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Chapter 3

Retrieval Analysis of Mechanical Heart Valves: Impact on design and clinical practice

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Explanted mechanical heart valves were examined non-destructively, and the findings were related to guidelines, technical reports, and other information in order to judge the risk of failure and its possible impact on valve design and clinical practice. Diagnoses for single valves could be made, but risks and rates of failure for patient populations could not be predicted due to insufficient information concerning manufacturing process and valve and patient numbers.

Based on the results of this study and the principle that decisions on recalls and patient counselling must be based on scientific knowledge rather than on wait-and-see policies, the following is recommended:

1. registration of all implanted valves
2. follow-up of a large cohort of valve carriers
3. comparison of wear test results of pre-implant and post-retrieval valves
4. maintenance of a reference stock of valves and materials
5. submission of failure scenarios to certifying bodies
3.2 INTRODUCTION

Although mechanical heart valves are known to provide a durable and effective solution to restore heart function, implant retrieval analysis, representing the final phase of an implant's life cycle, continues to be recommended \(^{(1-3)}\). Implant retrieval is often not initiated until (suspected) failure, but it can also be conducted to prove that retrieved implants still meet the specifications, thereby restoring or strengthening patient and doctor confidence \(^{(4,5)}\).

Implant retrieval can thus serve a number of purposes:
1. Confirmation of the implant's expected function and durability
2. Control of the risk of implant failure and patient damage by means of guidelines for early diagnosis, close-watch procedures, and implant explantation
3. Partial or complete redesign of implant

The interuniversity working group on Cardiovascular Implant Retrieval Analysis (iwCIRA), combining expertise from the departments of Cardiology, Cardiopulmonary Surgery, and Cardiovascular Pathology of the Academic Medical Center of the University of Amsterdam, and the departments of Materials Science and Safety Science of the Delft University of Technology, studied between 1991 and 1997 the following mechanical heart valves: Björk-Shiley convexo-concave (BSCC) (n=67), Edwards-Duromedics (EDUR) (n=5), Medtronic Parallel (MPAR) (n=2), St. Jude Medical Aortic High-Performance (SJMA) (n=4), Sorin Bicarbon (SBC) (n=4), and Medtronic Hall (MHAL) (n=2).

In this paper, we describe the findings of this study in terms of types and consequences of implant failure as well as impact on design and clinical practice. We also make recommendations for the assessment of failure risks, the interpretation of technical analyses, and the communication towards doctors and patients.

3.3 PATIENTS AND METHODS

With the permission of the patients or their relatives/legal representatives, all retrieved mechanical heart valves discussed in this paper were assessed by members of iwCIRA. Although many valves examined by iwCIRA come from patients abroad, this paper refers to valves retrieved from Dutch patients. Presented findings solely refer to non-destructive technical analysis by means of stereoscopy and scanning electron microscopy (SEM). Patient characteristics and dates of valve explantation were stored in a data base for analysis \(^{(6)}\). Guidelines, technical reports, and information of health authorities or manufacturers relating
to prophylactic mechanical valve replacement, instant diagnosis, and communication towards doctors and patients were collected and studied. The January 1995 to July 1996 Website of the American Food and Drug Administration (FDA) was also studied, as this would enable us to estimate type and number of valve-related failures.

3.4 RESULTS

Non-destructive technical analysis, guidelines, technical reports, and information from health authorities and manufacturers:

**Björk-Shiley convexo-concave (BSCC) valve (n=67)**
Failure rate was high. The generally accepted explanation for this observation was that the design and manufacturing flaws, which had remained undetected for a long period of time, had led to accelerated metallurgical fatigue, cracks, and fracture of the welded outlet strut, and finally to disk escape (fig. 1a-c). All retrieved valves, which varied widely in terms of implantation duration, were screened for prefracture signs \(^6\). Of the 67 valves, 10 (15%) showed minor defects and 20 (30%) showed major cracks or single-leg fracture \(^6-8\). Review of all manufacturing records in order to determine the risk of fracture more accurately \(^8,9\) had only little effect on risk assessment based on valve type, size, and position. However, its effect on risk assessment based on manufacturing date was considerable. Informal guidelines were available on prophylactic explantation (mainly based on a patient follow-up study) and instant diagnosis. Also available were the results of several population-based and technical studies, which had been made possible thanks to the availability of a complete registry, which included all implantations \(^7\).

**Edwards-Duromedics (EDUR) bileaflet valve (n=5)**
This valve showed a limited but unacceptably high number of unexplained leaflet failures \(^10\). Three of the five examined valves had failed and showed severe "chipping-away" of the pyrolytic carbon, while five out of seven "intact" leaflets showed severe pitting (fig. 1d). Most likely causes of these phenomena were increased wear, due to design and flaws in the pyrolytic carbon coating (still under investigation), and increased susceptibility to cavitation. A task force (with the manufacturer as one of its members) investigated the problems and drew up guidelines for instant diagnosis. Guidelines for prophylactic explantation were not available because they had been considered unwarranted by the task force.

**Medtronic Parallel (MPAR) bileaflet valve (n=2)**
Both valves had been explanted prophylactically in 1995, within one year following
implantation, because of a strongly increased risk of thrombus formation and thromboembolism, probably caused by the valve's parallel-leaflet design, which can lead to insufficient "washing-out" of the hinge area \(^{(11,12)}\). Apart from a very small apposition of a fresh thrombus in the hinge area in one valve, no functional abnormalities or relevant signs of wear could be observed. Guidelines for instant diagnosis (i.e., when to suspect and how to diagnose valve-related thromboembolic complications) were available.

*Figure 1: a-c: Various stages of strut leg failure of a Björk-Shiley convexo-concave heart valve: dislocated strut leg fracture (a), major crack preceding fracture (b), and striation due to fatigue (c); d: Surface of an intact Edward-Duromedics leaflet. Note the "porosity" and chipped defects.*
St. Jude Medical Aortic High-Performance (SJMA) valve (n=4)
Three of the four retrieved valves, which had all been implanted at the same center between 1994 and 1995, were explanted prophylactically due to severe bloodpressure-dependent prosthetic incompetence, probably caused by the use of an oversized implant. Examination revealed no structural obstructions (free leaflet movement) and no relevant signs of wear. Guidelines were not available.

Sorin Bicarbon (SBC) valve (n=4)
These valves were retrieved in 1994, 1996, and 1997, with an implantation time varying from six days to 14 months. High-SEM magnification showed evident loss of some of the 5μ-thin pyrolytic carbon coating in the hinge area but no signs of wear on the titanium surface or the pyrolytic carbon coating of the leaflets (13). Guidelines were not available.

Medtronic Hall (MHAL) valve (n=2)
Both valves had been retrieved in 1996 following a post-mortem study because of suspected valve-related death. Disk movement had been blocked completely due to impingement, most likely caused by surgical error. Examination revealed negligible wear of the disk and no signs of wear of the flange. Guidelines were not available.

FDA Website January 1995 to July 1996 (table 1):
Of the 369 reported valve-related incidents, 98 - (26.6%) were strictly device-related, consisting of fracture, leaflet escape, and impingement. The remaining reports referred to circumstances related to the valve replacement therapy, such as paravalvular leakage and endocarditis, not affecting the valve's structural function, or to unknown causes. The relevance of the absolute numbers listed in table 1 is unclear due to observed underreporting and lacking knowledge of exact numbers of valves implanted.

Table 1: Number of valve-related reports from the FDA registry

<table>
<thead>
<tr>
<th>valve type</th>
<th>number of reports</th>
<th>number of valve-related reports</th>
<th>number of valve-related deaths (% of valve-related reports)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSCC</td>
<td>66</td>
<td>50</td>
<td>25 (50%)</td>
</tr>
<tr>
<td>EDUR</td>
<td>104</td>
<td>5</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>MPAR</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SJMA</td>
<td>148</td>
<td>38</td>
<td>6 (16%)</td>
</tr>
<tr>
<td>SBC</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MHAL</td>
<td>51</td>
<td>5</td>
<td>3 (60%)</td>
</tr>
</tbody>
</table>
3.5 DISCUSSION

3.5.1 Interpretation and impact of implant retrieval analysis

As all valves presented different problems and failure scenarios, interpretation and impact of technical analyses varied, depending on number of failures, degree of failure acceptance by doctors, and kind of information obtained from other sources (e.g., follow-up studies and manufacturing records).

**BSCC valve**
Manufacturing date was singled out as the strongest determinator for the risk of fracture (e.g., none of the reported fractures involved valves manufactured after April 1, 1984). Certainty about the relevance of these findings for accurately predicting failure number and time interval, however, could not be obtained due to lack of preimplant references. The "improved" BSCC valve, with the opening angle changed from 60 to 70, turned out to have a much higher chance of fracture\(^7\). Manufacturing of the BSCC valve was halted in 1986.

**EDUR valve**
Of the roughly 1015 valves distributed in The Netherlands, the fate of 65 was unclear, while of the remaining 950 valves which had been implanted, 17 were lost to follow-up. Given the low number of fractures (five) and the mean follow-up time of about seven years, the risk of fracture was assumed to be well under 1% per year. The EDUR valve was distributed worldwide between 1984 and 1988.

**MPAR valve**
This valve was still going through the first phase of a clinical trial which was conducted in 16 European centers. Although preimplant tests on flow patterns and thrombogenicity had been carried out according to the current international standards\(^{11,12}\), test results were still subject of discussion.

**SJMA valve**
Valve failure was related to surgical error and not to structural defects.

**SBC valve**
The hemodynamic performance of this valve was good. Release of the ultra-thin pyrolytic carbon coating in the hinge area seemed without significance because there was no evidence of related complications of structural failures\(^{13}\). Although the naked titanium housing showed no signs of wear and harmful effects on patients were not expected, the purpose of a
carbon coating in the most critical area of the valve ring that apparently wears off soon after implantation, was questioned.

**MHAL valve**

The two cases of impingement represented a regularly reported problem (e.g., five times on the FDA's Website). Predominant factors are surgical skills and attentiveness. Considering the fact that this valve had been on the market for more than 15 years, one may wonder whether minor changes in the sewing ring still represent a design challenge. However, we must keep in mind the numerous examples of "minor design changes", which only increased the number of failures.

### 3.5.2 Retrieval analysis and preimplant tests

In this study, we observed that the release of technical information by manufacturer, independent investigators, or both always led to two questions:

1. What is the relevance of this information for still implanted valves \(^{(2,14)}\)?
2. Are expectations in relation to implantation duration still being met?

The total number of mechanical valves discussed in this paper is 84, which is small when compared with the 1500 annual implants in The Netherlands. As it lies in the nature of an implant retrieval study that chance and bias determine which implants become available for examination, the results of preimplant in-vitro tests, animal tests, and specific wear tests should be regarded as a first reference to establish whether wear or defects meet expectations. One should also check whether similar materials (e.g., pyrolytic carbon) have been used for other valves, so that data may be compared. However, results of preimplant material tests might be hard to obtain for reasons of confidentiality and liability \(^{(3,15)}\). Equally essential is the availability of information about user circumstances (e.g., surgical reports, basic patient information, implantation time, and patient follow-up).

### 3.5.3 Incident reporting and analysis

The damage toll on the FDA Website (table 2) revealed that roughly 75% of the reported "failures" were not structural in nature. Although this information might be interesting, it has no value for implant redesign, as this requires exact information on all potentially contributing factors. Adverse-event reporting should therefore be carried out with a special focus on the interactions between device and patient/user, preferably by means of state-of-the-art digital and structured incident reporting systems \(^{(16,17)}\).
In the series of the four SMJA valves, which appeared insufficient, we observed that the surgeon finally responsible for the implantation had been the same person in all cases. Furthermore, incorrect sizers were used and all valves were positioned improperly. This then probably led to excessive forces on the flange in the hinge area, thereby affecting leaflet motion due to plastic deformity of whole pyrolytic carbon valve rings (18,19).

Adequate adverse-event reporting should allow failure analysis, which is especially relevant in cases of non-structural failure, as observed in the MPAR, SJMA, and MHAL valve. What initially may look like failure due to human error may prove later to be due to organizational errors or design shortcomings (8,20).

3.5.4 Guidelines, practice changes, and communication

The availability of guidelines and recommendations for the recall of implants from the market depends not so much on type of failure but rather on number of failures. Also awareness plays a role. For example, in the early 1980's, it took more than 100 failed BSCC valves before adequate action was taken, whereas in the late 1980's 20 failed EDUR valves already led to device withdrawal from the market, followed in the 1990's by discontinuation of MPAR valve implantation after just three thromboembolic events.

In this study, it was not possible to measure the impact of "failure information" on doctors in terms of changing to prescribing other valves. Only few doctors had access to data on failure scenarios and retrieval analysis, because these data mostly remained in the hands of the manufacturers, as classified information (21). However, it is currently generally accepted that patients have the right to know and that doctors have the duty to warn. This then should prevent manufacturers from retaining information and doctors from not wanting to know. Moreover, retrieval analysis may very well become part of quality assessment protocols which require the involvement of doctors and patients, as may be concluded from the recent attention for "the wear phenomenon" in valves (22).

3.6 CONCLUSIONS AND RECOMMENDATIONS

Implant retrieval analysis can only be effective if based on a comprehensive programme in conjunction with the availability of preimplant test results, patient information, and protocols on how to retrieve the implants and how to analyze the data.

Shortcomings in design and manufacturing process and threats of market withdrawal can force manufacturers to embark on the expensive and sometimes painful process of implant redesign, which can be critical for a company's survival. The fact that improved versions of
the failed EDUR and BSCC valves appeared on the market indicates that manufacturers are indeed at times prepared to change design and manufacturing process. It remains puzzling, however, that manufacturers hardly ever attempt to prevent implant failure due to surgical error. In doing so, they not only miss a fine opportunity to increase product confidence, but they also play into the hands of competitors. They should realize that the general public is thrilled mostly by absolute numbers and types of failures rather than by hazard rates \(^{(23)}\). The absence of good patient follow-up programmes usually leads to underreporting of valve-related complications and problems with interpreting data pertaining to retrieval analysis, thereby limiting the impact on guidelines and risk control measures.

Based on the information we collected, we conclude that implant retrieval analysis can have a substantial impact on design and clinical practice in terms of improving the safety of artificial heart valves, and that the following can be done to achieve this:

1. Surgeons should keep a registry of all implanted mechanical heart valves. (It appeared sheer luck that the retrospective BSCC cohort in The Netherlands could be completed.) Such a registry should contain patient and implant characteristics, because this information is essential for hazard calculations and risk control action.
2. A long-term close-watch patient follow-up study of a large cohort, which can provide an epidemiological background in case of (suspected) failure, so that quick rating and early-warning thresholds as well as input for structured retrieval and incident analysis programmes can be defined.
3. Structured retrieval analysis programmes by independent research groups in order to compare in-vitro outcome with in-vivo outcome. In view of potential conflicts of interest between patients and manufacturers and from the perspective of patient confidentiality, surgeons should participate actively.
4. Maintenance of a reference stock of materials and documentation pertaining to the manufacturing process, which can be extremely helpful in case of future problems.
5. The testing of class-III device manufacturers by certifying bodies should include the manufacturers' capabilities with respect to the administration of components, the verification of failure scenarios, crisis management, and the communication of both good and bad news.
3.7 REFERENCES
