Downstream turbulence and high intensity transient signals (HITS) following aortic valve replacement with Medtronic Hall or St. Jude Medical valve substitutes

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Abstract

Objective: High intensity transient signals (HITS) representing microembolization to the brain have been found to contribute to cognitive impairment and psychoneurological dysfunction in patients carrying a mechanical aortic valve. It is unknown, whether HITS represent gaseous or solid emboli. This animal study evaluates the impact of valve orientation on HITS for two different mechanical valves with both valves implanted in their best and worst orientation, which has been defined in previous studies with respect to downstream turbulence.

Methods: In four pigs a rotation device carrying either a Medtronic Hall (MH) or St. Jude Medical (SJM) valve size 23 mm was implanted. The device allowed rotation of the implanted valves without reopening of the aorta. Approximately 30 min after weaning from extracorporeal circulation, a Doppler probe was placed on both common carotid arteries. In different orientations of the implanted valves (best and worst position), HITS were detected by the Doppler probe and recorded for ten min by a transcranial Doppler sonography device (Medilab Inc., Estenfeld, Germany).

Results: HITS showed significant change with rotation for both valve designs. With the major orifice of the MH oriented towards the non-coronary leaflet (optimum position) very low HITS-counts (0.8±1.7/min) were observed. In the worst orientation HITS rose to 43±66/min. For the SJM the HITS count in the optimum position was 23.4±24/min and in the worst orientation 38±48/min.

Conclusions: Valve orientation has an important impact on microembolization to the brain. In the optimum orientation (large orifice facing the non-coronary leaflet) the Medtronic Hall valve showed negligible incidence of HITS. The St. Jude Medical bileaflet valve showed less variation but demonstrated significant HITS counts at any orientation. As the MH in the worst position shows significantly higher turbulent stresses than the SJM but no higher incidence of HITS, a strong correlation between turbulence and HITS was not demonstrated by this study.

Keywords: High intensity transient signals; Prosthetic heart valves; Medtronic; St. Jude Medical

1. Introduction

High intensity transient signals (HITS) in the cerebral perfusion representing microembolization to the brain have been demonstrated in patients carrying a mechanical aortic valve [1–4]. They can be detected by transcranial Doppler sonography in vitro [5] and in vivo [6]. Although it is more than 20 years now since the first detection of microbubbles in the presence of mechanical heart valves [7], it remains still unknown, whether HITS represent gaseous [8,9] or solid [10] emboli. Also, under discussion remains the clinical impact of the continuous embolization to the brain [11], as some of the patients with high rates of emboli remain clinically unaffected [12]. Recently, several authors have demonstrated either silent brain infarcts or long-term neuropsychological dysfunction in patients with significant HITS counts [13–15].

The number of microemboli to the brain following mechanical valve replacement depends on valve size, implantation technique and especially valve design [1,16]. Sliwka et al. [17] observed less HITS in patients carrying a
Medtronic Hall (MH) valve compared to patients carrying a St. Jude Medical (SJM) valve substitute, but could not demonstrate a clinical relevance of this observation. Gencbay et al. [18] also demonstrated, that microbubbles were ‘associated more with bileaflet prosthetic heart valves than with monoleaflet valves’.

The aim of this study was to investigate the impact of valve orientation on HITS for the tilting disc and bileaflet valve with both valves in their best (Figs. 1 and 2) and worst orientation, which have been defined in previous studies [19,20] with respect to downstream turbulence and other hemodynamic parameters. In these studies the optimally oriented Medtronic Hall valve demonstrated almost physiological results with respect to turbulence, whereas the St. Jude bileaflet valve was less susceptible to orientation, but could not match the optimum results of the tilting disc valve.

2. Materials and methods

The study comprised of four healthy pigs (75–87 kg body weight). General anesthesia was achieved by administering Ketamin (7.5 mg/kg per h), Fentanyl (1.5 μg/kg per h) and Midazolam (0.25 mg/kg per h). A median sternotomy was performed in a typical manner, extracorporeal circulation (ECC) was established via cannulation of the aortic arch and the right atrial appendage. After cross-clamping of the aorta 1000 cm³ of St. Thomas solution were given initially to achieve cardiac arrest, followed by 500 cm³ every 20 min. Mild systemic hypothermia with a rectal temperature of 32°C was performed during ECC. After complete dissection of the ascending aorta, the native valve was excised and a ‘rotation device’ carrying either the MH (in two pigs) or the SJM (in the remaining two pigs) was implanted. The device allowed rotation of the artificial valve without reopening of the aorta.

2.1. Construction of the rotation device

The rotation device (Acutec, St. Michael, MN) [19] consisted of an outer conventional sewing ring and two inner rings, between which the rotation was performed via two fishing lines. Into the inner ring the Medtronic Hall and the St. Jude Medical valve with a diameter of 23 mm were implanted. The fishing lines were stitched through the aortic wall. Pulling one fishing line 2 cm led to 45° rotation of the valve implanted into the rotation device.

Having completed valve implantation, closure of the aortotomy was achieved via a running suture. Reperfusion led to a satisfying hemodynamic situation in all pigs. Approximately 30 min after weaning from extracorporeal circulation, a Doppler probe was placed on both common carotid arteries. In different orientations of the implanted valves (best and worst position as defined in the previous studies [19,20]), HITS were detected by the Doppler probe placed on both carotid arteries and recorded for ten min by a transcranial Doppler sonography device (Medilab Inc., Estenfeld, Germany). Throughout this time period hemodynamics were kept stable with a cardiac output between 4–5 l/min. All relevant regulations of Denmark concerning animal experiments were fully observed.

3. Results

Cardiac output was stable at 4–5 l/min in all pigs. No significant differences between the four experiments were obtained with respect to hemodynamic parameters.

The results of the HITS measurements are illustrated in Figs. 3 and 4. HITS counts varied with rotation for both valve designs. With the major orifice of the MH oriented towards the non-coronary leaflet (optimum position), very low HITS-counts (0.8–1.7/min) were observed, whereas the...
SJM in its optimum orientation showed significant HITS of 23.4±24/min. This difference was statistically significant ($P < 0.05$). In the worst orientation HITS rose to 43±66/min (MH) vs. 38±48/min (SJM) with no statistically significant difference between the two valves.

4. Discussion

The occurrence of microembolization in the presence of mechanical aortic valves has been described for more than 20 years now [7]. Microbubbles can be detected in approximately 75% of all patients [18] by transcranial Doppler sonography [1–4] or transesophageal echocardiography [18]. A thorough review of the literature has shown controversial reports on the clinical impact of these HITS, but recent reports [13–15] demonstrated silent brain inracts and neuropsychological deficits related to embolizing microbubbles.

The origin (up- or downstream the valve) as well as the nature (gaseous or solid) of HITS remain unclear. A clear correlation between HITS and the hemodynamic perfor-
mance of the valve has also not yet been proven, as HITS can occur independent of valve size, hemodynamic parameters and patient characteristics. It has though been observed, that valve design has an important impact on the occurrence and number of HITS with superior results for tilting disc valves [17,18].

In previous in vivo studies [19,20] the influence of valve orientation on the hemodynamic performance of mechanical aortic valves has been demonstrated for the tilting disc and bileaflet valve design. In these studies the optimally oriented Medtronic Hall valve (major orifice facing the non-coronary leaflet) showed superior results especially with respect to downstream turbulence over the bileaflet valve in any orientation. As downstream turbulence leads to platelet activation, the number of microembolization originating from a tilting disc valve might also be influenced and this might explain the superior results of the tilting disc valves regarding microembolization. Therefore, this study investigated the role of valve orientation on HITS with the tilting disc and bileaflet valve implanted in their optimum and worst implantation as defined previously.

A significant impact of valve orientation on HITS was indeed demonstrated by the study. In the optimum orientation the MH showed a negligible low number of emboli (with no significant difference between left- and right-sided HITS counts), but a significant rise in HITS was observed with rotation of the valve into the hemodynamically worst position. The SJM bileaflet valve demonstrated significant HITS counts in any orientation, but also a tendency to lower embolization rates in the hemodynamically optimum orientation. These results favor the hypothesis of a correlation between hemodynamic valve performance and microembolization, although the exact origin of HITS remains unclear. Further investigations in this field are necessary before HITS can account as a further parameter for the hemodynamic performance of a mechanical valve in aortic position.

As the MH in the worst position shows significantly higher turbulent stresses than the SJM [1] but no higher incidence of HITS, a strong correlation between downstream turbulence and HITS was not demonstrated by this study, which might be due to the limited number of experiments. As the MH in the optimum orientation shows almost physiological turbulent stresses in the animal model [19], the low HITS counts in this position may partially be explained by a reduced platelet aggregation, which is caused by turbulent shear stresses, although this study could not demonstrate a clear relationship between turbulence and HITS. Thus, the exact origin of HITS remains unclear, and further studies are required to investigate the role of turbulent shear stresses in the pathogenesis of continuous cerebral microembolization following mechanical aortic valve replacement.

In conclusion, valve design as well as valve orientation play an important role in microembolization rates of mechanical valve substitutes. The MH showed superior results in the optimum orientation. A one-to-one correlation between downstream turbulence and HITS was not observed. The origin and nature of HITS remain unclear, although platelet activation by turbulent shear stresses might contribute to the occurrence of HITS in the presence of mechanical aortic valves.

References

[14] Stump DA, Tegeler CH, Rogers AT. Neuropsychological deficits are associated with the number of emboli detected during cardiac surgery. Stroke 1993;24(3):A.
