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Mitral Valve Repair with Artificial Chords: Tips & Tricks

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Abstract

Mitral valve regurgitation (MR) is a common valvular disorder occurring in up to 10% of the general population. Mitral valve reconstructive strategies may address any of the components, annulus, leaflets and chords, involved in the valvular competence. The classical repair technique involves the resection of the prolapsing tissue. Chordal replacement was introduced already in the '60, but in the mid '80, some surgeons started to use expanded polytetrafluoroethylene (ePTFE) Gore-Tex sutures. In the last years, artificial chords have been exploited because of transcatheter techniques such as NeoChord DS 1000 (Neochord, USA) and Harpoon TSD-5. The first step is to achieve a good exposure of the papillary muscles that before approaching the implant of the artificial chords. Then, the chords are attached to the papillary muscle, with or without the use of supportive pledgets. The techniques to correctly implant artificial chords are many and might vary considerably from one center to another, but they can be summarized into three big families of suturing techniques: single, running or loop. Regardless of how to anchor to the mitral leaflet, the real challenge that many surgeons have taken on, giving rise to some very creative solutions, has been to establish an adequate length of the chords. It can be established basing on anatomically healthy chords, but it is important to bear in mind that surgeons work on the mitral valve when the heart is arrested in diastole, so this length could fail to replicate the required length in the full, beating heart. Hence, some surgeons suggested techniques to overcome this problem. Herein, we aimed to describe the current use of artificial chords in real world surgery, summarizing all the tips and tricks.

Mitral Valve Repair with Artificial Chords: Tips & Tricks

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ABSTRACT

Mitral valve regurgitation (MR) is a common valvular disorder occurring in up to 10% of the general population. Mitral valve reconstructive strategies may address any of the components, annulus, leaflets and chords, involved in the valvular competence. The classical repair technique involves the resection of the prolapsing tissue. Chordal replacement was introduced already in the '60, but in the mid '80, some surgeons started to use expanded polytetrafluoroethylene (ePTFE) Gore-Tex sutures. In the last years, artificial chords have been exploited because of transcatheter techniques such as NeoChord DS 1000 (Neochord, USA) and Harpoon TSD-5. The first step is to achieve a good exposure of the papillary muscles that before approaching the implant of the artificial chords. Then, the chords are attached to the papillary muscle, with or without the use of supportive pledgets. The techniques to correctly implant artificial chords are many and might vary considerably from one center to another, but they can be summarized into three big families of suturing techniques: single, running or loop. Regardless of how to anchor to the mitral leaflet, the real challenge that many surgeons have taken on, giving rise to some very creative solutions, has been to establish an adequate length of the chords. It can be established basing on anatomically healthy chords, but it is important to bear in mind that surgeons work on the mitral valve when the heart is arrested in diastole, so this length could fail to replicate the required length in the full, beating heart. Hence, some surgeons suggested techniques to overcome this problem.

Herein, we aimed to describe the current use of artificial chords in real world surgery, summarizing all the tips and tricks.

INTRODUCTION

Mitral regurgitation (MR) is a common valvular disorder occurring in up to 10% of the general population.[1] It is also the second most frequent indication for valve heart surgery in Europe.[2]

There are two pathways of MR, primary and secondary, and the indications for treatment vary accordingly.

In case of primitive MR, surgical treatment should be, whenever possible, the conservative one[2], as it is associated to better outcomes than surgical replacement[3].

Mitral valve (MV) reconstructive strategies may address any of the components involved in the valvular competence such as the annulus, the leaflets and chords. The classical repair technique encompasses the resection of the prolapsing tissue, the "French Correction"[4] . Chordal replacement was introduced already in the '60, when surgeons used silk and nylon[5,6]. Frater and colleagues[7]used glutaraldehyde fixed bovine

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pericardium to replace chords tendineae in a small number of patients with MR. Finally, in the mid '80, some surgeons started to use expanded polytetrafluoroethylene (ePTFE) Gore-Tex sutures[8,9]

In the last years, the concept of "respect rather than resect" has caught on, so the implantation of artificial chords to anchor the leaflets to the papillary muscles has been more widely used.[10,11] Alongside this concept, also the publication of satisfactory long-term results with 20-year freedom from re-operation ranging from 74% to 92%[12,13], contributed to the spread of this surgical approach. Moreover, in the last years, artificial chords have been exploited because of transcatheter techniques such as NeoChord DS 1000 (Neochord, USA) and Harpoon TSD-5 (Edwards Lifescience, USA), ChordArt (CoreMedic, Germany)[14,15].

Herein, we aimed to describe the current use of artificial chords in real world surgery, summarizing all the tips and tricks.

ARTIFICIAL CHORDS, STEP-BY-STEP.

Exposure of the papillary muscles

The first step is to achieve a good exposure of the papillary muscles that is of pivotal importance before approaching the implant of the artificial chords. Erlebach et al.[16] proposed an elegant way to push both MV leaflet aside to, using a standard valve prosthesis sizer so to have a clear view of the papillary muscles. They usually use a 29-mm valve sizer, advising to use smaller ones in case of a smaller mitral ring. Other surgeons[17] introduced a novel leaflets retractor manufactured from nickel–titanium alloy that can be easily rolled to a cylindrical form with a diameter of 15mm and grasped with a long needle holder. Once it is introduced into the MV annulus, releasing the needle holder, the retractor opens spontaneously, so that MV leaflets are pushed to the sides.

The attachment of the chords to the papillary muscle.

In most of cases, the surgeons prefer to use a pledget or a small pericardial patch as support to prevent any injury to the papillary muscle (PM) tip[18], otherwise a figure-of-eight suture or simply a U-stich are used[19].

The attachment of the chords to the mitral valve leaflets.

The techniques to implant the artificial chords are many and might vary considerably from one center to another. However, they can be summarized into three big families of suturing techniques: single[20,21], running[9] or loop chords.[22]

In the former technique, the ePTFE suture is passed through the free margin of the leaflet and anchored to the fibrous part of the PM. On the free margin of the leaflet, the suture is passed with both ends, which are then secured with knots.

At mid-term follow up, freedom from reintervention was 96 ± 4%, with only one patient undergoing reoperation because of hemolysis, but at the time of redo surgery, the artificial chords were found intact. In the same study, freedom from recurrent mitral regurgitation was 94 ± 4%[23].

Tirone David introduced the running suture to anchor ePTFE to the leaflet[24]. The suture is passed through the fibrous portion of the PM and the ends are tied together, leaving one end longer than the other. Then, the longer arm of the suture is passed one or two times through leaflet, 4-5 mm apart in the free margin. The same arm of the suture is brought inside the ventricle and passed again into PM head and then passed again through the free margin and from there back into the PM tip so to obtain numerous pairs of new chords (also known as multiple-loop technique). Recently, David[25] presented 20-year follow up, showing a cumulative of reoperation and MR recurrence were 4.2% and 14.1%, respectively. In case of running chords implantation, it is advisable to implant at least two sets because, if one breaks, there is still another one that is able to anchor the leaflet to the papillary muscle. Moreover, multiple sets even out the tension on the single suture and the chords adapt to the pressure exerted on the leaflet during systolic contraction.

Finally, surgeons from Leipzig[22] introduced the concept of the loop technique. It permits to create multiple loops of a prefixed length and anchored to a pledget placed on the PM, and each loop ligated to the free

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margin of the prolapsing segment with the knotting on the ventricular side, to avoid distortion of the free margin of the leaflet. The Leipzig group[26] recently published the results of their technique with a freedom from re-operation at 10 years up to 97 +- 1%.

Some modifications of the standard loop technique have been proposed over the years[27,28]; the use of small anchors to make easier eventual length adjustment after the hydrostatic test[27], or the use of small pieces of paper as wide as the desired length of the loop, which is tight around it[28].

The issue of the chordal length

Regardless of how to proceed to anchor the artificial chords to the PMs or to the mitral leaflet, the real challenge that many surgeons have taken on, giving rise to some very creative solutions, has been to establish an adequate length of the chord.

Ibrahim et al[29] tried to classify the different methods in some groups: fixed length with or without caliper, anatomical and adjustable length.

von Oppell and Mohr measured the length of the loop[22], taking into account the distance between the adjacent normal valve segment and the respective PM tip. Once the length is established, the surgeon constructs the loop using that fixed distance by means of a caliper. Then, the loop is attached to ventricular face of the free edge of the leaflet by means of a new Gore-Text suture passed inside the loop itself, while the two arms of the suture are passed into the PM head and knotted on two pledgets (Figure 1).

A different use of a caliper was proposed by Doi et al.[28] who passed the Gore-tex suture through the rough zone of the leaflet, from atrial to ventricular face, and then through the free edge of the leaflet. This leaves an adjustable loop, into which surgeon introduces the caliper set at a distance already established using preoperative transesophageal echocardiography. The loop is then tied. (Figure 2)

Matsui et al[30] introduced a new device consisting of two small metallic tubes with distal tip, one sliding over the other, to be used as a caliper. The exact length is established measuring the distance between the leaflet edge and the site of implantation of the artificial chords on the papillary muscle on the basis of a normal valve adjacent segment. The Gore-Tex suture can be tied without knot slipping.

Tam et al[31] proposed a technique similar to the one introduced by others[22], rolling a 4-0 ePTFE suture around a caliper at a fixed length and then the loops are fixed with a 5-0 ePTFE sutures and onto the PM tips using two pledgets.

Other authors suggested to determine the length of chords without using a caliper, by means of a series of tight reverse knots corresponding to a certain length[32], or tying loops at a predetermined length temporarily fixing them at a specific length using either a slit tube[33] (Figure 3) or a tourniquet[34], or fixing chordal length using a tube, that is after tying the chords to the papillary muscle using a pledget, the arms of the suture are each passed through plastic tubes cut to the required length. The sutures are tied down over the tube. After tying, the tubes are cut-off the chords[35]. Chan et al[36] proposed to mark the correct length (already established on the basis of the length of a normal chord) with a marker pen and then a covered clip holds the chords at the correct length, allowing them to be tied without movement (Figure 4).

All the mentioned techniques foresee the measure of new chordal length based on anatomically healthy chords, but it is important to bear in mind that surgeons work on the mitral valve when the heart is arrested in diastole, so this length could fail to replicate the required length in the full, beating heart.

Indeed, to overcome this possible bias, Calafiore[21]proposed to pull the anterior leaflet (AL) with nerve hooks up to its maximum length and then to tie the artificial chord adding 5 mm to the border of the AL (Figure 5).

Other proposed alternatives are to tie the chords under LV loading condition, that is after filling the left chamber with saline, using a temporary Alfieri stitch[37,38] or a clip[39] to hold the leaflets coapting.

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Another key point to take in mind implanting artificial chords is the issue of of knot slipping. Indeed, ePTFE sutures are very slippery, so the final length of the new chords may change when surgeon ties the knot. To avoid this possible mishap, some methods have been proposed[20,40].

Maselli et al[40] proposed an adjustable loop technique consisting of two parts: a papillary component with arrest knots at constant intervals and a leaflet component with a reversible noose-lace to fix the loop to one of the knots on the papillary component. After implantation and coupling of the two components at a presumable optimal length, a prosthetic ring is sutured in place. Hydrostatic testing is then performed. Optimal chords length can be obtained by releasing the noose-lace and sliding it over another fixing-knot. The adjustment can be performed as often as required without placing stress on the anatomic structures. The great advantage of this approach is that can be \soutto be done without damaging the neochords anchors at the leaflet or papillary component (Figure 6). Another approach to prevent knot-slipping is tying multiple knots to a normal leaflet scallop so to calculate the number of knots to be used in the prolapsing scallop, tying the suture only after filling test[20]. (Figure 7)

DRAWBACKS OF ARTIFICIAL CHORDS

MV repair is expected to last up to 20 years[12,13,25,41]. Nevertheless, there are some drawbacks that surgeons need to know when planning to perform a MV repair.[42] There are mainly three reasons for which a MV repair could fail, which are technical failures, progression of the disease or new disease (for example endocarditis).[43]This paragraph is focused on technical failures that a surgeon could encounter when utilizing artificial chords.

The symptomatology of patients facing failure of artificial chords varies. In the literature there are some reports regarding the presence of hemolytic anemia as presentation of mitral valve repair failure, which might be due to the lack of endothelization of the artificial chords[44].

First of all, artificial chords might break over time[45-47], possibly because of hyalinization of pores of ePTFE or calcification, even if it is not fully demonstrated, because of the paucity of scientific data. Therefore, surgeons should avoid pinching ePTFE with forceps and clamps at the time of surgery. Risk of MV repair failure is higher in case of chordal rupture and it is particularly higher when thinner suture (CV5) are used[48], in line with the previously described biomechanical studies.

Another hot topic regarding the failure of artificial chords is the effect of the remodeling of the left ventricle. It is possible that the positive remodeling of the left ventricle after correction of the mitral regurgitation might cause a mismatch between the artificial chords and the native ones[49]. Therefore, when facing patients with extremely dilated left ventricles, surgeons should measure the artificial chords bearing in mind that the left ventricle volumes might reduce over time[50].

CONCLUSIONS

In the current era, MR should be treated with MV repair whenever possible. Besides classical corrective techniques, the knowledge of artificial chords offers to the surgeon a strong tool to treat degenerative MR. Therefore, surgeons interested in MV repair should be familiar with artificial chords, to be able to customize each repair depending on the single mitral valve.

References

1. Wu S, Chai A, Arimie S, Mehra A, Clavijo L, Matthews RV, Shavelle DM. Incidence and treatment of severe primary mitral regurgitation in contemporary clinical practice. Cardiovasc Revasc Med. 2018 Dec;19(8):960-963
2. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, et al; ESC/EACTS Scientific Document Group. 2021 ESC/EACTS Guidelines for the management of valvular heart disease. Eur J Cardiothorac Surg. 2021 Oct 22;60(4):727-800.
3. Jung JC, Jang MJ, Hwang HY. Meta-analysis comparing mitral valve repair versus replacement for degenerative mitral regurgitation across all ages. Am J Cardiol 2019;123:446453.

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4. Carpentier A. Cardiac valve surgery—the "French correction." J Thorac Cardiovasc Surg 1983;86:323–3
5. Kay JH, William S, Egerton WS: The repair of mitral insufficiency associated with ruptured chords tendineae. Ann Surg 1963;157:351-360.
6. Morris JD, Penner DA, Brandt RL, et al: Surgical correction of ruptured chords tendineae. J Thorac Cardiovasc Surg 1964; 48:772-780,
7. Frater RWM, Gabbay S, Shore D, et al: Reproducible replacement of elongated or ruptured mitral valve chords. Ann Thorac Surg 35:14-18, 1983
8. Vetter HO, Factor SM, Frater RW. The use of glycerol-treated homologous pericardium as a substitute for cusps and chords tendineae of the mitral valve in sheep. Thorac Cardiovasc Surg 1987;35:11–5.
9. David TE. Replacement of chords tendineae with expanded polytetrafluoroethylene sutures. J Card Surg. 1989;4:286-90.
10. Perier P, Hohenberger W, Lakew F, Batz G, Urbanski P, Zacher M, Diegeler A. Toward a new paradigm for the reconstruction of posterior leaflet prolapse: midterm results of the "respect rather than resect" approach. Ann Thorac Surg. 2008 Sep;86(3):718-25
11. Mazine A, Friedrich JO, Nedadur R, Verma S, Ouzounian M, Juni P, Puskas JD, Yanagawa B. Systematic review and meta-analysis of chordal replacement versus leaflet resection for posterior mitral leaflet prolapse. J Thorac Cardiovasc Surg. 2018 Jan;155(1):120-128.
12. Hata H, Fujita T, Shimahara Y, Sato S, Ishibashi-Ueda H, Kobayashi J. A 25-year study of chordal replacement with expanded polytetrafluoroethylene in mitral valve repair. Interact Cardiovasc Thorac Surg. 2015 Apr;20(4):463-8
13. Salvador L, Mirone S, Bianchini R, Regesta T, Patelli F, Minniti G, Masat M, Cavarretta E, Valfre C. A 20-year experience with mitral valve repair with artificial chords in 608 patients. J Thorac Cardiovasc Surg. 2008 Jun;135(6):1280-7
14. Seeburger J, Rinaldi M, Nielsen SL, Salizzoni S, Lange R, Schoenburg M, Alfieri O, Borger MA, Mohr FW, Aidietis A. Off-pump transapical implantation of artificial neo-chords to correct mitral regurgitation: the TACT Trial (Transapical Artificial Chords Tendinae) proof of concept. J Am Coll Cardiol. 2014 Mar 11;63(9):914-9
15. Gammie JS, Wilson P, Bartus K, Gackowski A, Hung J, D'Ambra MN, Kolsut P, Bittle GJ, Szymanski P, Sadowski J, Kapelak B, Bilewska A, Kusmierczyk M, Ghoreishi M. Transapical Beating-Heart Mitral Valve Repair With an Expanded Polytetrafluoroethylene Cordal Implantation Device: Initial Clinical Experience. Circulation. 2016 Jul 19;134(3):189-97
16. Erlebach M, Lange R, Mazzitelli D. Placement of Neochords in Mitral Valve Repair: Enhanced Exposure of the Papillary Muscles Using a Standard Valve Sizer. Ann Thorac Surg. 2016 Jan;101(1):378-80
17. Tudorache I, Haverich A. Enhanced exposure of subvalvular structures during mitral valve repair with a novel flexible and reusable leaflets retractor. J Thorac Cardiovasc Surg. 2018 Aug;156(2):643-645
18. Kasegawa H, Kamata S, Hirata S, Kobayashi N, Mannouji E, Ida T et al. Simple method for determining proper length of artificial chords in mitral valve repair. Ann Thorac Surg 1994;57:237–8. discussion 238–239.
19. Moorjani N, Viola N, Janusauskas V, Livesey S. Adjusting the length of artificial polytetrafluoroethylene chords in mitral valve repair by a single loop technique. J Thorac Cardiovasc Surg 2009;138:1441–2.
20. Shudo Y, Taniguchi K, Takahashi T, Matsue H. Simple and easy method for chordal reconstruction during mitral valve repair. Ann Thorac Surg. 2006;82(1):348-9.
21. Calafiore AM. Choice of artificial chords length according to echocardiographic criteria. Ann Thorac Surg 2006;81:375–7
22. von Oppell UO, Mohr FW. Chordal replacement for both minimally invasive and conventional mitral valve surgery using premeasured Gore-Tex loops. Ann Thorac Surg 2000;70:2166–8
23. Maeda S, Funatsu T, Kondoh H, Shibukawa T, Yokota T, Kainuma S, Toda K, Sawa Y, Taniguchi K. Intermediate-term outcomes of our original multiple-knot technique using ePTFE sutures for anterior mitral leaflet prolapse. Surg Today. 2019 Apr;49(4):350-356.
24. David TE. Artificial chords. Semin Thorac Cardiovasc Surg. 2004;16(2):161-8.

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25. David TE, David CM, Lafreniere-Roula M, Manlhiot C. Long-term outcomes of chordal replacement with expanded polytetrafluoroethylene sutures to repair mitral leaflet prolapse. J Thorac Cardiovasc Surg. 2020 Aug;160(2):385-394.e1
26. Pfannmueller B, Misfeld M, Verevkin A, Garbade J, Holzhey DM, Davierwala P, Seeburger J, Noack T, Borger MA. Loop neochord versus leaflet resection techniques for minimally invasive mitral valve repair: long-term results. Eur J Cardiothorac Surg. 2021 Jan 4;59(1):180-186. doi: 10.1093/ejcts/ezaa255. PMID: 32776150.
27. Isoda S, Osako M, Kimura T, Mashiko Y, Yamanaka N, Nakamura S, Maehara T. The "loop with anchor" technique to repair mitral valve prolapse. Ann Thorac Cardiovasc Surg. 2012;18(2):170-3.
28. Doi A, Iida H, Sunazawa T. Intracardiac calipers for artificial chords replacement in mitral valve repair. Ann Thorac Surg 2009;87:326–8.
29. Ibrahim M, Rao C, Athanasiou T. Artificial chords for degenerative mitral valve disease: critical analysis of current techniques. Interact Cardiovasc Thorac Surg. 2012 Dec;15(6):1019-32
30. Matsui Y, Fukada Y, Naito Y, Sasaki S, Yasuda K. A new device for ensuring the correct length of artificial chords in mitral valvuloplasty. Ann Thorac Surg 2005;79:1064–5
31. Tam R, Joshi P, Konstantinov IE. A simple method of preparing artificial chords for mitral valve repair. J Thorac Cardiovasc Surg 2006;132: 1486–7.
32. Mandegar MH, Yousefnia MA, Roshanali F. Preoperative determination of artificial chords length. Ann Thorac Surg 2007;84:680–2.
33. Chang JP, Kao CL. Slit stent technique for ensuring the correct length of artificial chords in mitral repair. J Card Surg 2011;26:259–60.
34. Chocron S. Removable clips for mitral valve repair. J Thorac Cardiovasc Surg 2007;133:1682–3.
35. Matsui Y, Kubota S, Sugiki H, Wakasa S, Ooka T, Tachibana T et al. Measured tube technique for ensuring the correct length of slippery artificial chords in mitral valvuloplasty. Ann Thorac Surg 2011; 92:1132–4
36. Chan DT, Chiu CS, Cheng LC, Au TW. Artificial chords: a simple clip and tie technique. J Thorac Cardiovasc Surg 2008;136:1597–9
37. Fattouch K, Bianco G, Sbraga F, Sampognaro R, Ruvolo G. Simple, safe and easy technique to ensure the correct length of artificial chords in mitral valve repair. Ann Thorac Surg 2007;83:1902–3.
38. Duran CM, Pekar F. Techniques for ensuring the correct length of new mitral chords. J Heart Valve Dis 2003;12:156–61.
39. Rankin JS, Orozco RE, Rodgers TL, Alfery DD, Glower DD. Adjustabl artificial chordal replacement for repair of mitral valve prolapse. Ann Thorac Surg 2006;81:1526–8.
40. Maselli D, De Paulis R, Weltert L, Salica A, Scaffa R, Bellisario A et al. A new method for artificial chords length 'tuning' in mitral valve repair preliminary experience. J Thorac Cardiovasc Surg 2007;134:454–9.
41. Sideris K, Burri M, Prinzing A, Voss S, Krane M, Guenzinger R, Lange R, Voss B. Mitral valve repair with the edge-to-edge technique: A 20 years single-center experience. J Card Surg. 2021 Apr;36(4):1298-1304. doi: 10.1111/jocs.15377. Epub 2021 Jan 29. PMID: 33512725.
42. Calafiore AM, Totaro A, Foschi M, Di Mauro M. Durability of mitral valve repair for degenerative mitral regurgitation: is it gold all that glitters? Ann Transl Med. 2018 Nov;6(Suppl 1):S10. doi: 10.21037/atm.2018.08.43
43. Trumello C, Giambuzzi I, Del Forno B, Bargagna M, Blasio A, Ruggeri S, Meneghin R, Schiavi D, Nascimbene S, Castiglioni A, Alfieri O, De Bonis M. Re-repair after previous mitral valve reconstruction: handle with care! Interact Cardiovasc Thorac Surg. 2020 Jul 1;31(1):35-41.
44. Nakaoka Y, Kubokawa SI, Yamashina S, et al. Late rupture of artificial neochords associated with hemolytic anemia. *J Cardiol Cases* . 2017;16(4):123-125. Published 2017 Jul 26. doi:10.1016/j.jccase.2017.06.007
45. Bortolotti U, Celiento M, Pratali S, et al. Recurrent mitral regurgitation due to ruptured artificial chords: case report and review of the literature. J Heart Valve Dis. 2012;21:440-443.
46. Castillo JG, Anyanwu AC, El-Eshmawi A, Gordon RE, Adams DH. Early rupture of an expanded

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polytetrafluoroethylene neochord after complex mitral valve repair: an electron microscopic analysis. J Thorac Cardiovasc Surg 2013;145: e29–31.
47. Coutinho GF, Carvalho L, Antunes MJ. Acute mitral regurgitation due to ruptured ePTFE neo-chords. J Heart Valve Dis 2007;16:278–82
48. Butany J, Collins MJ, David TE. Ruptured synthetic expanded polytetrafluoroethylene chords tendineae. Cardiovasc Pathol. 2004;13:182-184
49. Mutsuga M, Narita Y, Tokuda Y, Uchida W, Ito H, Terazawa S, Nakaguro M, Usui A. Predictors of Failure of Mitral Valve Repair Using Artificial Chords. Ann Thorac Surg. 2021 May 19:S0003-4975(21)00864-X. doi: 10.1016/j.athoracsur.2021.04.084
50. Moore RA, Wierup P, Burns DJP, Gillinov AM. Early failure after non-resectional mitral valve repair with artificial chords. J Card Surg. 2020 Sep;35(9):2432-2435.

Figure legends

Figure 1. The loop technique proposed by von Oppell and Mohr[22] (see text)

Figure 2. A different use of a caliper was proposed by Doi et al.[28] (see text)

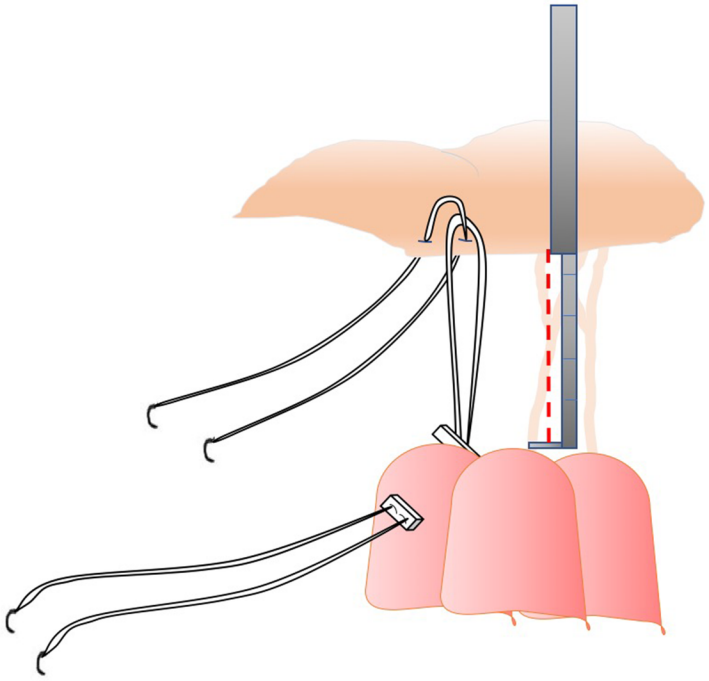
Figure 3. Loops are tied at a predetermined length temporarily fixing them at a specific length using a slit tube, as proposed by Chang et al[33]

Figure 4. Chan et al[36] proposed the use of a covered clip holding the chords at the correct length, allowing them to be tied without movement

Figure 5. Calafiore[21] proposed to pull the anterior leaflet (AL) with nerve hooks up to its maximum length and then to tie the artificial chord adding 5 mm to the border of the AL

Figure 6. Maselli et al[40] proposed a tuneable loop technique (see text)

Figure 7. Shudo et al[20] proposed to tie multiple knots to a normal leaflet scallop so to calculate the number of knots to use in the prolapsing scallop, tying the suture only after filling test, in order to prevent knot-slipping.



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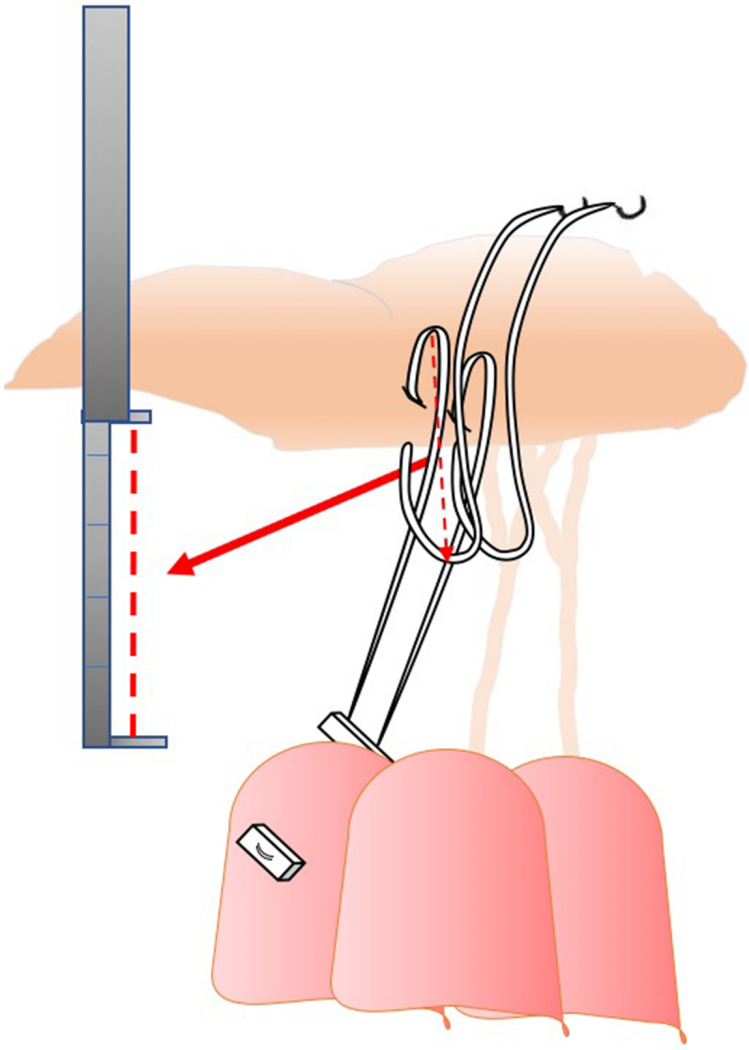

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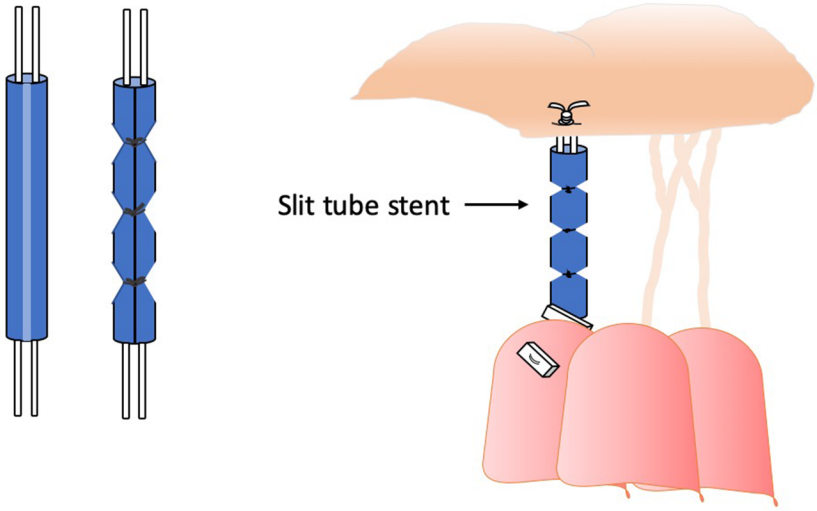

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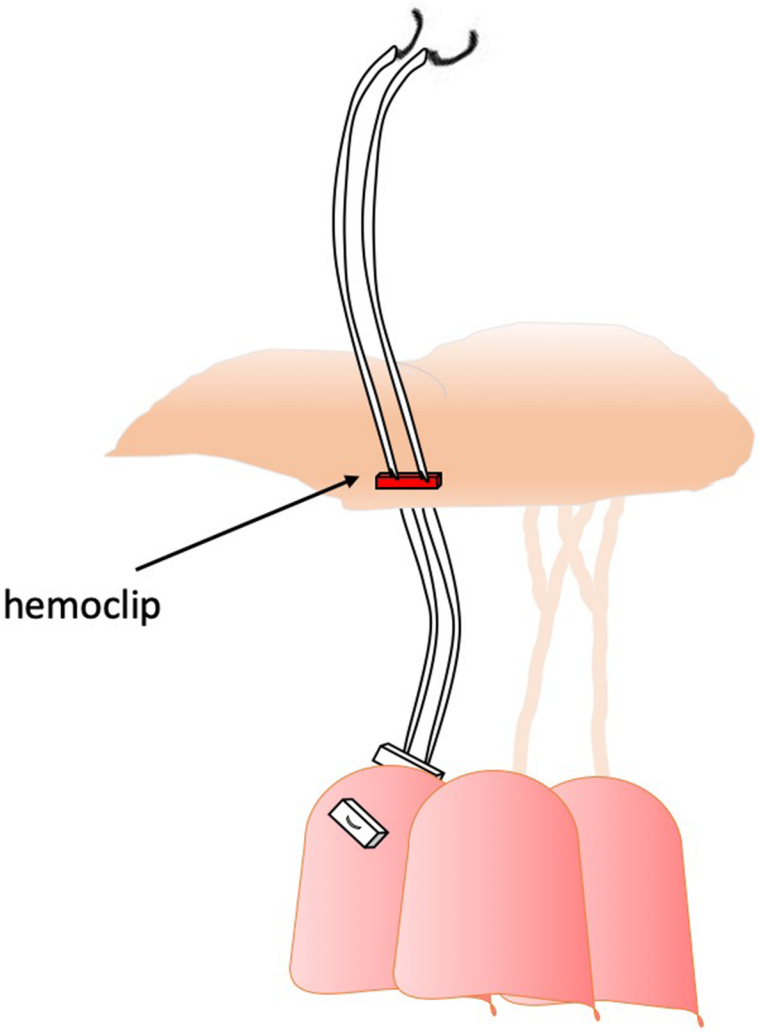

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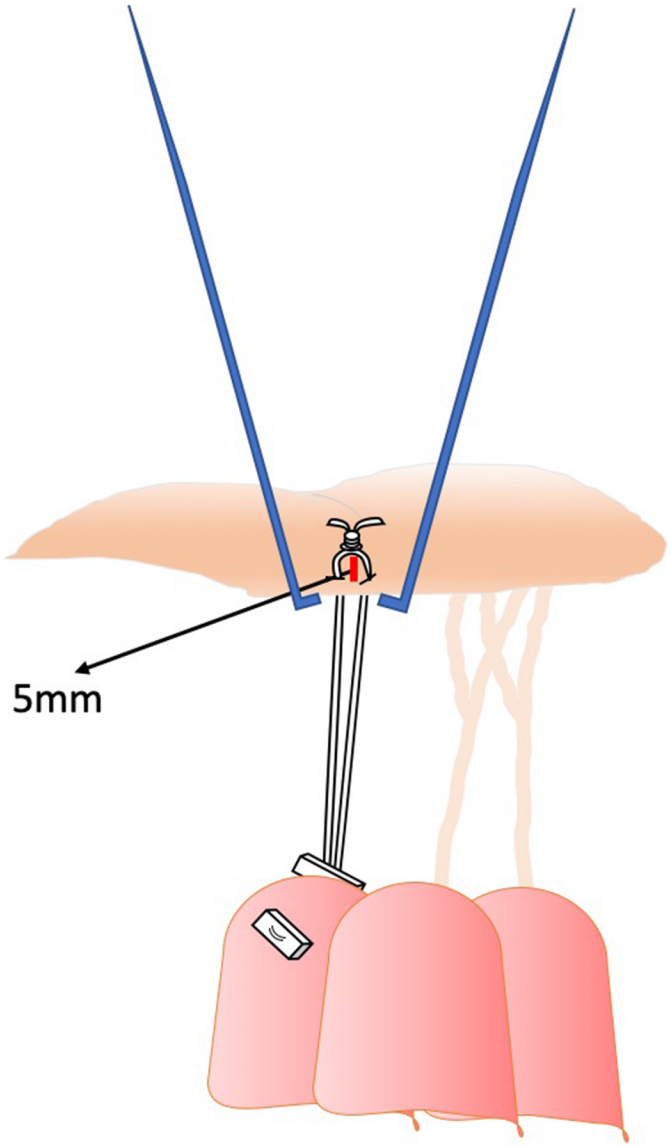

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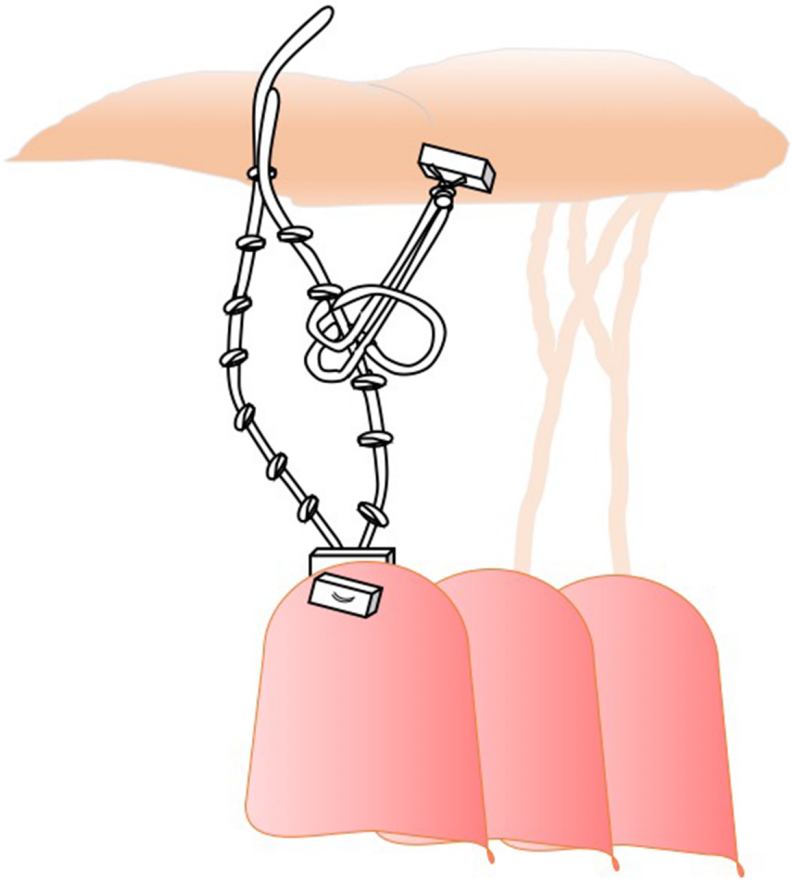

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