscle; PTL, posterior tricuspid leaflet; RALM, right antero-lateral minithoracotomy; SPM, septal papillary muscle; TAP, tricuspid annuloplasty.

<sup>a</sup>In this case, the tricuspid valve was repaired with the use of a CardioCel patch (LeMaitre Vascular, Inc. Burlington, Massachusetts, United States), and the e-PTFE neochordae were attached to the patch.

### Repair of Tricuspid Regurgitation with Expanded Polytetrafluoroethylene Neochordae in Adult Congenital Heart Disease

#### Case Reports

ePTFE neochordae were used in six adult patients, four females and two males aged 23 to 79 years, with congenital heart malformations<sup>46–51</sup> (– Table 3). TR was due to dilatation of the tricuspid annulus in one,<sup>46</sup> absence of chordae tendineae to the anterior leaflet in one,<sup>47</sup> agenesis of the anterior papillary muscle in one,<sup>50</sup> and cleft of the anterior leaflet in one.<sup>51</sup> In one patient, TR was caused by iatrogenic chordal rupture during the percutaneous removal of a displaced atrial septal occluder<sup>49</sup>; complex tricuspid robotic-assisted reconstruction was achieved with multiple ePTFE

neochordae. Another patient had previously undergone closure of a ventricular septal defect during infancy<sup>48</sup>; during late follow-up TR developed due to progressive annular dilatation and chordal rupture which was corrected with the use of neochordae.

### Tricuspid Valve Repair with Expanded Polytetrafluoroethylene Neochordae after the Excision of Intracardiac Neoplasms

#### Case Reports

During the excision of intracardiac tumors, three patients developed significant TR<sup>52–54</sup>; two were males and one female aged 25, 41, and 76 years (– Table 4). In one patient, a myxoma was attached by a short stalk to the anterior papillary muscle

**Table 2** Artificial neochordae for tricuspid regurgitation due to endocarditis

Author, year	Age, sex	Findings	Microorganism	Operation	F-U
Bortolotti et al 1993 <sup>33</sup>	67,F	Vegetations ATL, PTL, PM lead	<i>Staphylococcus epidermidis</i>	TVR; 2 neochordae (5/0) to ATL	15 mo
Sons et al 1997 <sup>34</sup>	19,F	Vegetations ATL, PTL	<i>Pseudomonas maltophilia</i> , <i>Candida albicans</i>	TVR with autologous pericardium; Neochordae to ATL, PTL	Lost
Pratali et al 1999 <sup>35</sup>	38,M	Perforation and vegetations AML, vegetations ATL	<i>Staphylococcus aureus</i>	MVR and TVR with autologous peri- cardium; 2 neochordae (4/0) to ATL, TAP	5 mo
Konstantinov 2008 <sup>36</sup>	33,M	Multiple vegetations, RV abscess	<i>Staphylococcus aureus</i>	TV resection and reconstruction with autologous pericardium; neochordae (4/0)	3 mo
Aoki et al 2010 <sup>37</sup>	77,M	Vegetations ATL	<i>Enterococcus faecalis</i>	TVR with autologous pericardium; neochordae (5/0) to ATL	2 y
Morokuma et al 2010 <sup>38</sup>	22,F	Vegetations ATL	NS	2 neochordae (4/0) to ATL; TAP	4 mo
Salhiyyah et al 2010 <sup>39</sup>	30,M	Vegetations ATL	<i>Pseudomonas aeruginosa</i>	TVR with bovine pericardium; 2 neochordae to ATL; TAP	3 mo
Atroshchenko et al 2021 <sup>40</sup>	34,M	Vegetations ATL, STS	<i>Staphylococcus aureus</i> , <i>Streptococcus anginosus</i>	TVR with equine pericardium; neo- chordae to ATL, STL; TAP	6 mo
Mohamed et al 2021 <sup>41</sup>	28,F	Destroyed ATL	<i>Staphylococcus aureus</i>	TVR with bovine pericardium <sup>a</sup> ; neo- chordae (5/0) to ATL; TAP	2 y

Abbreviations: AML, anterior mitral leaflet; ATL, anterior tricuspid leaflet; F-U, follow-up; MVR, mitral valve repair; PM, pace-maker; PTL, posterior tricuspid leaflet; STL, septal tricuspid leaflet; TAP, tricuspid annuloplasty; TVR, tricuspid valve repair.

<sup>a</sup>Admedus Cardioceel decellularized bovine pericardium (AdmedusRegen Pty Ltd, Perth, WA, Australia)

**Table 3** Artificial neochordae for tricuspid regurgitation TR in adults with congenital heart disease

Author, year	Age, sex	Disease	Associated malformations	Operation	F-U
Katogi et al 1998 <sup>46</sup>	23,F	Congenital TR	Huge RV	Neochordae (4/0) to ATL, TAP	NA
Shikata et al 2010 <sup>47</sup>	37,F	Absent chordae ATL	Hypoplastic APM	Chordal reconstruction with a 2/0 loop and 5/0 neochordae to ATL, TAP	3 mo
Sassa et al 2017 <sup>48</sup>	49,M	TR post VSD closure	Coronary stenosis	Neochordae to STL; TAP; CABG	NA
Onan et al 2017 <sup>49</sup>	35,F	Iatrogenic TV injury	ASD	Robotic repair; 4 neochordae (4/0) to ATL, PTL <sup>a</sup>	6 mo
Tian and Pan 2017 <sup>50</sup>	26,F	Congenital TR	Agenesis APM	Neochordae (5/0) to ATL, TAP	NA
Saku et al 2019 <sup>51</sup>	79,M	Cleft ATL	Aortic stenosis	AVR; cleft suture, 4 neochordae to ATL, TAP	6 mo

Abbreviations: APM, anterior papillary muscle; ATL, anterior tricuspid leaflet; AVR, aortic valve replacement; CABG, coronary artery bypass grafting; F-U, follow-up; NA, not available; PTL, posterior tricuspid leaflet; RV, right ventricle; STL, septal tricuspid leaflet; TAP, tricuspid annuloplasty; VSD, ventricular septal defect.

<sup>a</sup>This patient had previous removal of the atrial septal occluder using a percutaneous approach.

and floated into the right ventricular outflow<sup>52</sup>; the mass was excised causing TR repaired with annuloplasty and insertion of artificial chordae. In another patient, tricuspid valve injury occurred during the removal of a papillary fibroelastoma on the anterior papillary muscle<sup>53</sup>; tumor removal required the partial excision of the papillary muscle which was reconstructed with neochordae with the loop technique. Finally, in one patient, a metastatic cystic teratoma involved the anterior tricuspid leaflet; excision of the neoplasm and TVr with neochordae implantation was successfully accomplished.<sup>54</sup>

### Expanded Polytetrafluoroethylene Neochordae for Tricuspid Valve Repair after Heart Transplantation

#### Case Reports

We found two reports of the successful use of ePTFE neochordae for TVr after HTx<sup>55,56</sup> (→ **Table 5**). Crumbley and Van Bakel described two patients, one male and one female aged 49 and 25 years, in whom endomyocardial biopsy-induced TR developed after heart transplantation (HTx).<sup>55</sup> In both, rupture of several native chordae tendineae was observed; TVr was achieved with an annuloplasty ring and insertion of multiple neochordae to the posterior and septal leaflets. More recently, Tsai et al performed TVr in a 21-year-old male with TR 6 years after HTx; during follow-up, he had undergone a total of 13 endomyocardial biopsies which were considered responsible for the torn chordae of the posterior leaflet found at reopera-

tion.<sup>56</sup> TVR was performed through a median sternotomy using three loops of neochordae and an annuloplasty ring.

#### Patient Series

Huddleston et al also used neochordae to repair TR caused by repeated biopsies (mean, 16 per patient) in two patients among 20 with severe TR after HTx.<sup>57</sup> In both of them, TVr failed and valve replacement was necessary. Out of six patients who developed severe TR after HTx, Filsoufi et al reported the use of ePTFE neochords in one of them without providing any detail on this specific patient.<sup>58</sup>

### Other Causes of Tricuspid Regurgitation Repaired with Artificial Chordae

#### Case Reports

We found only a single case in whom ePTFE neochordae were used to correct isolated TR due to leaflet prolapse. Marin et al reported this procedure in a 72-year-old woman with severe prolapse of the anterior leaflet and annular dilatation.<sup>59</sup> Since after ring annuloplasty moderate TR was still present implantation of two 5/0 ePTFE sutures achieved stable valvular competence.

#### Patient Series

David reported in 1989 one patient with ischemic TR in whom the native chordae were replaced with a 5/0 Gore-Tex

**Table 4** Artificial neochordae for tricuspid repair after excision of intracardiac neoplasms

Author, year	Age, sex	Neoplasm	Tumor size	Operation	F-U
Shibamoto et al 2011 <sup>52</sup>	76,F	Mixoma APM	34 × 25 mm	Tumor excision; neochordae to ATL	NA
Isoda et al 2013 <sup>53</sup>	41,M	Papillary fibroelastoma APM	19 × 16 mm	Excision; APM reconstruction with 4/0 neochordae (loop technique); TAP	4 mo
Roubelakis et al 2014 <sup>54</sup>	25,M	Metastatic cystic teratoma, ATL	NA	Excision; APM reconstruction with 2 neochordae (4/0)	2 y

Abbreviations: APM, anterior papillary muscle; ATL, anterior tricuspid leaflet; F-U, follow-up; NA, not available; TAP, tricuspid annuloplasty.

**Table 5** Artificial neochordae for tricuspid regurgitation caused by endomyocardial biopsies

Author, year	Age, sex	Disease	Number of EMB	Interval from HTx	Reoperation	F-U
Crumbley and Van Bakel 1994 <sup>55</sup>	25,F 49,M	PPCM DCM	NA NA	2 y 1.4 y	6 neochordae (6/0) to STL, 2 to PTL; TAP Neochordae (4/0) to STL and PTL; TAP	3 y 1.6 y
Tsai et al 2021 <sup>56</sup>	21,M	HCM	13	6 y	Neochordae (3 loops) to PTL; TAP	4 y

Abbreviations: DCM, dilated cardiomyopathy; EMB, endomyocardial biopsy; F-U, follow-up; HCM, hypertrophic cardiomyopathy; HTx, heart transplantation; NA, not available; PPCM, postpartum cardiomyopathy; PTL, posterior tricuspid leaflet; STL, septal tricuspid leaflet; TAP, tricuspid annuloplasty.

suture attached to the stump of the anterior papillary muscle and the free margin of the anterior leaflet.<sup>60</sup> Zussa, out of 223 patients having MVr, reported 5 patients in whom TVr was performed with ePTFE chordae.<sup>61</sup> The only information obtainable from this paper was that two patients had post-traumatic, two infective, and one rheumatic TR.

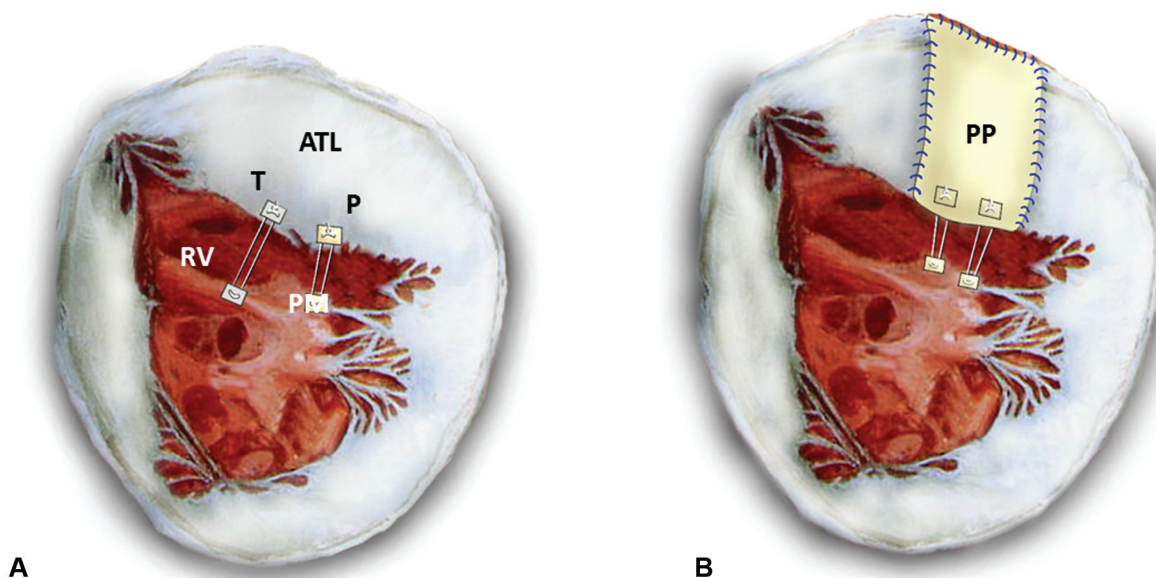
### Technical Aspects of Tricuspid Valve Repair with Expanded Polytetrafluoroethylene Neochordae

In the present review, most of the surgical procedures were performed through a standard median sternotomy or re-sternotomy although occasionally a minimally invasive approach or a robotic-assisted repair was used.<sup>17,21,49</sup> Nevertheless, in any case, TVr was performed on cardiopulmonary bypass and either on a beating heart or during a period of moderate hypothermia after aortic cross-clamping and cardioplegic cardiac arrest.

The implantation of ePTFE to correct TR was performed using the same techniques employed for MVr. Each pair of neochordae was secured distally to the tip of one papillary muscle pulled through and then secured to the free margin of the corresponding tricuspid leaflet. Both distal and proximal anastomoses were

generally reinforced with Teflon pledgets although in IE pericardial pledgets were preferred<sup>34,36</sup> (► Fig. 1A). In some instances, when there was a complete agenesis of the supporting papillary muscle, the neochordae were attached directly to the right ventricular septum or free wall.<sup>36,45,61</sup> In many reported cases of patients with IE-related TR, extended resection of infected leaflets and subvalvular apparatus was required. Valve reconstruction was accomplished with patches of pericardium, while the neochordae were sutured to the free margin of the patches<sup>38,40,41</sup> (► Fig. 1B).

The size of ePTFE neochordae was assessed generally with the hydrostatic method, namely tying the knots on the leaflets after the injection of saline into the ventricle, testing at the same time valve competence; the result of repair was then confirmed with transesophageal echocardiography prior to discontinuation of bypass. Interestingly, in one patient with TR due to IE requiring extended tissue replacement with pericardium, pairs of neochordae were brought outside the right ventricle and reinforced externally with a Teflon pledget; on a beating heart, the sutures were then pulled and tied under echocardiographic guidance with optimal length tuning of the neochordae.<sup>34</sup>



**Fig. 1** (A) Tricuspid valve repair with artificial neochordae fixed on the stump of a papillary muscle (PM) or the right ventricular (RV) free wall. Sutures may be reinforced with Teflon (T) or pericardial (P) pledgets. (B) The anterior tricuspid leaflet (ATL), destroyed by infection, is reconstructed with a pericardial patch (PP), connected to the tip of a papillary muscle (PM) with neochordae. In this case, the use of pericardial pledgets is generally preferred.

### Outcomes of Tricuspid Valve Repair with Expanded Polytetrafluoroethylene Neochordae

All patients with posttraumatic TR survived the operation with a follow-up available in 13 cases for single-patient reports, ranging from 3 months to 4 years, while it was not reported in the remaining 11 patients. In the series by Maisano et al,<sup>30</sup> there were no hospital deaths and the mean follow-up was 29 months. Also, all patients reported by Zhang et al survived TVr and no postoperative complications were observed at a maximum follow-up of 72 months.<sup>33</sup>

In patients with IE, there were no operative deaths reported; follow-up ranged from 3 months to 2 years in seven patients, while one patient was lost. From other larger reports, no follow-up data were available. TVr was successful also in all patients with congenital heart disease; in this group, follow-up ranged from 3 to 6 months, while in three cases, it was not stated.

All patients who had TVr after excision of cardiac tumors were discharged and followed from 4 months to 2 years. Finally, there were no hospital deaths, also in the three patients with endomyocardial biopsies-related TR who were followed from 1.6 to 4 years.

From the available follow-up data, it appears that at last echocardiographic control almost all patients had a significant reduction of TR with not more than trivial-to-mild residual TR, regardless of the original tricuspid valve disease; in particular, no transvalvular gradient was observed when the double-orifice TVr was performed.<sup>31</sup>

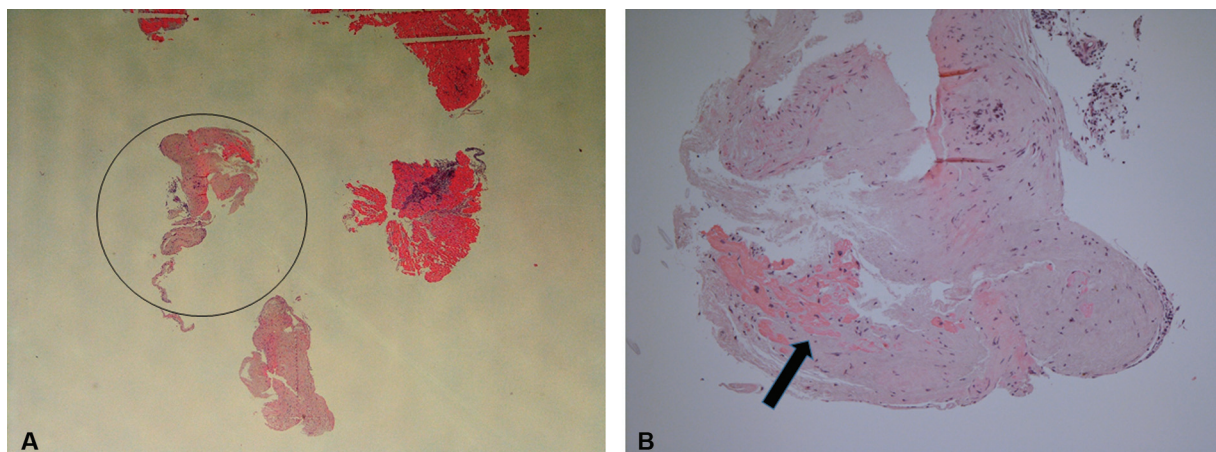
### Comment

The use of ePTFE neochordae for TVr was first reported by David<sup>60</sup> and Zussa.<sup>61</sup> Since then, unlike for MVr, employment of ePTFE neochordae to correct TR has received limited attention. In the present review, we have identified a number of patients in whom this technique achieved excellent results in TVr. Most cases regarded posttraumatic TR, a well-recognized pathology, leading to TVr even up to 45 years from initial trauma<sup>28</sup>; indeed, the need to repair an injured tricuspid valve on an urgent basis or early after rupture was almost exceptionally reported.<sup>13,22,26</sup>

An interesting finding has been a small, albeit significant number of patients in whom ePTFE neochordae were used in the setting of IE. In this complex scenario, pericardial patches have been frequently employed to reconstruct damaged tricuspid valves,<sup>34–37,39,40</sup> attaching the neochordae to the free margins of the reconstructed leaflets.<sup>62,63</sup> This is extremely useful in a subset of patients, as intravenous drug abusers, in whom the minimal use of foreign material is of paramount importance to prevent TR recurrences. Even if ePTFE neochordae have been used in infected areas, no dismal consequences were observed, indicating that such material is quite resistant to infection; this is confirmed also by a recent review where no cases of neochordae IE as the cause of MVr failure were found.<sup>64</sup> Furthermore, no cases of ePTFE neochordae mechanical failures have been so far reported after TVr. This may be due to the fact that this material is resistant to wear and stress forces especially in a low-pressure cavity as the right ventricle; it must also be stressed, however, that at present follow-up of reported cases is still quite short.

ePTFE neochordae have been employed for TVr in other peculiar and rare pathologies such congenital TR in adults,<sup>46–51</sup> in TR after excision of cardiac neoplasms<sup>52–54</sup> or following repeated endomyocardial biopsies in HTx recipients.<sup>55,56</sup> This has been demonstrated to be an extremely rare but possible occurrence after HTx since native chordal tissue was detected in biopsy specimens in patients who developed severe post-HTx TR<sup>65</sup> (► Fig. 2).

The largest series of ePTFE neochordae used for TVr has been reported by Huang et al.<sup>66</sup> A total of 54 adult patients with a mean age of 45 years, 43% of whom were females. A mean of three pairs of neochordae (4/0 and 5/0) was implanted; the most frequent mechanism of TR was congenital chordal rupture. The mean follow-up was 3.5 years for adult patients with a 92% actuarial survival at 3 years. Another important contribution to this topic has been provided by Salihi et al who demonstrated the effectiveness of neochordal implantation in TR reporting 48 patients.<sup>67</sup> The median age was 62 years and 50% were females, but this series also included pediatric patients and the number of



**Fig. 2** (A) Endomyocardial biopsy specimens. The circle indicates the magnified fragment (hematoxylin and eosin x20). (B) Magnified fragment with features of loose fibrous tissue, divided from focal myocardial tissue (arrow), consistent with a chordal insertion (hematoxylin and eosin x100).

adult ones could not be identified. Finally, the possibility of using ePTFE neochordae for TVr in redo cardiac operations was stressed by Chen et al although any specific detail was not reported.<sup>68</sup>

Concerning the technical aspects of ePTFE implantation, TVr was in most cases obtained by replicating the standard, well-established methods used for MVr, limiting the repair to replace torn or absent native chordae by rejoining papillary muscles to the free edges of the leaflets in most cases. However, in some patients, a peculiar tricuspid valve pathology required complex procedures suggesting the adoption of technical variations as in the case of destructive IE; in this setting, the use of ePTFE sutures, as part of TVr, proved effective together with some innovative solutions which demonstrated once more the importance of each surgeon ingenuity. Furthermore, except for few cases, the methods used for sizing neochordae length were far from being too sophisticated, most likely because, at variance with MVr, even a trivial-to-mild degree of residual regurgitation would have been well tolerated in the long term. It must be also recognized that the tricuspid valve leaflets are generally thinner and more fragile compared to those of the mitral valve; therefore, some authors suggest to reinforce the suture ends with fabric or pericardial pledgets.<sup>34,36,61</sup> However, in rheumatic or long-standing posttraumatic TR, the valve leaflets may be thickened and strong enough to hold sutures without any reinforcement.<sup>67</sup>

This review has obvious limitations. The main concern regards the impossibility to trace all patients having neochordae implantation for TVr. This pertains mainly to patient series having isolated TVr, or combined to MVr due to functional TR, since from these reports the rate of TVr with artificial chordae, if mentioned, could not be extrapolated. Furthermore, many details potentially useful for this review were not reported also when large experiences with ePTFE neochordae were analyzed. In some cases, a description of the technique employed or of the material used to construct neochordae and other important information were also frequently not available. In particular, it was often difficult to verify the number of neochords used for each case; in fact, from a single Gore-Tex suture a pair of neochordae is obtained and in most articles the terms “chords,” “neochordae,” or “pair of neochordae” are used indifferently generating possible confusion. Most of the data present in this review derive from single-case reports. For all the above considerations, it appears evident that the real number of patients receiving ePTFE neochordae for TVr is currently limited, but since it could not be clearly assessed, it is likely to be underestimated. Furthermore, the paucity of data available even from consistent patient series indicates that the use of ePTFE neochordae for TVr was, at least in some cases, most likely an occasional decision and not yet considered as a routine surgical strategy.

However, the excellent results reported demonstrated that neochordae implants may also be feasible through mini-invasive or robotic approaches and their extended use should be more favored to TVr. It is likely that, with the continuing improvements of techniques and devices, the

use of ePTFE neochordae might be soon adapted also to percutaneous TVr procedures.<sup>69</sup>

In conclusion, the use of ePTFE sutures is a valid adjunct to the surgical armamentarium during TVr procedures. This review, together with lessons learned from MVr experiences, has shown that ePTFE is an ideal material to successfully correct TR caused by chest trauma, IE, repeated endomyocardial biopsies, or congenital malformations. The feasibility of ePTFE neochordae implantation through minimally invasive approaches or robotically assisted procedures may allow this surgical option to be used more routinely.

#### Conflict of Interest

None declared.

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