

EXPERT  
REVIEWS

## Repair of the anterior mitral leaflet prolapse

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Repair of anterior mitral leaflet prolapse is one of the most challenging aspects in mitral valve repair surgery. In this review, we discuss the various techniques developed over the past three to four decades for the repair of anterior mitral leaflet prolapse, debate the pros and cons of each and compare their results, keeping reoperation for recurrent mitral regurgitation as the focal point of follow-up. At our center, chordal replacement with artificial expanded polytetrafluoroethylene sutures in the form of premeasured loops is the most commonly used technique for repair of anterior mitral leaflet prolapse for the past decade. We recommend and provide justification for the use of this technique, especially when mitral valve repair is performed through a minimally invasive approach. We believe that the trend towards a minimally invasive approach for mitral valve repair will exponentially increase in the next 5–10 years, at least until percutaneous techniques, if at all, become more reliable and safe.

**KEYWORDS:** anterior leaflet prolapse • chordal replacement • mitral valve • surgical techniques**Pathology of the anterior mitral leaflet prolapse**

The mitral valve (MV) consists of two leaflets, the anterior and posterior leaflet. The two leaflets are connected by chordae tendineae to the anterolateral and posteromedial papillary muscles of the left ventricle. The anterior leaflet contributes to almost two-thirds and the posterior leaflet to one third of the surface area that closes the MV orifice during the systolic phase of the cardiac cycle. Although anterior mitral leaflet prolapse is most commonly seen in degenerative disease, rheumatic affection of the MV can also result in prolapse. Anterior or posterior leaflet prolapse develops due to elongated or ruptured chordae tendineae of the leaflets and is in most cases associated with annular dilatation and in few pathologies with excess leaflet tissue (FIGURE 1). The reconstruction techniques usually involve repair of the anterior mitral leaflet (AML) and/or posterior mitral leaflet (PML) prolapse, combined with a ring annuloplasty. Repair techniques for AML prolapse form the focus of this article and are described below.

**AML repair techniques**

Differentiating between degenerative MV prolapse, which is commonly encountered in the developed world, and rheumatic disease, more commonly seen in the developing countries, is

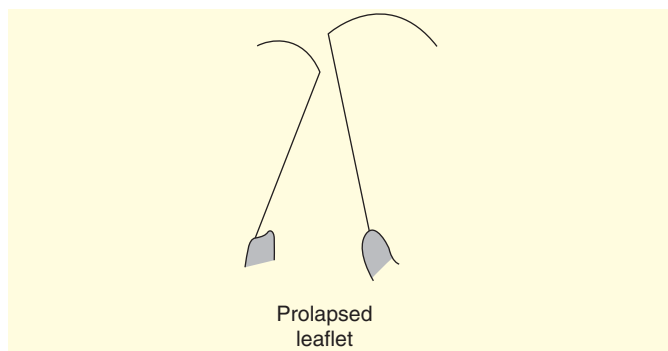
extremely important to achieve a successful repair. The repair techniques for degenerative AML prolapse can be divided into four sections: repair at the leaflet level; repair at the chordal and leaflet level; repair at the chordal and papillary muscle level; chordal replacement. All repair techniques, which are used for degenerative AML prolapse, can also be used in patients with rheumatic AML prolapse too and are summarized in TABLE 1. Additional AML repair techniques, which can be performed in patients with rheumatic valvular disease, have also been described.

**Repair techniques for degenerative AML prolapse****Leaflet level**

These techniques focus on the leaflet itself and correct the prolapsing segment of the AML without addressing the subannular structures. Most of the techniques, described below, result in a mild reduction in the MV orifice area.

**Triangular resection**

The prolapsed segment of the anterior leaflet can be excised using a triangular or quadrangular resection of the excessive tissue (FIGURE 2). This technique was described in 1983 by Alain Carpentier in the famous paper 'The French correction' [1]. However, he elucidated on the rather disappointing results of this technique due



**Figure 1. Prolapsed leaflet.**

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to the significant reduction in AML mobility, especially during systole. Resection of larger segments of AML results in inadequate tissue for effective closure of the MV orifice, culminating in MV replacement.

Thus, this repair technique should be preferably performed by highly experienced MV surgeons. Nevertheless, long-term results following triangular resection are acceptable with freedom from reoperation of  $93 \pm 5\%$  in 32 patients at 10 years reported by Sakamoto *et al.* in 2005 [2]. Furthermore, in case of elongated and/or ruptured chordae tendineae, additional repair techniques may be necessary.

#### *Plication of the anterior leaflet*

Plication of the anterior leaflet, which was first published by Ellis *et al.* in 1966, can be used as an alternative to leaflet resection techniques [3]. The major advantage of this technique over triangular resection is that it is possible to revise the procedure, if the intraoperative echocardiographic findings are suggestive of an unsatisfactory repair. Seitelberger and colleagues reported the use of the modified Ellis' plication technique for anterior leaflet prolapse in 2004 (FIGURE 3) [4] with an excellent repair rate of 96% (16/17 patients). The maximum width of the base of the triangle plicated did not exceed 1.5 cm. The postoperative freedom from significant MV regurgitation was 90 and 86% at 24 (n = 10) and 36 (n = 7) months, respectively.

#### *Plication of the free edge of the anterior leaflet*

An alternative method for plication of the anterior leaflet was published by Fundaro in 1997 [5]. The plication is performed directly on the prolapsing edge of the AML, including all involved primary and secondary elongated chordae tendineae attached to the prolapsing segment of the leaflet (FIGURE 4). In 2001, they reported the long-term results of 26 patients, who underwent MV repair with this technique and showed a freedom from reoperation of  $94.6 \pm 3.0\%$  at 8 years [6].

#### *Edge-to-edge technique*

The edge-to-edge technique was initially described by Alfieri in the 1990s [7]. The free edge of the prolapsing leaflet is anchored to the corresponding segment edge of the opposing leaflet. This results in a so-called double orifice MV (FIGURE 5). In 2004,

Alfieri *et al.* published their experience with this technique in more than 150 patients suffering from anterior mitral leaflet prolapse with a very high freedom from reoperation of  $96.6 \pm 1.7\%$  at 10 years [8]. The major advantage of this repair technique is that it is highly reproducible and easy to perform with short aortic clamp times. However, there are many indications and contraindications for the use of the edge-to-edge technique. In a well-summarized review by DeBonis, he describes the indications for the edge-to-edge technique as bileaflet prolapse with facing segments, segmental anterior leaflet prolapse/flail, functional mitral regurgitation, systolic anterior movement (prevention/treatment in mitral repair or hypertrophic obstructive cardiomyopathy), suboptimal conventional MV repair (the so-called 'rescue' edge-to-edge) in patients with complex pathology. In contrast, this technique should be avoided as the 'first-line approach' in patients with a heavily calcified mitral annulus, complex MV pathology and rheumatic mitral regurgitation (to prevent MV stenosis) [9]. He also states that an edge-to-edge technique should always be supported with a ring annuloplasty to avoid future annular dilatation. This was further confirmed in a report by Bhattacharya and coworkers who showed that patients undergoing anterior leaflet prolapse repair had greater probability for annular dilatation than those undergoing the posterior leaflet prolapse after an edge-to-edge repair [10]. In addition, Glower *et al.* emphasized on the use of a minimum ring diameter of 30 mm to avoid development of postrepair MV stenosis in patients operated upon with this technique [11].

#### *Chordal & leaflet level*

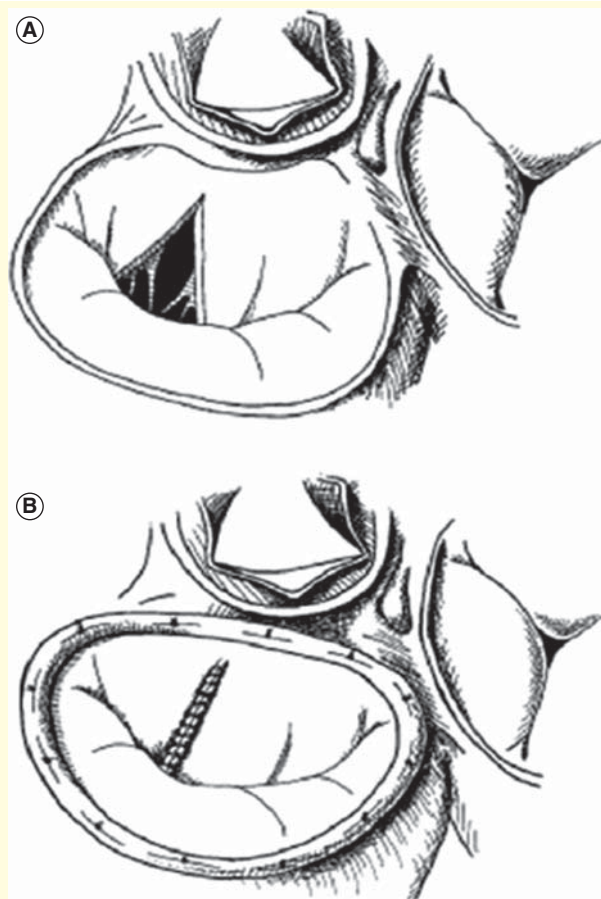
These techniques enable correction of the prolapsed segment of the AML by addressing the diseased chordae tendineae attached to it. All the techniques are supported by a ring annuloplasty as well. The main advantage of these techniques is that the prolapsed segment is supported by normal chordae tendineae procured from the opposing segment of the healthy posterior leaflet. The chief drawback is that a healthy segment of the posterior leaflet has to be sacrificed to support the prolapsing segment of the AML. This was well phrased by Aubert *et al.* as being "a case of robbing Peter to pay back Paul..." [12]. Overall, postoperative results obtained by these techniques are promising.

#### *Chordal transposition*

The so-called 'transposition technique' was first described by Carpentier in 1983 [1]. This technique enables replacement of the elongated and diseased anterior chordae tendineae attached to the prolapsed segment of the AML by complete transfer of either chordae tendineae alone or a combined package of a small leaflet segment and chordae tendineae from the normal PML to the prolapsed AML segment (FIGURE 6). The limitations of this technique are that its success obviously depends on the number and quality of the transferred chordae and it can only be used in isolated AML prolapse. Nevertheless, when appropriately used, good long-term results can be achieved, as was shown in a publication by Smedira and coworkers, in which the 5-year freedom from reoperation was 96% [13].

**Table 1. Repair techniques for anterior mitral leaflet prolapse.**

Surgical Technique	Original description	Advantage (⊕)/disadvantage (⊖)	Freedom from reoperation	Studies with long-term results
<b>Leaflet level</b>				
Triangular resection	Carpentier (1983) [1]	⊕ No foreign material ⊖ Reduction of mobility and size of the anterior leaflet ⊖ In case of elongated/ruptured chordae additive repair necessary	10 years: 93 ± 5% 5 years: 93%	Sakamoto (2005) [2] Saunders (2004) [56]
Plication of the anterior leaflet	Ellis (1966) [3] Modification: Seitelberger (2004) [4]	⊕ Revision possible ⊖ See above (Triangular resection)	36 months: 86%	Seitelberger (2004) [4]
Plication of the free edge of anterior leaflet	Fundaro (1997) [5]	⊕ Includes all involved primary and secondary elongated chordae ⊖ Rupture of the involved primary and secondary elongated chordae possible	8 years: 94.6 ± 3%	Fundaro (2001) [6]
Edge-to-edge repair	Alfieri (1999) [7]	⊕ Easy to perform ⊕ Short cross-clamp time ⊕ Rescue technique after failed repair ⊖ Reduction of the orifice area of the mitral valve ⊖ Unsatisfactory results in patients with calcified annulus, complex pathology, rheumatic mitral valve disease	13 years: 92.3 ± 3.2% 9 years: 96.6 ± 1.7%	Fucci (2007) [59] Alfieri (2004) [8]
<b>Chordal and leaflet level</b>				
Chordal transposition	Carpentier (1983) [1]	⊕ Enables replacement of diseased anterior chordae tendineae ⊖ Result of repair is dependent on the quality and number of transferred chordae ⊖ Only possible in isolated anterior prolapse	5 years: 88.6 ± 4.8% 5 years: 96%	Salati (1997) [60] Smedira (1996) [13]
Flip-over technique	Duran (1986) [14]	⊕/⊖ See above (Chordal transposition)		
Extended chordal transfer	Elwatidy (2010) [15]	⊕ Repair of wide prolapse segments possible ⊖ complex procedure More ⊕/⊖: see above (Chordal transposition)	4 years: 96.2%	Elwatidy (2010) [15]
<b>Chordal and papillary muscle level</b>				
Chordal shortening	Carpentier (1983) [1]	⊕ No foreign material ⊖ Result of repair dependent on the quality of chordae tendineae	14 years: 88% 5 years: 74% 1 year: 100%	Perier (2004) [17] Smedira (1996) [13] Kumar (1992) [16]
Papillary muscle repositioning	Dreyfus (2001) [18]	⊕ No foreign material ⊕ Especially useful in case of paramedian and paracommissural prolapse of the anterior leaflet ⊖ Result of repair dependent on the quality of chordae tendineae	10 years: 92.8%	Dreyfus (2006) [61]
Chordal replacement (Pericardial strip)	Frater (1963) [20]	⊕ Maintenance of the mitral orifice area ⊖ Restricted or loss of mobility of pericardial strips over time		
Chordal replacement (PTFE suture)	Frater (experimental) (1965) [62] David (clinical) (1989) [22]	⊕ Maintenance of the mitral orifice area ⊕ Possible for every type of prolapse ⊕ PTFE remains flexible ⊖ Determination of the correct length of chordae tendineae	18 years: 90.2 ± 2.4% 12 years: 89.9 ± 2.9% 3 years: 91.9%	David (2012) [24] Kasegawa (2006) [25] Lawrie (2006) [26]
Chordal replacement (Loop technique)	Von Oppell/Mohr (1999) [34]	⊕ See above (Chordal replacement; PTFE suture) ⊕ Determination of the correct length of chordae tendineae reproducible	5 years: 95.7 ± 1.9% 5 years: 95.6%	Pfannmüller (2013) [37] Seeburger (2009) [36]



**Figure 2. Triangular resection.** (A) Triangular resection of the anterior mitral leaflet. (B) Completed triangular leaflet resection with ring annuloplasty.

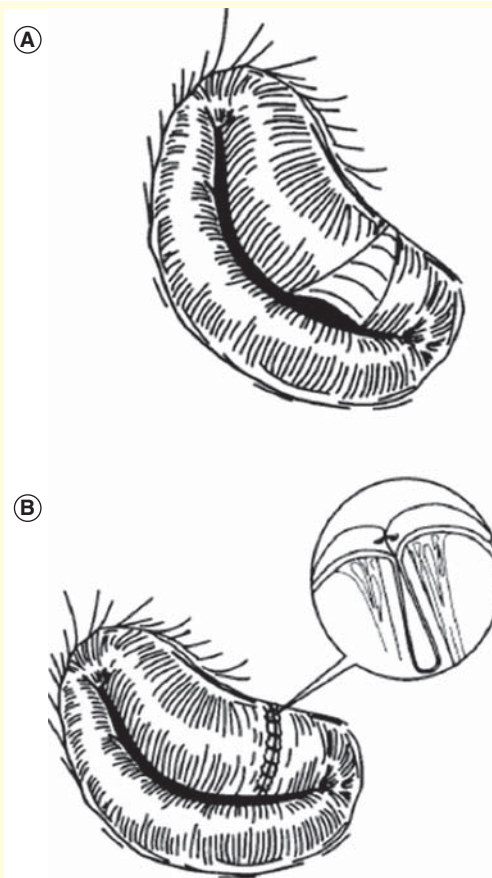
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#### Flip-over technique

A rather similar technique, to the one described above, was published by Duran *et al.* in 1986 – it has been called the ‘Flip over technique’ (FIGURE 7A & 7B) [14]. In patients with a normal posterior leaflet, a quadrangular resection of a segment of the posterior leaflet directly opposite the prolapsing AML segment is performed and then sutured to the atrial surface of the prolapsing AML segment, thus correcting the prolapse.

#### Extended chordal transfer

In 2010, Elwatidy *et al.* described a technique for repair of a very wide prolapsing segment of the AML used in 26 patients [15]. After a quadrangular resection of a normal segment of the posterior leaflet opposite the prolapsing segment of the anterior leaflet (as performed for the transposition- or flip-over techniques), the resected segment is extended as shown in FIGURE 8. This technique enables to support a length of the free margin of the AML that is double the width of the resected segment of the posterior leaflet. The 4-year reoperation rate for recurrent MR was an impressive 3.8% (1/26). However, its clinical use is rather limited due to the complexity of this repair.



**Figure 3. Plication of the anterior leaflet.** (A) Plication of the anterior leaflet. (B) Schematic drawing of segmental anterior leaflet prolapse (SALP) with suture line for triangular plication. Result after triangular plication of SALP with inversion of plicated area toward the ventricular aspect of the anterior leaflet (inset). Reproduced with permission of Elsevier from [4].

#### Chordal & papillary muscle level

The following repair techniques focus on shortening the elongated chordae tendineae at the level of the papillary muscles. These techniques avoid resection of normal healthy valve tissue and address only the diseased subvalvular apparatus.

#### Chordal shortening

In 1983, Carpentier described the technique of chordal shortening for surgical repair of MV leaflet prolapse [1]. The papillary muscle, to which the elongated chordae tendineae are attached, is longitudinally incised from the tip toward the base. The elongated chordae are then entrenched into the deepest point of the split with a suture, thus shortening it (FIGURE 9). The long-term results of this technique are variable. In 1992, Kumar *et al.* reported a 100% freedom from reoperation at 1 year in patients with rheumatic MV disease with elongated and thickened chordae, who underwent AML repair by chordal shortening [16]. However, Smedira and colleagues published in 1996 that the freedom from reoperation at 5 years after chordal shortening was 74%, with chordal rupture as a risk factor for reoperation [13]. Contrary to the



above report from the Cleveland Clinic, Perier *et al.*, in 2004, reported an acceptable freedom from reoperation of 88% at 14 years [17].

#### Papillary muscle repositioning

Dreyfus *et al.* described the technique of papillary muscle repositioning as an option for repair of AML prolapse (FIGURE 10) [18]. This technique has been used successfully for repair of the AML and PML with similar postoperative results compared with the chordal shortening technique [19].

#### Chordal replacement

This technique focuses on the replacement of the diseased, elongated or ruptured chordae tendineae either with pericardial strips or polytetrafluoroethylene (PTFE) sutures. The major advantage of this technique is that it does not normally require the excision of valve tissue, diseased or normal. Thus, it follows the principle of 'respect' rather than 'resect' tissue. This obviously results not only in the preservation of leaflet surface area, but also leaflet anatomy and mobility. Second, the procedure is simple and easily reproducible with excellent long-term results.

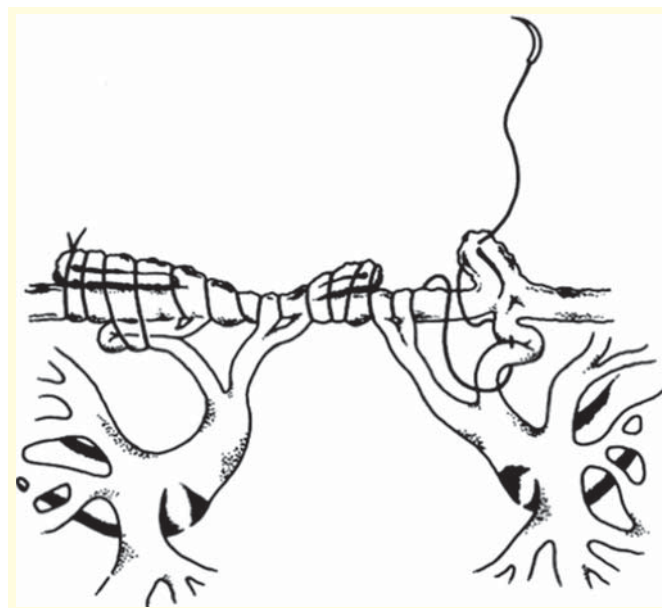
#### Chordal replacement with pericardial strips

In the early 1960s, Frater described a technique to replace chordae tendineae of the PML using autologous pericardial strips (FIGURE 11) [20]. However, pericardial strips experienced significant thickening and calcification, resulting in restricted or loss of mobility over time. Hence, it is not a 'first line' repair technique. Pericardial strips have been substituted by artificial PTFE chordae as a replacement for diseased chordae tendineae (as described below) [20].

#### Chordal replacement with PTFE sutures

The introduction of artificial chordae using Gore Tex sutures (W.L. Gore & Associates, Flagstaff, AZ, USA) has been a very important step in the development of contemporary MV repair. These sutures were introduced by Frater [21] and have been first used clinically in a large number of patients by David *et al.* [22].

Frater and coworkers have shown experimentally that the artificial PTFE chordae in small sizes retain flexibility and get covered with normal fibrosa and intima over time [23]. Tirone David started implanting PTFE-chordae in patients as early as 1985 and soon reported excellent results [22]. He also showed that this technique leads to excellent results in a large number of patients including isolated AML prolapse [24]. Overall freedom from reoperation at 18 years was  $90.2 \pm 2.4\%$ . However, isolated prolapse of the AML was identified as the only significant risk factor for reoperation (hazard ratio [HR]: 2.6). Kasegawa *et al.* showed a freedom from MV-related reoperation of  $89.9 \pm 2.9\%$  12 years after surgery in a total of

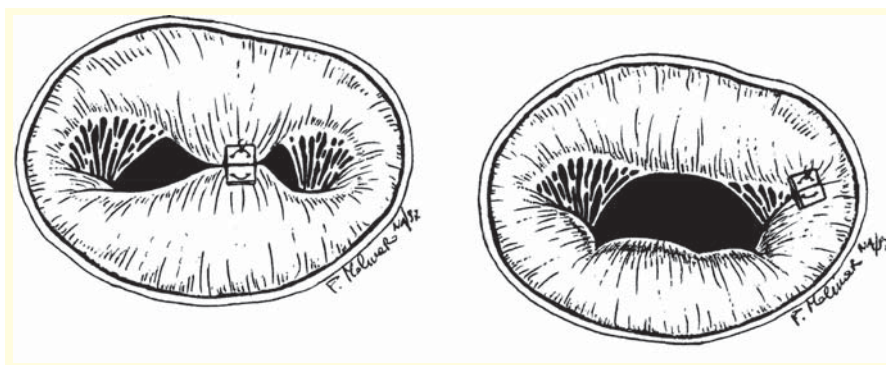


**Figure 4. Suture plication and remodeling of the free edge of the anterior leaflet.**

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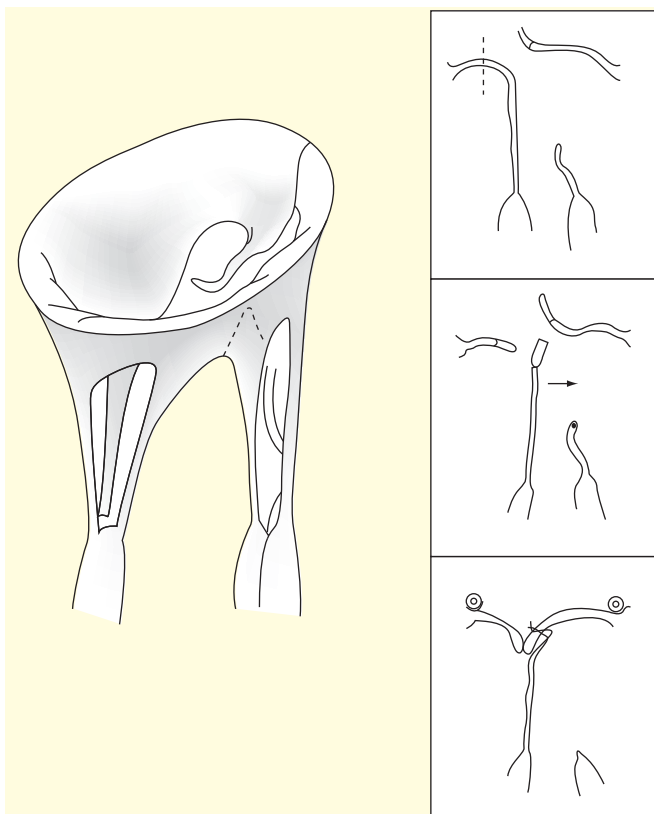
204 patients. He demonstrated that a large MV orifice area ( $4.0 \text{ cm}^2$ ) after repair, achieved in 12.9% of the patients, was advantageous and described the benefit of a 'no resection approach' [25]. Lawrie and coworkers published similar results after MV repair with PTFE neochordae with a freedom from reoperation at 3 years of 91.9 and 90.7% in patients with prolapse of the anterior and/or posterior leaflet, respectively [26].

From a procedural standpoint, this technique is challenging since it is rather difficult to determine the correct length of the PTFE sutures. Sutures that are too short cause restriction and those that are too long do not eliminate the prolapse. Both these constellations lead to persistent MR. As Frater has shown, a temporary suture between the prolapsing AML segment and the normal opposing PML segment can be used to maintain appropriate chordal length and tension during implantation of artificial chordae (FIGURE 12B) [23]. Duran has also described a special knot



**Figure 5. Edge-to-edge technique.**

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**Figure 6. Transposition of posterior chordae to the anterior leaflet.**

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technology to fix the suture temporarily while determining the perfect length (FIGURE 13) [27]. Several groups have contributed significantly to the development and progress of artificial chordae, which emphasizes the importance of this technique [28–33].

#### The 'Loop technique'

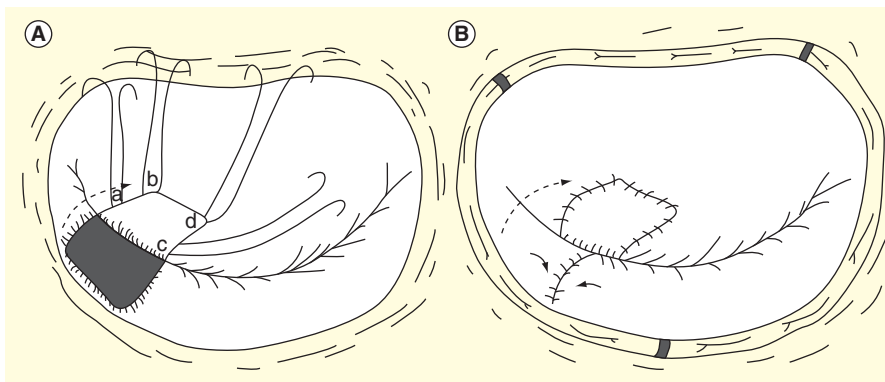
Von Oppell and Mohr introduced an innovative but simple technique using premeasured PTFE neochordae, the so-called

'Loop technique' in 1999 [34]. The correct length of the PTFE loops can be determined with a caliper (FIGURE 14A). Premeasured and premade loops (FIGURE 14B) are commercially available in different sizes from 10 to 26 mm. The base of these loops, which is formed by a pledget, is initially fixed to the body of the papillary muscle. The free ends of the loops are then attached to the prolapsing segment of the AML using additional PTFE sutures (FIGURE 15). This technique has standardized chordal replacement and enables successful MV repair through a minimally invasive right thoracotomy approach even in complex cases. Kuntze *et al.* published the early and mid-term results of MV repair using the 'loop-technique' in 2008 and showed an excellent freedom from reoperation of  $97.4 \pm 1.4\%$  at 3 years for AML and PML prolapse in patients operated upon through a minimally invasive approach or conventional sternotomy [35]. Further publications from our group showed that patients with AML prolapse had 95.7% freedom from reoperation at 5 years after MV repair with the loop technique [36,37].

#### Repair techniques for rheumatic AML prolapse

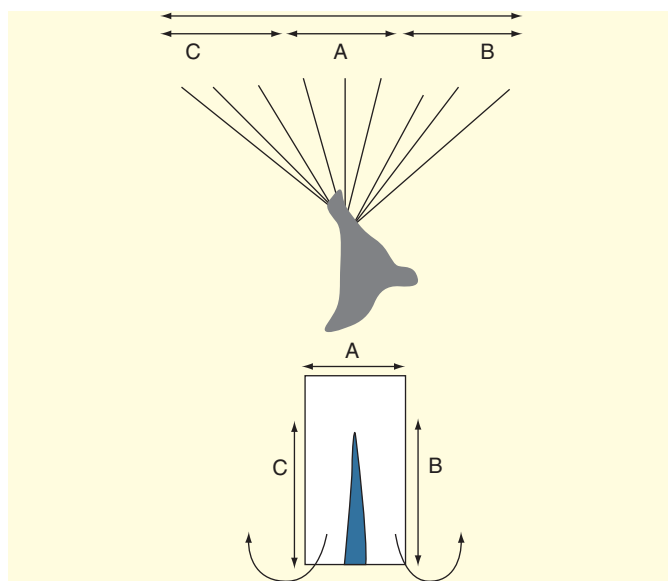
AML prolapse due to rheumatic heart disease, which is chiefly found in the developing world, commonly affects females with a mean age of approximately 20 years. These patients mostly belong to a low socioeconomic strata of society rendering a poor compliance with anticoagulation. Many patients have to complete their somatic growth, and most female patients are still in the childbearing age. As a result, accelerated degeneration of bioprostheses and anticoagulation related and thromboembolic complications in patients with mechanical prostheses is a more common occurrence than in developed countries. Thus, MV replacement is associated with poor outcomes in these patients [38,39], making MV repair a better alternative in many patients. The techniques used for repair of degenerative AML prolapse are also applicable to rheumatic AML prolapse repairs. In addition, the mobility of the AML, which is restricted by an inflammatory fibrotic layer, can be improved through leaflet shaving, peeling or cusp thinning. Splitting of the papillary muscles, which are mostly thickened in patients with rheumatic

heart disease, can further enhance AML mobility. In patients with a combination of AML prolapse and restricted PML mobility, the PML can be extended with a pericardial patch [39,40] as an additional procedure to AML repair. The best results are found in patients with pure MR with adequate mobility of the AML. If the AML is thick or immobile, early reoperation is necessary [41]. The postoperative results are good in experienced hands [39–42]. Yakub *et al.* found no significant differences in the freedom from reoperation (at 5 and 10 years; rheumatic MV repair:  $91.8 \pm 4.8\%$  and  $87.3 \pm 3.9\%$  vs degenerative MV repair:  $92.0 \pm 1.7\%$  and  $91.8 \pm 4.8\%$ , respectively) and valve repair



**Figure 7. Flip-over technique. (A)** Quadrangular resection of a segment of the posterior mitral leaflet. **(B)** The segment is 'flipped over' and sutured to the atrial surface of the prolapsed segment of the anterior mitral leaflet.

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**Figure 8. Extended chordal transfer.** The rectangular segment is cut, starting from the middle of the posterior margin along the posterior two-third of the transferred segment. The two-cut segments are stretched bilaterally and sutured to the anterior mitral leaflet. Reproduced with permission of Wolters Kluwer Health from [15].

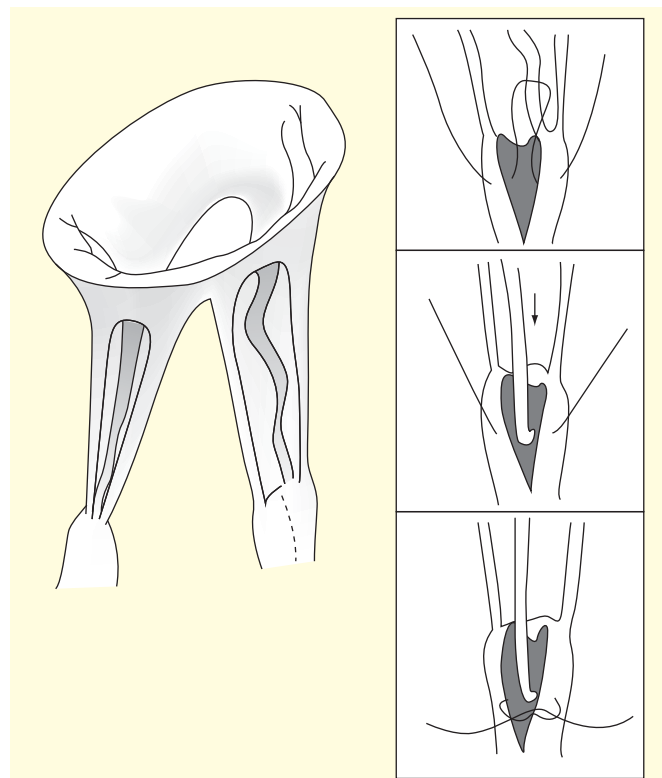
failure (at 5 and 10 years; rheumatic MV repair:  $91.8 \pm 4.8\%$  and  $87.3 \pm 3.9\%$  vs degenerative MV repair:  $92.0 \pm 1.7\%$  and  $91.8 \pm 4.8\%$ , respectively) in 1344 patients (46.7% rheumatic MV failure) undergoing MV repair for degenerative or rheumatic MV disease [39].

MV repairs for rheumatic heart disease are associated with a higher reoperation rate, which usually peaks at 7–8 years due to recurrent attacks of rheumatic fever and gradual degeneration of the leaflets. Regular penicillin prophylaxis [41], which must be continued even after surgery, can at least help in slowing down the progress of the disease process, if not in completely preventing the attacks.

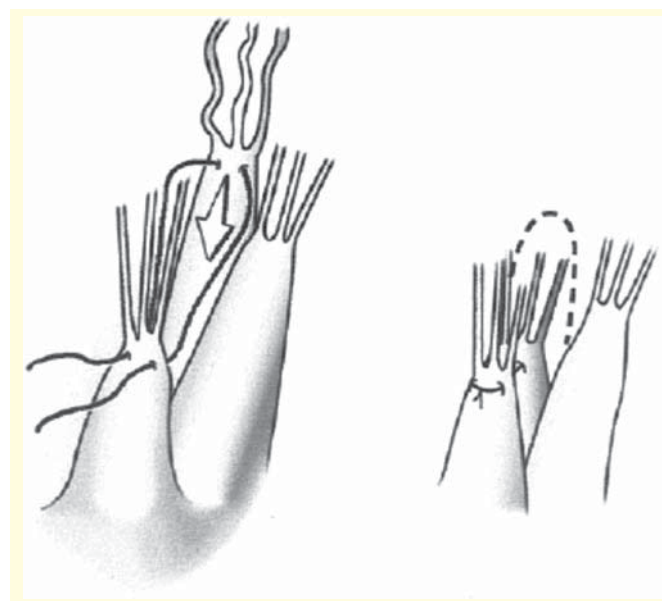
### Expert commentary

There are several reports in the literature, which aim to compare different common techniques for MV repair due to AML prolapse. The experience with chordal shortening and chordal transfer in patients with AML prolapse was reported by Smedira [13]. He stated that chordal transfer is superior to chordal shortening, providing a more predictable correction of mitral regurgitation and a lower incidence of reoperation. Reoperations after chordal shortening are a result of rupture of the previously shortened chordae tendineae. Gillinov and coworkers from the same group revealed that the rupture of chordae tendineae after chordal shortening was usually found at the site of insertion into the papillary muscle trench [43].

A comparison between chordal replacement versus chordal shortening in patients with AML prolapse has been published by Phillips *et al.* [44]. They showed that the risk of reoperation at 3.5 years after MV repair was significantly lower at 1.4%

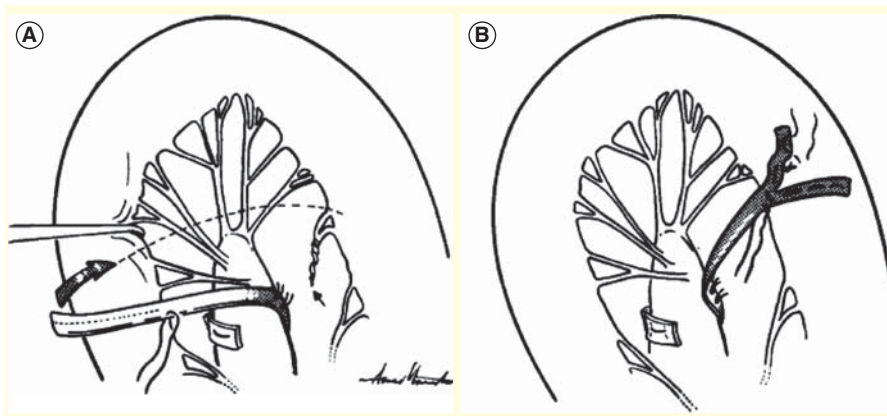


**Figure 9. Chordal shortening.** Reproduced with permission of Elsevier from [1].



**Figure 10. Papillary muscle repositioning.** The anterior head of the papillary muscle is separated from the other heads and taken down into the left ventricle. The fibrous segment of the posterior head is tied down after a stitch in the fibrous segment of the anterior head. Reproduced with permission of Elsevier from [18].





**Figure 11. Chorda replacement with pericardial strips.** (A) Strip of pericardium sutured to the body of the papillary muscle. (B) The other end of the pericardial strip is split into two to form a Y, which is then sutured to the atrial surface of the prolapsing segment. Reproduced with permission of Elsevier from [58].

after chordal replacement compared with 14.8% following chordal shortening ( $p = 0.025$ ).

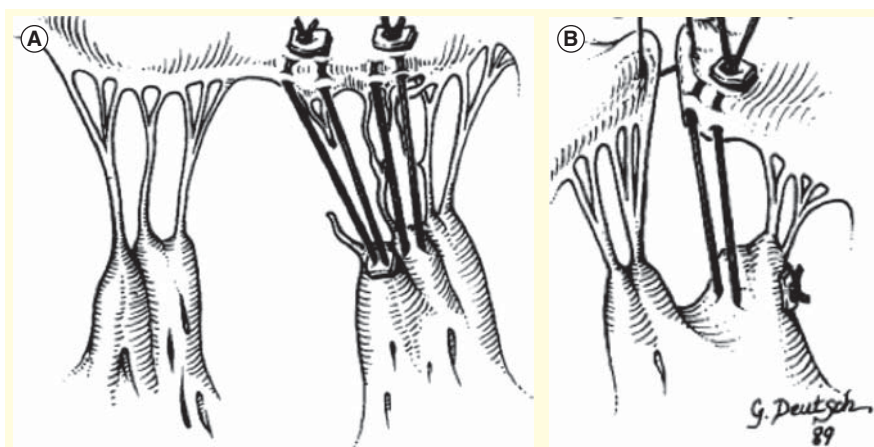
As already stated above, De Bonis *et al.* reported similar freedom from reoperation at 10 years following edge-to-edge repair for AML prolapse ( $96 \pm 2.3\%$ ) compared with the classical and highly reproducible Carpentier type quadrangular resection in patients with PML prolapse ( $96.5 \pm 1.2\%$ ) [45].

A high freedom from reoperation for patients with PML prolapse has been reported by Perier *et al.* in 2008 [46]. His group achieved a 10-year freedom from reoperation of  $93 \pm 3\%$  applying solely the 'respect rather than resect' technique (chordal replacement with PTFE without resection of tissue in MV repair in patients with PML prolapse). Perier compared this technique to the standard quadrangular resection technique in his own

90.7–96.1%; log-rank  $p = 0.005$ ). Cox regression analysis revealed that implantation of a flexible, incomplete band was an independent predictor of reoperation (HR: 6.2; 95% CI: 1.3–110.7), whereas use of leaflet resection had an insignificant trend toward an increased reoperation rate (HR: 2.6; 95% CI: 0.9–9.1). The loop technique resulted in a larger effective orifice area and a lower transvalvular mean gradient than did leaflet resection.

As current literature shows, there seem to be three different surgical techniques (in combination with annuloplasty) with similar postoperative results for AML prolapse regarding freedom from MV-related reoperations:

- Transposition of chordae from the posterior to the anterior leaflet: the prerequisite of this technique is a healthy posterior leaflet without prolapse and/or elongated chordae. An advantage is the predefined length of chordae, which makes it a safe and highly reproducible technique. A disadvantage, however, is the reduction of the MV orifice area due to the quadrangular resection of the posterior leaflet.
- Edge-to-edge technique: this technique can be easily performed with short cross-clamp times. However, it can be used only in cases of unifocal AML prolapse. Furthermore, the length of the AML should exceed 30 mm to avoid excessive reduction in the MV orifice area resulting in mitral stenosis.
- Chordal replacement: this technique has many advantages. Implanted PTFE chordae get endothelialized and eventually become similar to native chordae tendineae over time. As no leaflet is



**Figure 12. Chordal replacement with PTFE.** (A) Artificial PTFE chords are seen anchored to the tips of the papillary muscle heads and to the free margin of the anterior mitral leaflet. (B) The temporary stay suture between the opposing segments of the anterior and posterior leaflets helps to maintain free margin of the prolapsing segment at the appropriate level, so that accurate measurement of the length and implantation of the neochords can be performed. Reproduced with permission of Wolters Kluwer Health from [23].



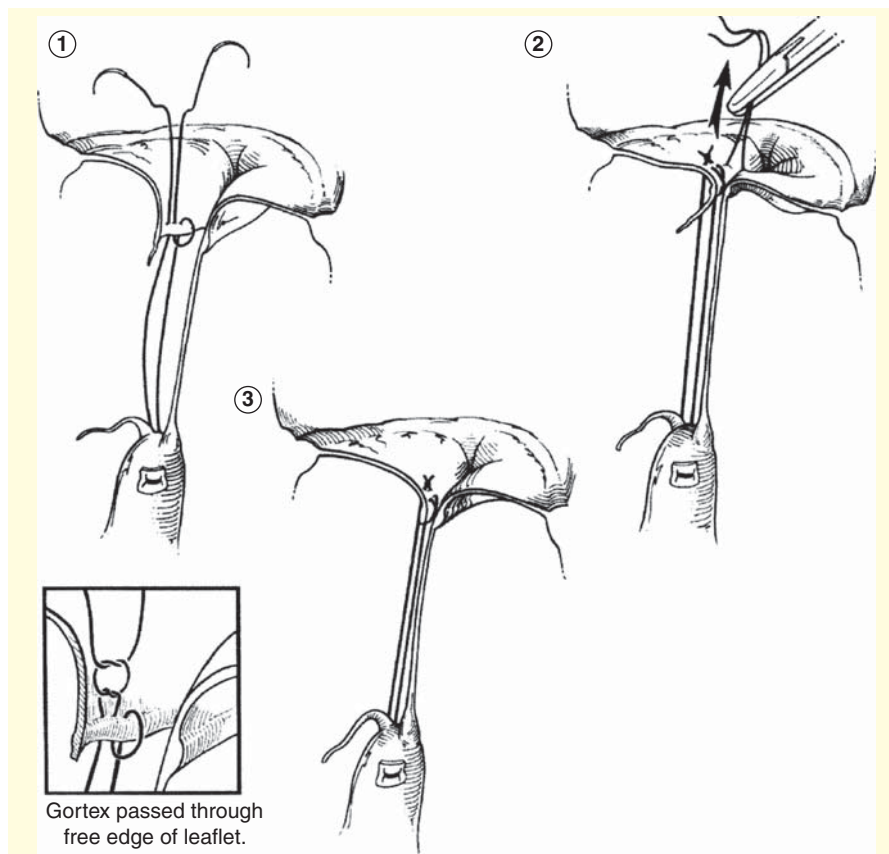
resected, the MV leaflet surface area is not compromised by the application of this technique. The only difficulty lies in the estimation of the proper length of the neochordae, in order to avoid prolapse or restriction of the leaflet. The so-called loop technique with the use of premeasured sutures makes this easy and reproducible, even through a minimally invasive approach.

So, what is the best repair technique for AML prolapse? In our experience, chordal replacement addresses the pathology of the anterior leaflet prolapse in the best possible way and provides a very good functional and morphological repair that is closest to nature and hence durable. It helps create a significantly greater area of coaptation compared with other techniques. We utilize the loop technique to repair the AML prolapse in majority of our patients with excellent results. In cases where we do encounter a hemodynamically relevant MR after repair, an edge-to-edge repair can be easily added to prevent MV replacement with minimal increase in aortic clamp time – always keeping in mind that the anterior leaflet needs to be larger than 30 mm to avoid a mitral stenosis.

### Five-year view

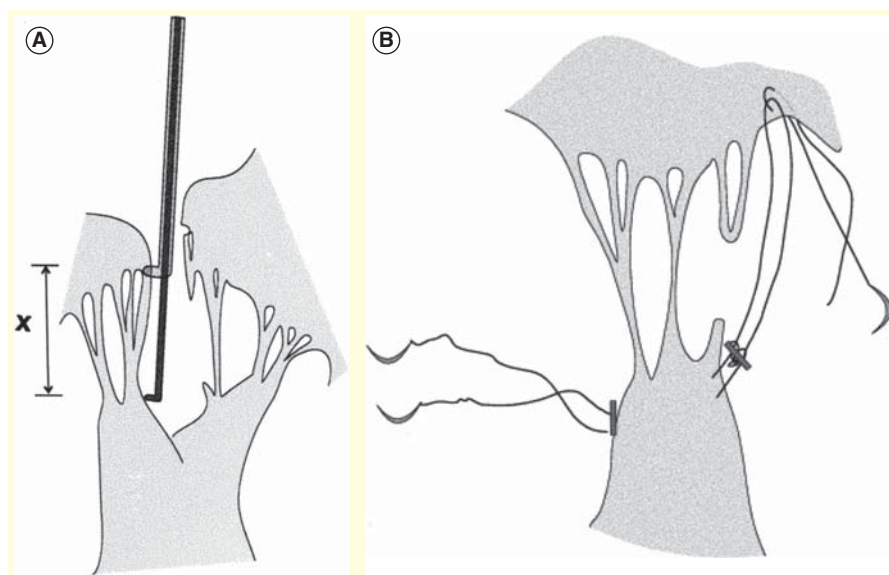
What will be the status of MV repair for AML prolapse in 5 years from now? Will there be an exclusive MV repair technique for AML prolapse?

Currently, great efforts are being undertaken to successfully and reliably accomplish MV repairs using catheter based and/or even completely percutaneous techniques. The Mitralclip<sup>®</sup> therapy, which is based on the principle of the edge-to-edge repair technique in patients with annular dilatation, is questionable. Recurrent MR in patients undergoing MV repair with the conventional edge-to-edge technique without the use of an accompanying ring annuloplasty is a true problem that tends to surface over time [9,10,49]. Thus, patients undergoing MV repair with the Mitralclip<sup>®</sup> would face the same problem of recurrent MR as the MV annulus is not addressed. The short-term results of the clip technique can be considered satisfactory, given the high-risk profile of



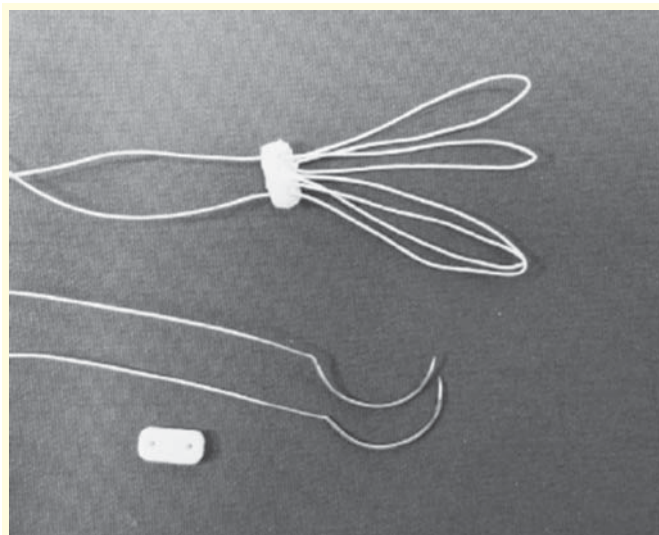
**Figure 13. Technique to define the correct length of the neochordae.**

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**Figure 14. Measurement of the correct loop length. (A) Measurement of the correct loop length with the caliper. (B) Implantation of the loop.**

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**Figure 15. Premeasured loops.**

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patient undergoing these procedures and the postoperative decrease in New York Heart Association class. However, long-term results are yet unknown.

In addition to this, there are several percutaneously and/or transapically implanted devices, used for annuloplasty and/or chordal replacement, under development. These are, however, in the very early stage of development and have to be refined and tested before being implemented into clinical practice. Until then, surgical MV repair is there to stay.

In this review, we have mainly focused on different surgical techniques used for repair of the AML prolapse. However, the operative approach has not yet been discussed. Which is the best approach, sternotomy or minimally invasive through the right anterior minithoracotomy? Since the late 1990s, the latter approach has become very common. Although, this approach was questioned initially, many studies can show today that the

results of minimally invasive surgery are as good as those with sternotomy [50,51]. Casselman *et al.* reported that 46.1% of their patients undergoing minimally invasive MV surgery went back to work 4 weeks after surgery [52]. Svensson *et al.* concluded in their paper on minimally invasive approach versus sternotomy for MV surgery, that minimally invasive MV surgery had cosmetic benefits, lower blood product use and respiratory complications, and pain advantages over conventional surgery, and no apparent detrimental effects [53]. Seeburger *et al.* showed that the minimally invasive approach can also be used effectively and safely in patients who have undergone previous cardiac surgery (especially coronary artery bypass graft surgery or aortic valve replacement with a sternotomy) [54].

Since the right minithoracotomy approach for MV repair has become a routine at our institute in the past decade, we find it to be an extremely comfortable approach with superior exposure of the AML and its associated pathologies, especially when compared with sternotomy. Hence, we highly recommend the treatment of AML prolapse with a minimally invasive MV repair through chordal replacement by loop technique accompanied by an appropriate annuloplasty ring by experienced hands. We do foresee, for reasons stated previously, that more and more surgeons all over the world will adopt this technique in the next 5–10 years, at least until catheter-based techniques become full proof.

Given the aforementioned, rather pronounced statement, “repair of the AML prolapse is challenging” may be history in the near future, as underlined by Castillo [55]: “A near 100% repair rate for mitral valve prolapse is achievable in a reference center.”

#### Financial & competing interests disclosure

*The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.*

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#### Key issues

- ‘Repair of anterior mitral leaflet prolapse is challenging’, is a statement commonly encountered in current surgical literature on the treatment of mitral valve regurgitation. However, with the availability of a variety of surgical options described above, this challenge can be overcome with the correct use of these techniques.
- Current literature suggests that chordal transposition, edge-to-edge repair and chordal replacement are surgical techniques that have similar long-term results. However, the former two techniques result in reduction of the mitral orifice area due to leaflet resection and creation of a double orifice mitral valve, respectively.
- Chordal replacement does not reduce the mitral orifice area as it follows the principle of ‘respect rather than resect’. It addresses the pathology of anterior leaflet prolapse in the best possible way and provides a very good functional and morphological repair that mimics the native valve and hence provides excellent long-term durability. We believe that chordal replacement is one of the most important factor for making anterior leaflet prolapse highly reparable in our institution. Chordal replacement with premeasured loops not only simplifies the technique, but also makes it reproducible and safe. It enables surgeons to achieve near 100% repair rates for anterior mitral leaflet prolapse, which would otherwise require complex reconstructive techniques.
- Finally, the loop technique makes this ‘so-called’ challenging repair safely and reliably possible even through a minimal access right anterior thoracotomy, which offers an excellent view of the anterior mitral leaflet.

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### Notice of correction

The version of this article published online ahead of print on 2 December 2013 contained a number of minor typographical errors. These have been corrected for this version.