Rapid right ventricular pacing for balloon valvuloplasty in congenital aortic stenosis: A systematic review

Konstantinos S Mylonas, Ioannis A Ziogas, Charitini S Mylona, Dimitrios V Avgerinos, Christos Bakoyiannis, Fotios Mitropoulos, Aphrodite Tzifa

**ORCID number:** Konstantinos S Mylonas 0000-0002-2356-6694; Ioannis A Ziogas 0000-0002-6742-6909; Charitini S Mylona 0000-0003-3969-8031; Dimitrios V Avgerinos 0000-0003-2409-2188; Christos Bakoyiannis 0000-0002-7613-3200; Fotios Mitropoulos 0000-0003-3928-6897; Aphrodite Tzifa 0000-0002-5883-1021.

**Author contributions:** Mylonas KS did conception/design of the study, acquisition, analysis and interpretation of data, manuscript drafting, critical revision, final approval; Ziogas IA did acquisition, analysis and interpretation of data, manuscript drafting, critical revision, final approval; Mylona C did acquisition of data, critical revision, final approval; Avgerinos DV, Bakoyiannis C, Mitropoulos F and Tzifa A did conception/design of the study, critical revision, final approval.

**Conflict-of-interest statement:** The authors have no conflict of interest and no financial ties to declare.

**PRISMA 2009 Checklist statement:** We conducted the present systematic review according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.

**Abstract**

**BACKGROUND**

Balloon aortic valvuloplasty (BAV) is a well-established treatment modality for congenital aortic valve stenosis.

**AIM**

To evaluate the role of rapid right ventricular pacing (RRVP) in balloon stabilization during BAV on aortic regurgitation (AR) in pediatric patients.

**METHODS**

A systematic review of the MEDLINE, Cochrane Library, and Scopus databases was conducted according to the PRISMA guidelines (end-of-search date: July 8, 2020). The National Heart, Lung, and Blood Institute and Newcastle-Ottawa scales was utilized for quality assessment.
RESULTS

Five studies reporting on 72 patients were included. The studies investigated the use of RRVP-assisted BAV in infants (> 1 mo) and older children, but not in neonates. Ten (13.9%) patients had a history of some type of aortic valve surgical or catheterization procedure. Before BAV, 58 (84.0%), 7 (10.1%), 4 (5.9%) patients had AR grade 0 (none), 1 (trivial), 2 (mild), respectively. After BAV, 34 (49.3%), 6 (8.7%), 26 (37.7%), 3 (4.3%), patients had AR grade 0, 1, 2, and 3 (moderate), respectively. No patient developed severe AR after RRVP. One (1.4%) developed ventricular fibrillation and was defibrillated successfully. No additional arrhythmias or complications occurred during RRVP.

CONCLUSION

RRVP can be safely used to achieve balloon stability during pediatric BAV, which could potentially decrease AR rates.

Key Words: Congenital aortic stenosis; Rapid right ventricular pacing; Balloon aortic valvuloplasty; Congenital heart disease; Systematic review; Aortic regurgitation

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Core Tip: Balloon aortic valvuloplasty (BAV) for congenital aortic valve stenosis is well established. Rapid right ventricular pacing (RRVP) is helpful in achieving balloon stability in children undergoing aortic valve dilatation. Our findings demonstrate that RRVP is an effective and safe procedure that helps stabilize the balloon during BAV and decreases the rate of aortic regurgitation in the pediatric population. No reports of severe aortic regurgitation after RRVP-assisted BAV have been published to date.

INTRODUCTION

Congenital aortic valve stenosis (AS) is the most frequent type of left ventricular outflow tract obstruction in the pediatric population and accounts for more than three-fourths of the left ventricular outflow tract obstruction cases in children[3-5]. The severity of obstruction and symptoms typically guide the management of valvar AS, while a peak-to-peak systolic gradient > 50 mmHg is associated with an increased likelihood of ventricular arrhythmias and sudden death mandating immediate intervention[6]. Treatment modalities focus on adequately relieving the obstruction, while simultaneously avoiding valvular damage and regurgitation. The two most commonly implemented modalities include balloon aortic valvuloplasty (BAV) and surgical aortic valvotomy (SAV), which have demonstrated an equivalent incidence of aortic regurgitation (AR), gradient reduction, and survival outcomes[7]. However, the invasiveness and long recovery period associated with SAV render BAV a more appealing first-line treatment option. On the other hand, BAV is also not a risk-free intervention because cardiac contractions and pulsatile blood flow can lead to balloon displacement during aortic valve dilation. Additionally, damage to vessels or intraluminal structures may also result from increased wall stress during cardiac contraction against an inflated balloon[8-10]. Overall, moderate to severe AR develops in about 15% post-BAV even if the balloon diameter does not oversize the aortic valve annulus[11,12].

To increase stability during balloon placement and to minimize the risk of AR, several techniques have been implemented, including extra-stiff wires, long balloons, long sheaths, compliant balloons in the inferior and superior vena cavae or in the main pulmonary artery[13-16]. Bolus adenosine is a considerably safe and effective method to achieve transient, pharmacologic cardiac standstill; however, periods of asystole may
occur, which are variable and cannot be easily controlled or predicted\cite{19}. Moreover, adenosine does not prevent ventricular contractions, which may occur spontaneously or be triggered by the balloon itself during inflation\cite{20}.

Another mode of balloon stabilization during BAV includes rapid ventricular pacing, which decreases stroke volume, pulse pressure, and blood pressure without causing cardiac standstill and without the limitations associated with other techniques. Rapid right ventricular pacing (RRVP) was initially reported in 2002 and has since been broadly implemented throughout the world\cite{5-12}. Rapid left ventricular pacing has also been reported but is less widely implemented\cite{21,22}. RRVP is commonly utilized during BAV in older children and adults, but there is a scarcity of data regarding neonates and infants. We aimed to systematically review the literature and assess the safety and efficacy of RRVP-assisted BAV in children.

**MATERIALS AND METHODS**

**Study design and inclusion/exclusion criteria**

We conducted the present systematic review according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines (Supplementary Table 1)\cite{23}. Since this study utilized only already published data, no patient written consent or Institutional Review Board approval was required.

The study selection criteria were defined by applying the PICO (Population/Participants, Intervention, Comparison, and Outcome) framework: Participants: Children (< 18 years) of any sex or race with congenital aortic stenosis; Intervention: RRVP-assisted balloon aortic valvuloplasty; Comparison: Not applicable; Outcomes: Aortic valve gradient reduction, incidence of AR, freedom from re-intervention, arrhythmias, and other procedure-related complications; Study design: Original randomized clinical trials, non-randomized prospective or retrospective clinical studies (i.e., cohort, case-control, case series, case reports).

Exclusion criteria for the present systematic review were: (1) Non-English articles and (2) Narrative or systematic reviews and meta-analyses, animal and in-vitro studies, errata, comments, perspectives, letters to the editor, and editorials that did not provide any primary patient data. No publication date, sample size restrictions or any other search filters were applied.

**Literature search strategy**

Two independent researchers (Mylonas KS, Ziogas IA) identified eligible studies through a systematic search of MEDLINE (through PubMed), the Cochrane Library, and Scopus (end-of-search date: July 8th, 2020). The search was executed using the following algorithm: (rapid ventricular pacing OR cardiac stimulation) AND aortic valvuloplasty AND (balloon OR transcatheter OR percutaneous) AND (pedi* OR child* OR adolescent OR neonat*). The reference lists of eligible articles were hand-searched for potentially missed studies\cite{24}. All eligibility concerns were addressed via consensus with the senior author (Tzifa A).

**Data tabulation and extraction**

A pre-specified spreadsheet was utilized to perform data tabulation and extraction for evidence synthesis and assessment of study quality. Two reviewers (Mylonas KS, Ziogas IA) extracted the data independently, and any disagreements were addressed via consensus with the senior author (Tzifa A). We extracted the following data from the eligible articles: Study characteristics (PubMed identification number, first author, publication year, country, study design, study sample), patient demographics (sex, age in years, weight in kg, length in cm), cardiac pathology, past cardiac intervention history, timing of RRVP, pacing mode, pacing rate in beats/minute, pacing time in seconds, balloon length and diameter in mm, balloon displacement, pre-/post-BAV peak systolic gradient in mmHg, pre-BAV AR, aortic valve gradient post-BAV, incidence of AR after dilatation, freedom from re-intervention sustained arrhythmias, and other procedure-related complications.

**Assessment of study quality**

The quality of the included case series was assessed using the National Heart, Lung, and Blood Institute (NHLBI) scale\cite{25}. The NHLBI scale ranges from 1 to 9; with a score of 1-3 denoting poor quality, 4-6 fair quality and 7-9 suggesting good quality. In the item assessing whether the follow-up period was long enough for outcomes to occur,
the cut-off value was a priori set at one year after BAV. The mean and standard deviation for the NHLBI score of the entire review were calculated.

The Newcastle-Ottawa scale was utilized to evaluate the quality of case-control studies\(^26\). In the item assessing whether the follow-up period was long enough for outcomes to occur, the cut-off value was a priori set at 1 year after BAV. In line with standard practice, adequacy of follow-up was set at the 90% rate.

**Statistical analysis**
Continuous variables were reported as medians and ranges or as means and standard deviations, while categorical variables as frequencies and percentages. All relative rates were estimated according to the available data for each variable of interest, and all data were handled based on the Cochrane Handbook principles\(^27\).

**RESULTS**

**Study selection and characteristics**
Five publications reporting on RRVP-assisted BAV for congenital aortic stenosis fulfilled our predetermined literature search criteria (Figure 1)\(^5\)-\(^9\). All included eligible studies enrolled a total of 72 patients from September 1999\(^5\) until August 2009\(^9\). Median patient age ranged from 10 to 13.4 years (1 mo-32 years) and median weight at the time of the intervention ranged from 14 to 48.5 kg (range: 4.4-79 kg). No neonates were treated with RRVP-assisted BAV in any of the published studies. Only 10 (13.9%) patients had a history of some type of aortic valve surgical or catheter-based procedure (Table 1).

**Assessment of study quality**
According to the NHLBI scale, all published case series\(^5\)-\(^8\) were studies of good quality, and the mean NHLBI score of the review was 7.5 ± 1.0. The case-control study by Gupta \( et\) \( al\)\(^9\) comparing RRVP alone to RRVP plus controlled transient respiratory arrest also showed high quality according to the Newcastle-Ottawa scale (score: 6). Detailed quality assessment for each study is provided in Supplementary Tables 2 and 3.

**RRVP-assisted BAV outcomes**
Published studies have evaluated the use of rapid pacing for transcatheter valvuloplasty in infants (over 1 mo of age) and older children, but not in neonates. Daheeret \( et\) \( al\)\(^6\) used RRVP after the failure of an initial non-paced balloon placement attempt. All other teams utilized rapid pacing from the outset of the procedure. Although initial pacing rates varied, most protocols employed RRVP until a 50% reduction in systolic aortic blood pressure was achieved.

Median pacing rates ranged between 209-240 (200-260) beats per minute. On average, pre-BAV peak systolic gradient was in the upper 60s (mmHg), whereas after the procedure, it typically dropped below 20 mmHg (three-fold reduction). To accurately quantify the impact of RRVP on post-BAV AR rates, we had to exclude 3 patients from the Mehta \( et\) \( al\)\(^8\) series since they had “mixed aortic valve disease” of unknown severity.

Prior to BAV, 58 (84.0%), 7 (10.1%), and 4 (5.9%) patients respectively had AR grade 0 (none), 1 (trivial), 2 (mild). After BAV, 34 (49.3%), 6 (8.7%), 26 (37.7%), 3 (4.3%), patients respectively had AR grade 0, 1, 2, and 3 (moderate). No patient developed severe aortic insufficiency after BAV with RRVP.

Gupta \( et\) \( al\)\(^9\) compared RRVP alone to RRVP plus controlled transient cessation of positive-pressure ventilation and found no statistically significant difference in terms of peak systolic gradient reduction \((P = 0.25)\) and post-BAV aortic insufficiency rates \((P > 0.05)\). Lastly, among 72 reviewed patients, only one (1.4%) developed ventricular fibrillation and was cardioverted successfully\(^8\). No additional arrhythmias or other complications occurred after RRVP (Table 2).

**DISCUSSION**

BAV constitutes the treatment of choice for severe congenital AS in several centers worldwide, as there is no requirement for cardiopulmonary bypass, the length of hospital stay is shorter, and its outcomes are comparable to that of SAV. However,
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| PMID     | Ref. (year of Publication) | Country        | Study type                 | Study period | Patient sample | Male:female | Patient age (years) | Age groups     | Weight (kg) | Length (cm) | Cardiac pathology                      | Past cardiac intervention history |
|----------|----------------------------|----------------|----------------------------|--------------|----------------|-------------|---------------------|---------------|-------------|-------------|----------------------------------------|-----------------------------------|
| 20826965 | Gupta et al[9] (2010)      | India          | Retrospective case series  | June 2006-   | A: 5 B: 5       | A: 5.0: B: 4.1 | 0                   | 0             | 10          | NR          | AS NYHA II & III                         | 0                                 |
|          |                            |                |                            | August 2009  |                |             |                     |               |             |             |                                        |                                   |
| 20465717 | Mehta et al[8] (2010)      | United Kingdom | Retrospective case series  | NR           | 25            | NR          | 11.6±1 (1.0  mo-32.0) | NR            | NR          | NR          | Isolated AS: 18/25 (72%)                | 7/25 (28%)                        |
|          |                            |                |                            |              |               |             |                     |               |             |             | Mixed aortic valve disease: 3/25 (12%) |                                   |
| 1688946  | David et al[7] (2007)      | Mexico         | Non-randomized, prospective| September 2004-July 2005 | 10 | 6: 4 | 10.0±1 (3.0-16.0) | 0             | 0           | 10          | Other associated lesions: 4/25 (16%)   | 0                                 |
|                |                            |                |                            |              |               |             |                     |               |             |             |                                        |                                   |
| 15310898 | Daehnert et al[6] (2004)   | Germany        | Prospective pilot          | September 2001-August 2003 | 14 | 9: 5 | 13.4±1 (0.3-20.2) | 0             | 1           | 13          | Untreated AS with gradient ≥ 50 mm Hg or less, with obstructive and AR grades I- II or without insufficiency. | 1                                 |
|          |                            |                |                            |              |               |             |                     |               |             |             |                                        |                                   |
| N/A      | Ing et al[5] (2002)        | United States  | Retrospective case series  | September 1999-June 2001 | 13 | NR   | 9.9±1 | NR             | NR           | 31.7±1 | AR: Aortic regurgitation; CTRA: Controlled transient respiratory arrest; NYHA: New York Heart Association. | 0                                 |

1David et al[9] reported on 25 patients who underwent balloon aortic valvuloplasty and 4 patients who had stenting of coarctation (these demographics were not grouped according to type of cardiac pathology).
2Seven patients had previous interventions either in the form of surgery or catheterization.
3Ing et al[5] was the first group to describe rapid right ventricular pacing for balloon aortic valvuloplasty in an abstract at the Journal of the American College of Cardiology.
4Median.
5Range.
6Mean. A: Rapid right ventricular pacing (RRVP); B: RRVP + controlled transient respiratory arrest.

Table 1 Study and patient characteristics

Patients treated with BAV are at risk of developing AR, which can be moderate to severe in about 15%-16% and may progress over time[13-16]. Several approaches have been implemented to stabilize the balloon and decrease the risk of post-BAV AR, including the use of special equipment (extra-stiff guidewires and double balloons)[28,29] or bolus intravenous adenosine. The latter is generally considered to be safe and effective in decreasing cardiac output and generating a transient state of asystole by inducing sinoatrial and atrioventricular block[19,20]. Nevertheless, adenosine needs to be titrated on a patient-by-patient basis, and the onset and duration of pharmaco logical the transient cardiac standstill is dose-dependent and variable among patients. As RRVP can decrease stroke volume, blood pressure, and transvalvular flow without causing
## Table 2 Outcomes of rapid right ventricular pacing-assisted balloon aortic valvuloplasty

| PMID       | Ref. (year of Publication) | Timing of RRVP                                                                 | Pacing mode | Pacing rate (bpm) | Pacing time (sec) | Balloon length (mm) | Balloon diameter (mm) | Balloon displacement | Pre-BAV PS gradient (mmHg) | Post-BAV PS gradient (mmHg) | Pre-BAV AR | Post-BAV AR | Sustained arrhythmias | Other procedure-related complications |
|------------|----------------------------|-------------------------------------------------------------------------------|-------------|-------------------|-------------------|---------------------|-----------------------|---------------------|--------------------------|-----------------------------|-----------|-------------|-------------------|----------------------------------|
| 20826965   | Gupta et al[6] (2010)      | Pacing until SBP dropped by 50%                                               | NR          | NR                | NR                | Balloon:aortic annulus size = 1:1 | A: 1/5 (20%) B: 0% | Gradient reduction (%): A: 52.2% B: 70.1%; \( P = 0.25 \) | G0: 10/10 (100%) | A: 0% | B: 2/5 | (40%)          | None                                           |
| 20465717   | Mehta et al[8] (2010)      | Initially 180 bpm. Pacing rate was increased by 20 bpm until SBP dropped by 50% | AAI/AO      | 240\(^6\) (200-260) | NR                | NR | NR | 1/25 (4%) | Gradient reduction: 20\(^5\) (0-60) | G0: 16/22 (72.7%) | G0: 22 (88%) | G1: 16/22 (72.7%) | 1/25 (4%) VFib which was successfully cardioverted | None |
| 16889846   | David et al[7] (2007)      | Initially at a frequency slightly higher than the spontaneous patient's frequency. Pacing rate was increased until SBP dropped by 50% | NR          | 209\(^7\) (170-250) | NR                | 40 (40-40) | 18\(^6\) (14-22) | NR | 68.5\(^7\) ± 20\(^7\) | 19.7\(^7\) ± 8.3\(^7\) | G0: 6/10 (60%) | G0: 5/10 (50%) | None | None                                           |
| 15310698   | Daehnert et al[6] (2004)   | After failure of first non-paced dilatation attempt                           | VVI         | 220\(^2\) (7-16) | 12.7\(^2\) (7-16) | 60\(^2\) (30-60) | 20\(^5\) (10-25) | 3/14 (21.4%) | 82.5\(^5\) (60-110) | 28.6\(^5\) (10-50) | G0: 7/14 (50%) | G0: 1/14 (7.1%) | None | None                                           |
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| N/A | Ing et al.[5] (2002) | Pacing just prior to balloon inflation. HR increased by an average of 80 ± 29% & LV systolic pressure decreased by 36 ± 12%. |
|-----|----------------------|----------------------------------------------------------------------------------------------------------------------------------|
| G0: 13/13 (100%) | G1: 1/13 (7.7%) | G2: 1/13 (20.1%) |
| G1: 0% | G2: 11/14 (78.6%) | G3: 2/14 (14.3%) |
| G2: 2/13 (18.4%) | G3: 0% | G4: 0% |
| G3: 0% | G4: 0% | None |

### Notes

1. Two in the aorta and 1 in the left ventricle.
2. In 2 patients the balloon continued to move and rapid right ventricular pacing (RRVP) was increased to 240 bpm.
3. Ing et al.[5] was the first group to describe rapid right ventricular pacing for balloon aortic valvuloplasty in an abstract at the Journal of the American College of Cardiology.
4. To accurately quantify the impact of RRVP on post-balloon aortic valvuloplasty (BAV) aortic regurgitation (AR) rates, we had to exclude 3 patients since pre-BAV they had "mixed aortic valve disease" of unknown severity.
5. Median.
6. Range.
7. Mean.
8. Standard deviation. G0: No AR; G1: Grade 1 AR (trivial); G2: Grade 2 AR (mild); G3: Grade 3 AR (moderate); G4: Grade 4 AR (severe); A: RRVP; B: RRVP + controlled transient respiratory arrest; NR: not reported; PMID: PubMed identification number; RRVP: Rapid right ventricular pacing; PS: Peak systolic; AR: Aortic regurgitation; SBP: Aortic systolic blood pressure; VFib: Ventricular fibrillation; CTRA: Controlled transient respiratory arrest.

Asystole and can be modified according to the needs of the procedure, a growing number of centers began using this approach as the method of choice for balloon stabilization in children and adults[5-9]. In the present systematic review, we sought to summarize all published literature assessing the safety and efficacy of RRVP-assisted BAV for congenital aortic valve stenosis.

Our findings suggest that the maximum aortic valvular gradient after aortic dilatation with pacing decreases significantly[5-9]. In children, RRVP is typically implemented from the beginning of the intervention, since even a single balloon displacement event can be enough to damage the aortic valve[7,8]. However, it should be emphasized that according to our systematic review, no cases of severe AR after rapid pacing have ever been reported. Despite its well-known benefits, RRVP has not been broadly employed in neonates and infants, and thus the outcomes of RRVP-assisted BAV in congenital AS patients < 1 year are largely unknown. The absence of a unified pacing approach during BAV in this population is based on the hypothesis that the low stroke volumes (1.0-1.5 mL/kg), higher heart rates, and low ejection fractions are unable to cause uncontrolled balloon movement and valvar damage. However, this theory cannot explain the need for a surgical bailout for severe AR post-BAV, which has been repeatedly reported for neonates and infants subjected to BAV without...
Figure 1 PRISMA flow diagram of the search strategy and study selection.

CONCLUSION

In conclusion, RRVP is an effective and safe procedure that can help stabilize the balloon during BAV and decrease subsequent AR rates. No reports of severe AR after RRVP-assisted BAV in children have been published to date.

ARTICLE HIGHLIGHTS

Research background

Congenital aortic valve stenosis is the most frequent type of left ventricular outflow tract obstruction in the pediatric population and accounts for more than three-fourths of the left ventricular outflow tract obstruction cases in children. The two most commonly implemented modalities include balloon aortic valvuloplasty (BAV) and
surgical aortic valvotomy, which have demonstrated an equivalent incidence of aortic regurgitation (AR), gradient reduction, and survival outcomes.

**Research motivation**

Another mode of balloon stabilization during BAV includes rapid ventricular pacing, which decreases stroke volume, pulse pressure, and blood pressure without causing cardiac standstill and without the limitations associated with other techniques. Rapid right ventricular pacing (RRVP) was initially reported in 2002 and has since been broadly implemented throughout the world. Rapid left ventricular pacing has also been reported but is less widely implemented. RRVP is commonly utilized during BAV in older children and adults, but there is a scarcity of data regarding neonates and infants.

**Research objectives**

RRVP is commonly utilized during BAV in older children and adults, but there is a scarcity of data regarding neonates and infants. We aimed to systematically review the literature and assess the safety and efficacy of RRVP-assisted BAV in children.

**Research methods**

A systematic review of the MEDLINE, Cochrane Library, and Scopus databases was conducted according to the PRISMA guidelines (end-of-search date: July 8, 2020). The National Heart, Lung, and Blood Institute and Newcastle-Ottawa scales was utilized for quality assessment.

**Research results**

Five studies reporting on 72 patients were included. The studies investigated the use of RRVP-assisted BAV in infants (> 1 mo) and older children, but not in neonates. Ten (13.9%) patients had a history of some type of aortic valve surgical or catheterization procedure. Before BAV, 58 (84.0%), 7 (10.1%), 4 (5.9%) patients had aortic regurgitation (AR) grade 0 (none), 1 (trivial), 2 (mild), respectively. After BAV, 34 (49.3%), 6 (8.7%), 26 (37.7%), 3 (4.3%), patients had AR grade 0, 1, 2, and 3 (moderate), respectively. No patient developed severe AR after RRVP. One (1.4%) developed ventricular fibrillation and was defibrillated successfully. No additional arrhythmias or complications occurred during RRVP.

**Research conclusions**

RRVP is an effective and safe procedure that can help stabilize the balloon during BAV and decrease subsequent AR rates. No reports of severe AR after RRVP-assisted BAV in children have been published to date.

**Research perspectives**

Future studies should explore the role of RRVP-assisted BAV in neonates and infants.

**REFERENCES**

1. Kitchiner D, Jackson M, Malaiya N, Walsh K, Peart I, Arnold R. Incidence and prognosis of obstruction of the left ventricular outflow tract in Liverpool (1960-91): a study of 313 patients. *Br Heart J* 1994; 71: 588-595 [PMID: 8043345 DOI: 10.1136/hrt.71.6.588]

2. Hoffman JI, Kaplan S. The incidence of congenital heart disease. *J Am Coll Cardiol* 2002; 39: 1890-1900 [PMID: 12084585 DOI: 10.1016/S0735-1097(02)01886-7]

3. Keane JF, Driscoll DJ, Gersony WM, Hayes CJ, Kidd L, O’Fallon WM, Pieroni DR, Wolfe RR, Weidman WH. Second natural history study of congenital heart defects. Results of treatment of patients with aortic valvar stenosis. *Circulation* 1993; 87: 116-127 [PMID: 8425319]

4. Hill GD, Ginde S, Rios R, Frommelt PC, Hill KD. Surgical Valvotomy Versus Balloon Valvuloplasty for Congenital Aortic Valve Stenosis: A Systematic Review and Meta-Analysis. *J Am Coll Cardiol* 2016; 5 [PMID: 27503847 DOI: 10.1161/JAHA.116.002931]

5. Ing FF, Boronamanu NK, Mathewson J, Maginit K, Perry JC. Transcatheter aortic valvuloplasty assisted by right ventricular pacing. *J Am Coll Cardiol* 2002; 39: 412 [DOI: 10.1016/S0735-1097(02)81849-6]

6. Daehnert I, Rotzsch C, Wiener M, Schneider P. Rapid right ventricular pacing is an alternative to adenosine in catheter interventional procedures for congenital heart disease. *Heart* 2004; 90: 1047-1050 [PMID: 15310698 DOI: 10.1136/hrt.2003.025650]

7. David F, Sánchez A, Yáñez L, Velásquez E, Jiménez S, Martínez A, Alva C. Cardiac pacing in balloon aortic valvuloplasty. *Int J Cardiol* 2007; 116: 327-330 [PMID: 1688946 DOI: 10.1016/j.ijcard.2006.03.038]

8. Mehta C, Desai T, Shebani S, Stickley J, De Giovanni J. Rapid ventricular pacing for catheter interventions in congenital aortic stenosis and coarctation: effectiveness, safety, and rate titration for optimal results. *J...
9 Gupta SD, Das S, Ghose T, Sarkar A, Goswami A, Kundu S. Controlled transient respiratory arrest along with rapid right ventricular pacing for improving balloon stability during balloon valvuloplasty in pediatric patients with congenital aortic stenosis— a retrospective case series analysis. Ann Card Annu Meet 2010; 13: 236-240 [PMID: 20826965 DOI: 10.4103/0971-9784.69676].

10 Sánchez A, David F, Velázquez E, Yáñez L, Jiménez S, Martínez A, Ortegón J, López D, Lascano S, Alva C. [Balloon stabilization by means of cardiac stimulation during balloon valvuloplasty]. Arch Cardioi Mex 2005; 75: 455-459 [PMID: 1654772].

11 Li YQ, Wang HS, Qin YZ. [Percutaneous balloon aortic valvuloplasty with rapid ventricular pacing in the right ventricle in managing congenital aortic valve stenosis in infants: report of 2 cases]. Zhonghua Er Ke Za Zhi 2011; 49: 710-711 [PMID: 2217913].

12 Song Y, Li J, Zeng G, Zhang Z, Li Y, Qian M, Pan W, Wang S. [Efficacy and experience in right ventricular pacing-percutaneous balloon aortic valvuloplasty]. Zhonghua Er Ke Za Zhi 2014; 52: 703-705 [PMID: 25476435].

13 McCrindle BW. Independent predictors of immediate results of percutaneous balloon aortic valvotomy in children. Valvuloplasty and Angioplasty of Congenital Anomalies (VACA) Registry Investigators. J Am Coll Cardiol 1996; 77: 286-293 [PMID: 8607410 DOI: 10.1016/s0002-8703(97)89395-2].

14 Galal O, Rao PS, Al-Fadley F, Wilson AD. Follow-up results of balloon aortic valvuloplasty in children with special reference to causes of late aortic insufficiency. Am Heart J 1997; 133: 418-427 [PMID: 9124163 DOI: 10.1016/s0002-8703(97)70183-2].

15 Alva C, Sánchez A, David F, Jiménez S, Jiménez D, Ortegón J, Hernández M, Magaña JA, Argüero R, Ledesma M. Percutaneous aortic valvuloplasty in congenital aortic valve stenosis. Cathrider Young 2002, 12: 328-332 [PMID: 12206554 DOI: 10.1016/s0147-9580(01)001919].

16 Brown DW, Dipilato AE, Chong EC, Lock JE, McElhinney DB. Aortic valve reinterventions after balloon aortic valvuloplasty for congenital aortic stenosis intermediate and late follow-up. J Am Coll Cardiol 2010; 56: 1740-1749 [PMID: 21070926 DOI: 10.1016/j.jacc.2010.06.040].

17 Harrison GJ, How TV, Vallabhaneni SR, Brennan JA, Fisher RK, Naib JB, McWilliams RG. Guidewire stiffness: what's in a name? J Endovasc Ther 2011; 18: 797-801 [PMID: 22149229 DOI: 10.1583/11-3592.1].

18 Mehta C, Shebani S, Grech V, Degiovanni J. How to achieve balloon stability in aortic valvuloplasty using rapid ventricular pacing. Images Paediatr Cardiol 2004; 6: 31-37 [PMID: 12358431].

19 De Giovanni JV, Edgar RA, Cranston A. Adenosine induced transient cardiac standstill in catheter interventional procedures for congenital heart disease. Heart 1998; 80: 330-333 [PMID: 9875106 DOI: 10.1136/het.80.4.330].

20 Hashimoto T, Young WL, Aagaard BD, Joshi S, Opatovich ND, Pile-Spellman J. Adenosine-induced ventricular asystole to induce transient profound systemic hypotension in patients undergoing endovascular therapy. Dose-response characteristics. Anesthesiology 2000; 93: 998-1001 [PMID: 11020753 DOI: 10.1097/00000542-200010090-00021].

21 Karagüöz T, Ayüz E, Erdğöan I, Sahin M, Özer S, Celiker A. Congenital aortic stenosis: a novel technique for ventricular pacing during catheter balloon valvuloplasty. Catheter Cardioi intervent 2008; 72: 527-530 [PMID: 18814324 DOI: 10.1002/ccd.21695].

22 Ertugrul I, Karagöz T, Celiker A, Alehan D, Özer S, Oktulu S. The Impact of Rapid Left Ventricular Pacing during Pediatric Aortic Valvuloplasty on Postprocedural Aortic Insufficiency. Congentit Heart Dis 2016; 11: 584-588 [PMID: 27079283 DOI: 10.1111/chd.12340].

23 Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Lang T. PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 2009; 339: b2700 [PMID: 19622552 DOI: 10.1136/bmj.b2700].

24 Wohlin C. Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering. Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering. New York, NY, USA. ACM; 2014: 1-38.

25 National Heart Lung and Blood Institute. Quality assessment tool for case series studies. Available from: www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools.

26 Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of quality of nonrandomized studies in meta-analyses. Eur J Epidemiol 2010; 25: 603-605 [PMID: 20652370 DOI: 10.1007/s10654-010-9491-7].

27 Higgins J, Green S (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 (updated March 2011). The Cochrane Collaboration, 2011. Available from: www handbook.cochrane.org.

28 Mullins CE, Nihill MR, Vick GW 3rd, Ludomirsky A, O'Laughlin MP, Bricker JT, Judd VE. Double balloon technique for dilation of valvular or vessel stenosis in congenital and acquired heart disease. J Am Coll Cardiol 1987; 10: 107-114 [PMID: 2955014 DOI: 10.1016/0735-1097(87)80168-7].

29 Kahn RA, Moskowitz DM, Marin ML, Hollier LH, Parsons R, Teodorescu V, McLaughlin M. Safety and efficacy of high-dose adenosine-induced asystole during endovascular AAA repair. J Endovasc Ther 2000; 7: 292-296 [PMID: 10958293 DOI: 10.1171/152660280000700406].

30 Luciani GB, Lucchese G, Carotti A, Braonnaccio G, Abbrazzese P, Caiminelli G, Galletti L, Gargiulo GD, Marzennesi SM, Mazzecco A, Faggian G, Murri B, Pace Napoliene C, Pozzi M, Zannini L, Frigioja A. Two decades of experience with the Ross operation in neonates, infants and children from the Italian Paediatric Ross Registry. Heart 2014; 100: 1954-1959 [PMID: 25056868 DOI: 10.1136/heartjnl-2014-305873].

31 Slicker K, Lane WG, Oyetayo OO, Copeland LA, Stock EM, Michel JB, Erwin JP. Daily cardiac catheterization procedural volume and complications at an academic medical center. Cardioviase Diag Ther 2016; 6: 446-452 [PMID: 27747168 DOI: 10.21037/cdt.2016.05.02].
