3. Ouzounian M, Rao V, Manlhiot C, Abraham N, David C, Feindel CM, et al. Valve-sparing root replacement compared with composite valve graft procedures in patients with aortic root dilation. *J Am Coll Cardiol*. 2016;68:1838-47.
4. Schneider U, Feldner SK, Hofmann C, Schope J, Wagenpfeil S, Giebels C, et al. Two decades of experience with root remodeling and valve repair for bicuspid aortic valves. *J Thorac Cardiovasc Surg*. 2017;153:S65-71.
5. Boodhwani M, de Kerchove L, Glineur D, Rubay J, Vanoverschelde JL, Noirhomme P, et al. Repair of regurgitant bicuspid aortic valves: a systematic approach. *J Thorac Cardiovasc Surg*. 2010;140:276-84.e1.
6. Akins CW, Travis B, Yoganathan AP. Energy loss for evaluating heart valve performance. *J Thorac Cardiovasc Surg*. 2008;136:820-33.
7. Cameron DE, Alejo DE, Patel ND, Nwakanma LU, Weiss ES, Vricella LA, et al. Aortic root replacement in 372 Marfan patients: evolution of operative repair over 30 years. *Ann Thorac Surg*. 2009;87:1344-9.
8. Kvitting JP, Kari FA, Fischbein MP, Liang DH, Beraud AS, Stephens EH, et al. David valve-sparing aortic root replacement: equivalent mid-term outcome for different valve types with or without connective tissue disorder. *J Thorac Cardiovasc Surg*. 2013;145:117-26, 127.e1-5.
9. Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. *J Thorac Cardiovasc Surg*. 2007;133:1226-33.
10. Fazel SS, Mallidi HR, Lee RS, Sheehan MP, Liang D, Fleischman D, et al. The aortopathy of bicuspid aortic valve disease has distinctive patterns and usually involves the transverse aortic arch. *J Thorac Cardiovasc Surg*. 2008;135:901-7, 907.e1-2.
11. Kari FA, Liang DH, Kvitting JP, Stephens EH, Mitchell RS, Fischbein MP, et al. Tirone David valve-sparing aortic root replacement and cusp repair for bicuspid aortic valve disease. *J Thorac Cardiovasc Surg*. 2013;145:S35-40.e1-2.
12. Ashikhmina E, Sundt TM III, Dearani JA, Connolly HM, Li Z, Schaff HV. Repair of the bicuspid aortic valve: a viable alternative to replacement with a bioprosthesis. *J Thorac Cardiovasc Surg*. 2010;139:1395-401.
13. Svensson LG, Al Kindi AH, Vivacqua A, Pettersson GB, Gillinov AM, Mihaljevic T, et al. Long-term durability of bicuspid aortic valve repair. *Ann Thorac Surg*. 2014;97:1539-47.
14. Aicher D, Kunihara T, Abou Issa O, Brittner B, Graber S, Schafers HJ. Valve configuration determines long-term results after repair of the bicuspid aortic valve. *Circulation*. 2011;123:178-85.
15. Kari FA, Kvitting JP, Stephens EH, Liang DH, Merk DR, Fischbein MP, et al. Tirone David procedure for bicuspid aortic valve disease: impact of root geometry and valve type on mid-term outcomes. *Interact Cardiovasc Thorac Surg*. 2014;19:375-81.
16. Bavaria JE, Desai N, Szeto WY, Komlo C, Rhode T, Wallen T, et al. Valve-sparing root reimplantation and leaflet repair in a bicuspid aortic valve: comparison with the 3-cusp David procedure. *J Thorac Cardiovasc Surg*. 2015;149:S22-8.
17. de Kerchove L, Boodhwani M, Glineur D, Vandyck M, Vanoverschelde JL, Noirhomme P, et al. Valve sparing-root replacement with the reimplantation technique to increase the durability of bicuspid aortic valve repair. *J Thorac Cardiovasc Surg*. 2011;142:1430-8.

Key Words: aneurysm, aortic root, aortic valve repair, bicuspid aortic valve

Discussion

Dr Lars G. Svensson *(Cleveland, Ohio)*. Maral, that is a wonderful report and your team has certainly led the efforts in this area. I would like to separate out your procedures, though, because I think many of us have believed that remodeling is the operation of choice for patients with bicuspid valves, but increasingly we are using reimplantation in the patients with bicuspid valves. You also point out in your manuscript that you were highly selective in using reimplantation for patients with bicuspid valves. We have done the same; our ratios are about the same. As of the end of March we have done 677 reimplantations of which 102 were bicuspid valves, so a low rate versus remodeling, and in our series there have been overall 3 deaths, and for elective procedures in 617 patients, 1 death, so a very safe operation.

I have a couple of questions for you. In the paper there was maybe a contradiction between what you said in the paper and your tables. Our general rule, as Craig Miller has pointed out to us, is using a bigger graft in the bicuspid valves; we will go out to a 32, 34 graft. Unless there is an error in your paper, the text section, it looks like you should have switched that, that you used in fact a bigger graft in your bicuspid valves. That's the first question.

And the other interesting reference in your paper is that your mean size of the aorta with bicuspid valves was 5.2 cm $\pm$ 8 mm. So, can you just talk a bit about your procedure when it comes to your choice of graft and the type of patients you are putting it into, for the reimplantation group of procedures?

Dr Maral Ouzounian *(Toronto, Ontario, Canada)*. Thank you very much, Dr Svensson, and thank you for discussing the paper. We have been, as you said, very selective in who gets a valve-sparing operation in patients with bicuspid aortic valves. We have done isolated bicuspid valve repair at our institution, but anyone with even moderate root dilatation, and particularly those with annuloaortic ectasia, so an annulus, anything really above 26, 27 mm, we favor reimplantation to stabilize the annulus long-term.

The graft sizing has been written about extensively, and with Dr David, there is a whole bunch of formulas with calculations, and it ends up being more of an art form than an eyeball choice, truthfully, than an actual calculation. But the graft sizes were and do tend to be slightly larger in patients with bicuspid valves.

Dr Svensson. So it sounds like you are following a bit what Mike Borger wrote about when he was with Tirone that 4.5 cm and bigger you will replace the root.

Another question is your repair technique for the actual leaflets. In 77% of the patients with bicuspid valves you did plications, and obviously that is the asymmetric values, usually, but you used a running suture on the leaflet edge in one quarter. I would like to hear you comment a bit more about that. Tirone has talked about it. I am increasingly convinced that in bicuspid valves we probably should be doing that more often, in other words, using a running suture on that leading edge, because I think over time some of the failures we have seen with bicuspid valve repairs is that the

leaflets stretch; even if you have a perfect symmetrical result, over time those leaflets will still stretch. Increasingly, I am using a running leaflet edge stitch for bicuspid valve repairs. Any comments about that?

Dr Ouzounian. Initially examining the leaflet, about a third of the patients had their raphe resected or shaved off. If it was thick and fibrous or even a little bit calcified, it would be resected and then either primarily repaired—none of these patients had a patch, they were mostly primarily repaired—or just shaved off.

And then we favor plication. The patients who had a running stitch rather than plication were more patients with fenestrations along the commissures. But your point is an interesting one. I think that may potentially be a factor for late durability.

Dr Svensson. One other final comment and question for you to comment on is that you had 47 patients with bicuspid valves, not all of those, I presume, were reimplantations, and the failure rates if you look at moderate severe aortic insufficiency and reoperations at 10 years is 18.8%, if you combine those. Although you say there is no difference, you may not have had statistical power to show the difference, and the 2 graphs you show have a divergence between the bicuspid valves and the tricuspid valves, and this is a very long series. Over time, what have you done to try and make your bicuspid valve repairs last better after reimplantation?

The reason why I ask that is because it is going to be a very different reoperation to do for a redo reimplantation than it is going to be for a patient who has had a remodeling or, for that matter, if a patient doesn't have a root procedure, just a bicuspid valve repair.

Dr Ouzounian. Thank you. Excellent comment. Only 2 of the patients among the 47 had remodeling, and those 2 had a smaller annulus and they were older patients, and interestingly, neither of those 2 had any of the failures, neither of those 2 were in the failure group.

Over time we have changed a few things that we have done. One is to be more aggressive with leaflet repair in general, so more plication over time has happened. Dr David now also uses Dr Gleason's described technique of actually detaching the fused cusps from the aortic annulus and moving it down to the right ventricular outflow tract with a pericardial patch, which is not at the leaflet edge but rather on the inner surface at the base of the leaflet. We will see how those techniques evolve.

Dr Svensson. Congratulations on a great paper.

Dr Malakh Lal Shrestha *(Hannover, Germany)*. In the 77% of the patients where you did the leaflet plasty, did you see any stenosis in follow-up?

Dr Ouzounian. No. We have not seen anyone come back for a stenotic valve. I can't comment exactly on the gradients over time, we haven't look at that, but that is an interesting point.

Dr Michael A. Borger *(Leipzig, Germany)*. Is calcium on the aortic valve cusps a contraindication?

Dr Ouzounian. We have been quite selective. So a little bit of calcium that we can shave off we will, but a heavy amount of calcification that makes a leaflet immobile, we would replace those valves.

Dr Joseph S. Coselli *(Houston, Tex)*. Maral, a great presentation. You have shown us some of your other studies that the patients who undergo remodeling with Marfan syndrome have had a much worse outcome. You have a very high percentage of Marfan in your tricuspid and the usual in the bicuspid. Since you know that those were possibly at much higher risk of failure, did you think about pulling those out of the analysis to compare them?

And the second question is, you showed a difference between the bicuspid and tricuspid, and you mentioned that one of the possible differences is age. You can statistically adjust those curves to see if age really was a factor or it wasn't.

Dr Ouzounian. Those are good points. In the first decade, some of the Marfan patients had remodeling, but in the later era that stopped, and almost none of the bicuspid valve patients had remodeling because we learned the patients having reimplantation with bicuspid valves come with an aortic root phenotype and they have annuloaortic ectasia; they are in fact quite phenotypically similar to the Marfan patients.

I think the age idea is excellent. We may be a little bit underpowered to stratify that.

Dr Coselli. I know your group saves any valve you possibly can, we get that, but part of the stress on the aortic valve leaflet has to do with the fact that the tricuspid valve can open to the full circumference of the aortic annulus, because if you look at the free edge of the leaflet and the circumference, basically you have got 6 times R and that's what the free edge is. In a bicuspid valve, it is only 4 times R, and that's why on echo we see a fish-mouth opening, and the stress levels on those kinds of leaflets are far different. At 8 years, you are sort of getting to the point almost where if you replaced it just simply with a tissue valve you would begin to start seeing a follow-up. So, we are very much looking forward to the longer-term follow-up.

I know that they are highly selective, but how do they really compare to the patients who underwent just a Bentall operation?

Dr Ouzounian. Of course, they are different patients. We published in *JACC* last year looking at Bentall with biological or mechanical valves compared with valve-sparing roots and showed what you would expect but improved outcomes following valve-sparing root procedures. But we have been selective. And I think the stresses on the leaflets

and the root dynamics is an interesting one where we have some 4D flow MRI studies in place right now looking at re-implantation, remodeling in patients with bicuspid and tricuspid valves following valve-sparing root procedures. It is very preliminary, but we are looking forward to sharing those data.