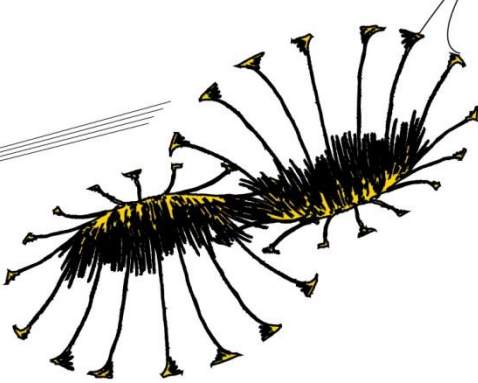




IT'S HEART TO SEE.

an Early Health Technology Assessment of
rendering 3D-images prior to Transcatheter Aortic Valve
Implantation.



Max Analbers

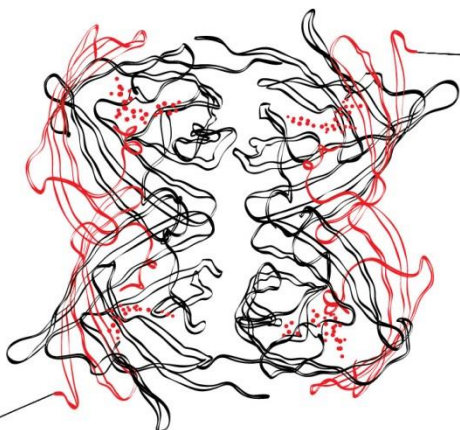
Dept. of Health Technology & Services Research

Examination Committee:

Dr. H. Koffijberg

Dr. J.M. Hummel

Prof. Dr. J. Grandjean



UNIVERSITEIT TWENTE.

MASTER THESIS HEALTH SCIENCES

HEALTH TECHNOLOGY ASSESSMENT & INNOVATION TRACK

TITLE ITS HEART TO SEE:
AN EARLY HEALTH TECHNOLOGY ASSESSMENT OF RENDERING 3D-
IMAGES PRIOR TO TRANSCATHETER AORTIC VALVE IMPLANTATION

AUTHOR MAX ANALBERS

SUPERVISORS *UNIVERSITY OF TWENTE:*
H. KOFFIJBERG, PhD
M. HUMMEL, PhD
THORAX CENTRUM TWENTE:
PROF. J. GRANDJEAN, MD PhD
F. HALFWERK, MD MSc

INSTITUTE UNIVERSITY OF TWENTE
DEPARTMENT OF HEALTH TECHNOLOGY & SERVICES RESEARCH

POSTAL ADDRESS P.O. Box 217
7500 AE ENSCHEDE, THE NETHERLANDS

VISITING ADDRESS RAVELIJN BUILDING
DRIENERLOLAAN 5
7522 NB ENSCHEDE
THE NETHERLANDS

DATE 30TH OF JUNE 2016

UNIVERSITEIT TWENTE.



Thorax Centrum Twente

ABSTRACT

ITS HEART TO SEE

BACKGROUND:

Patients undergoing heart surgery are preoperatively examined using a combination of imaging modalities. Dependent on the outcome, the type of surgery is determined, risks are estimated and the surgery is planned. New types of technology are able to convert CT, MRI and ultrasound images into a 3-Dimensional object, to look at the image from different angles and get a cross-sectional view of the heart as a whole. The use of 3D-imaging is not yet common for cardiac surgery, since it is unknown whether 3D-imaging is actually beneficial, and if so, where it could be used and what the potential effect could be. A preliminary survey indicated its value may be highest in transcatheter surgery.

METHOD:

The aim of this study is to investigate the potential effect of 3D-imaging on the outcome of TAVI procedures. The potential effect on different outcomes - compared to the costs – is estimated in an early Health Technology Assessment using a Discrete Event Simulation Model. Input data for the model is obtained from individual patient data, and data gaps are filled in with the use of Expert Elicitation. Uncertainty is assessed with the use of both deterministic and probabilistic sensitivity analysis

RESULTS:

Results showed that TAVI costs could potentially be reduced with █████ and the system itself costs █████ (with █████ TAVI procedures a year and payment in 5 years). Therefore, the expected cost savings equal █████ per TAVI procedure when using 3D-imaging, and the corresponding Cost-Benefit Ratio is █████. Sensitivity analysis showed that █████ has the most influence on cost-savings, and could potentially result in a cost-saving between █████ Probabilistic sensitivity analysis showed that the probability of 3D-imaging reducing costs is █████

CONCLUSION:

Using 3D-imaging prior to TAVI procedures has a favourable Cost-Benefit Ratio. However, it is still uncertain whether costs would be saved, and if so, how large cost savings would be. Also, the actual use and implementation of 3D-imaging in clinical practice will determine its impact to a large extent. Use of 3D-imaging in patients where conventional imaging results are unsatisfactory, and more preoperative imaging is necessary to safely perform the procedure, could lead to lower costs and higher benefits.

keywords: TAVI; 3D-imaging; 3D-rendering; cost-benefit study; discrete event simulation; early health technology assessment

1. BACKGROUND

CARDIAC SURGERY

Patients undergoing cardiac surgery are preoperatively examined using either CT-scan, MRI-scan, Trans Oesophageal Echo (TEE), Trans Thoracic Echo (TTE), Coronary Arteriography (CAG), or a combination of those scans (1–3). These diagnostic imaging tools give detailed information about the type and seriousness of the abnormality in the heart, after which the treatment and further prognosis is assessed (4). Dependent on the outcome of the examination, the type of surgery is assessed, risks are estimated and the surgery is planned (1, 4).

Most common types of surgery are Coronary Artery Bypass Graft (CABG) and valve replacement surgery (aortic or mitral). Access to the heart can be obtained through either full sternotomy (open heart operation), minimal sternotomy, or with a transcatheter approach (5). The type of surgical approach used is based on patient anatomy and patient risk. Most common are open heart operations, but when these are difficult to perform (e.g.: in reoperations), another approach must be chosen. The transcatheter approach is mostly used in older, high-risk patients, in whom a sternotomy is no longer a safe option. Examination is sometimes difficult due to the complex nature of the cardiac problem. Ageing population, previous cardiac operations and continues progress in cardiovascular medicine makes patients differ in their cardiovascular morphology, making the anatomical structures of the heart difficult to assess preoperatively (6–8).

3-DIMENSIONAL IMAGING IN CARDIAC SURGERY

New types of technologies are able to convert the CT, MRI and ultrasound images into an 3-dimensional object (see list of figures and figure 1), providing the user with the opportunity to look at the image from different angles and get a cross-sectional view of the heart as a whole (9–12). With better insight in the patients morphology, the surgical type and approach can be assessed more correctly before surgery, decreasing the surgical risks for the patient.

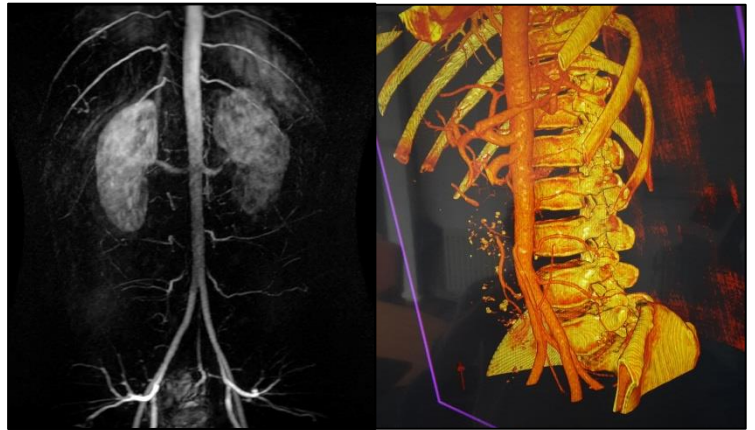


Figure 1: Comparison between conventional and 3D-imaging. Left image shows a contrast CT of the Aorta Abdominalis, where the right image shows a 3D-image.

Besides the 3D-TEE, the uses of 3D-imaging techniques have not yet been standardized for cardiac surgery. The current limitations lay in the poor image quality, the high price of the image-rendering systems and the difficulty of rendering and using 3D-data (13). These limitations are diminishing due to ongoing advances in technology, but it is unknown whether 3D-imaging is actually beneficial, and if so, where it could be used and what the potential effect could be.

EARLY HEALTH TECHNOLOGY ASSESSMENT

Since only single-centre experiences and/or case studies are available concerning 3D-imaging in cardiac surgery (6, 14–17), an early Health Technology Assessment (HTA) can be used to investigate the potential effect of 3D-imaging in cardiac surgery.

With early HTA, assessment of the usefulness and (possible) advantages of a new technology during their development is possible, even when data from clinical trials is lacking (18). By modelling simplified scenarios of real-life, an estimate of the potential impact can be derived (19).

Discrete Event Simulation Modelling (DES) is a modelling technique which simulates ‘individual’ patients that undergo events. The main advantage of DES, relative to other modelling techniques, is that it can be used to mimic complex environments – like a hospital – by simulating time, probabilities, resources and queues (20, 21). When exploring the effect of using 3D-imaging in

cardiac surgery, the potential effect on surgical outcome is important, as well as the effect on the process and costs. Discrete Event Simulation takes individual patients into account instead of following a cohort of patients, which makes it a valuable modelling technique when looking at the potential benefit of using 3D-imaging in cardiac surgery (21, 22).

PRELIMINARY SURVEY

The expected usability of using 3D-imaging is very broad (23, 24). A preliminary survey is taken under cardiologists (n=4), radiologists (n=2) and thoracic surgeons (n=5) in order to investigate where in the current process 3D-imaging is expected to be beneficial.

Based on the results from the preliminary survey, the impact of 3D-imaging is expected to be linked to [REDACTED]

[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]

The effect of using 3D-rendering systems is

[REDACTED]
[REDACTED]
[REDACTED]). One of the cardiologist stated that:
[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]

The full survey and the remaining results can be found in Appendix I and II.

Based on the results, the potential effect of 3D-imaging is expected most in Transcatheter Aortic Valve Implementations (TAVI). In a TAVI procedure, a deflated aortic valve is implemented transfemoral, transapical or transaortal. The valve is placed in the right spot with the use of a catheter and expanded; pushing the current aortic valve away. TAVI procedures are mostly done in high-risk and older patients, in whom a sternotomy no longer is safe (25). With the transcatheter approach patients can be operated who otherwise could not be operated due to the high risk of mortality.

Prior to TAVI, a TTE or TEE is made to assess the valve morphology and a CT scan is made to determine the right surgical approach. During surgery, TEE is used to assess the valve size and the right placement of the replacement valve. Since there is currently limited data available about 3D-imaging in TAVI procedure, this study aims to investigate the cost-benefit of pre-operatively using 3D-imaging next to conventional imaging in patients undergoing a TAVI procedure.

2. Method

OBJECTIVE OF THE STUDY

The aim of this study will be accomplished by answering the following main question:

“What is the expected cost-benefit of pre-operatively using 3D-imaging next to conventional imaging in patients undergoing a TAVI procedure?”

To answer this question, a Discrete Event Simulation Model is made using a framework from the Good Research Practices in Modelling Task Force, a collaboration between ISPOR and the Society for Medical Decision Making (26).

Making and running the model exist of 4 steps:

1. The model itself is made by converting the clinical pathway into a series of events the patient is simulated through. More information can be found under ‘Discrete Event Simulation Model’
2. Input data is obtained from MST patient data. See “MST patient data” for more information.
3. Because of lacking data on the outcome of cardiac surgery with 3D-imaging, experts are asked to fill in the data gaps in the model. More information about this can be found under ‘Expert Elicitation’
4. The model is executed and results are gathered. Analysis of the results is done by performing a sensitivity analysis.

Outcome of the study is the expected cost-benefit of using 3D-imaging prior to TAVI procedures.

Figure 2: Discrete Event Simulation model. Successful surgery is identified as both successful access and successful implant in the first try. Otherwise the procedure is regarded unsuccessful. TAVI: Transcatheter Aortic Valve Implementation, IC: Intensive Care, IHD: In-Hospital Days

DISCRETE EVENT SIMULATION MODEL

A DES-model is made to simulate the effect of 3D-imaging on the outcome of TAVI surgery. The model is shown in figure 1. Based on the attributes from the patient, probabilities are adjusted within the model. When 3D-imaging is used, corresponding probabilities will be loaded in the rest of the model. The model will simulate a 30-day timeframe, since long-term outcome data is not available and experts are unable to correctly estimate long-term outcomes. The model will simulate 10.000 patients to reach a 95% confidence interval (27). More detailed information about the development of the DES model for this study can be found in Appendix III.

PATIENT DATA MST

To get data for the 'TAVI without 3D'-pathway, patient characteristics and input data for the model are retrospectively obtained from MST patient data. Data from [REDACTED]

[REDACTED] For every patient, an intraoperative report and 30-day follow-up must be available, otherwise successful access and successful implantation cannot be assessed. Costs are based on [REDACTED]

EXPERT ELICITATION

Data for the 'TAVI with 3D'-pathway of the model is gathered with the use of expert elicitation. Expert elicitation is subjected to bias, so a framework from Haakma et. al. (2014) is used to minimize bias (28, 29).

A sample of 15 experts – either (interventional) cardiologist or thoracic surgeons – is invited to attend a demonstration from Ps-Medtech (Amsterdam, Netherlands), in which their 3D-imaging system will be demonstrated. The aim is to include 15 experts in this study, since it is assumed that the benefit of including more experts starts to decrease after 12 (30). After the demo, experts are asked to estimate the procedural differences and the changes in outcome when using 3D-imaging prior to TAVI procedures. Experts are asked about 'operation approach success', 'operation implant success', 're-operation', 'adverse events' and '30-day mortality'.

The experts are asked to give the most likely value for a parameter (the mode), followed by the lowest and highest likely value, plotted as a Probability Density Function (PDF) by using the Project Evaluation and Review Technique (PERT) approach (31).

As heterogeneity was expected, a calibration method is applied. Experts are given a weight to adjust for expertise, so that the expert with most experience is weighted most. The weighting is based on both TAVI and 3D experience (see table 3), since these are factors that determine the reliability of the answer.

Table 1: Criteria and weights for the calibration of experts

Experience with TAVI procedures		Experience with 3D-imaging procedures	
None	1	None	1
Involved in planning	2	Demo	2
Performs TAVIs	3	Work with 3D-system	3

Where $P(\Theta)$ is the overall probability distribution, W_i is the weight of the expert (summing up to 1) and $P_i(\Theta)$ is the distribution probability (32). The overall probability distributions will then be used in the model. Further details can be found in Appendix IV and V.

To assess parameter uncertainty and the effect of different parameters on the outcome of the model, both Deterministic Sensitivity Analysis (DSA) and Probabilistic Sensitivity Analysis (PSA) will be executed, since, according to the NICE Technology Appraisal Committee, they should be used both to fully address uncertainty (33).

In DSA, all input parameters are independently changed within the parameter distributions – also known as univariate sensitivity analysis -, and the

change in outcome compared to the mean benefit (33). In PSA, probability distributions are applied to the ranges of input parameters. By randomly drawing from those distributions (Monte Carlo simulation), different outcomes are estimated. These outcomes are used to calculate the parameter uncertainty surrounding the cost-benefit (34).

PATIENT DATA

Data from 71 TAVIs performed between January 2015 and March 2016 was obtained. Of those 71, 1 patient was still in the hospital at the time of this study. No outcome data was available, so the patient was excluded. Baseline characteristics, procedural outcomes and clinical outcomes are shown in table 1. Mean age was [REDACTED]. The mean Logistic EuroSCORE II was $4.13 \pm 4.2\%$.

given in Mean (%), Mean \pm SD or n/N (%). PM: Pacemaker

OUTCOME EXPERT ELICITATION

Table 3: Respondents and their weighting

Weight is calculated by dividing individual score by total (34). 'No score' is given when the respondent was unable to fill in the form

[REDACTED]

[illegible]

OUTCOME OF THE DES MODEL

The mean results in table 4 show that, on average, a TAVI patient [REDACTED] this could potentially be lowered [REDACTED] when using 3D-imaging. Making the benefit [REDACTED] Most benefit is gained by less unnecessary valve implementations. Due to the high price of the valve, this could save up [REDACTED] average.

Table 4: mean results from the DES model

Mean results:	Valve costs	Operation costs	In-hospital costs	Re-operation costs	Re-admittance costs	Total
Conventional imaging	████	████	████	████	████	████
████████	████	████	████	██	████	████
████████████████	██	██	██	██	██	██

Cost of TAVI procedure with and without 3D-imaging. Not accounted for the costs of the 3D-imaging system. Conventional imaging is based on patient data from MST. 3D-imaging is based on the outcome from the expert elicitation.

Table 5: Input data for the DES model

Age Group	High School	Bachelor's	Master's
18-24	150	250	100
25-34	100	200	100
35-44	80	180	100
45-54	60	160	100
55-64	40	140	100
65-74	20	120	100
75-84	10	100	100
85-94	5	80	100
95-104	2	60	100
105-114	1	40	100

Cost of the 3D-system is estimated [REDACTED]
[REDACTED]
[REDACTED] t. Assuming that the system will be fully
paid in 5 years (which is the standard), and for
[REDACTED] the
costs for 3D-imaging will be; [REDACTED]
per TAVI patient; making the mean cost-savings
[REDACTED]
[REDACTED] gives the Cost-Benefit
Ratio (CBR):

$$CBR = \frac{Benefits}{Costs} \times \frac{\text{[Redacted]}}{\text{[Redacted]}} \times \text{[Redacted]}$$

Cost-benefit ratio is used to show the value of an investment.

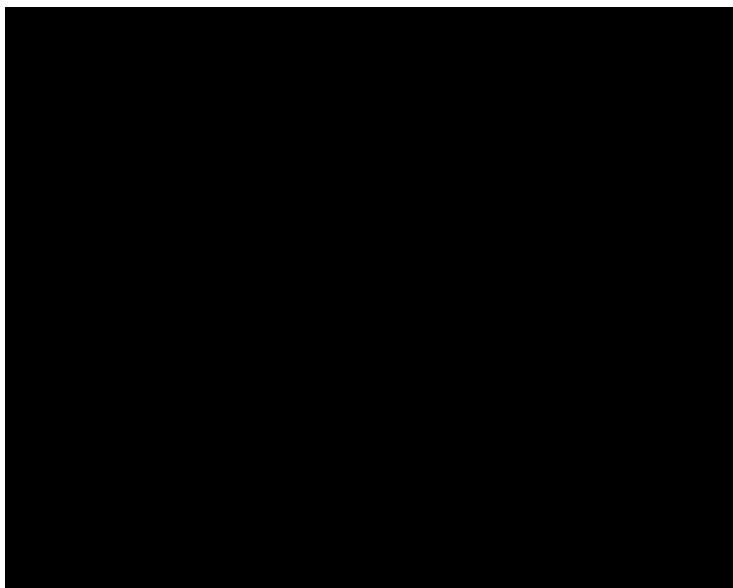


Figure 5: Cost-saving acceptability curve. Cumulative probability is shown for every minimal amount of cost-saving

Figure 4: Tornado graph. Results from the deterministic sensitivity analysis. Change in € from mean average (table 4) is shown.

OUTCOME OF THE SENSITIVITY ANALYSIS

Both deterministic and probabilistic sensitivity analysis is performed to assess the parameter uncertainty. The result of the deterministic sensitivity analysis is shown in figure 4. Uncertainty of the model is mostly based on the MST data, since the relatively low sample size (n=70) results in substantial uncertainty. The successful valve implementation when using conventional imaging was estimated to lie between 90,9% and 100%, and in the mean results this was 95,7%.

The sensitivity analysis showed that, depending on this parameter estimation, [REDACTED]

[REDACTED] analysis is performed to assess the parameter uncertainty in the model itself. Figure 5 shows the cost-saving acceptability curve, visualizing the uncertainty surrounding the cost-savings. For every cost-saving the surrounding uncertainty is calculated.

4. Discussion

This study aimed to provide insight in the potential effect of using 3D-imaging prior to TAVI procedures. Since there is a lack of randomized studies, this effect is not yet known. Using a Discrete Event Simulation it was found that using 3D-imaging prior to TAVI procedures could potentially improve both procedural success and clinical outcome. Results from expert elicitation indicated an increase in operational success and a decrease in 30-day mortality. Mean outcome showed that TAVI [REDACTED], resulting in cost savings of [REDACTED]

However, as mathematician George E.P. Box once said: *“Essentially, all models are wrong, but some are useful.”* (36). Implying that models give useful information, but will always be a simplification of the real world. Parameter uncertainty was assessed to find out how big this deviation with the real world could be and where this would come from. Sensitivity analysis showed that the amount of successful valve implementations is the most important factor for the cost savings, and this could potentially result in [REDACTED]

Limitations

Uncertainty originates from limitations in either the model or the data used. Patient data from MST is based on a small patient group [REDACTED]. This caused some patient data to differ from literature data. The EuroSCORE I [REDACTED] SOURCE XT registry and [REDACTED] PARTNER trial, with [REDACTED] (37, 38). Patients are classified as high-risk with a EuroSCORE I above 15% (39). With less high-risks patients, better procedural and clinical outcomes are expected. This is shown in a better procedural [REDACTED] and device success [REDACTED] MST vs SOURCE XT). However, the amount of rehospitalizations [REDACTED] is [REDACTED] the amount of the rehospitalizations in the SOURCE XT registry [REDACTED] (37), [REDACTED]. The type of valve used is also an important factor. Newer valves have been produced which are safer (40), and since implant success is an important factor whether or not 3D-imaging is cost-beneficial, this should be accounted for.

Heterogeneity of the elicitation from the experts differs per variable. Successful approach and 30-day mortality show the least heterogeneity between estimations. In the ‘valve-

implementation' parameter, a clear distinction is visible between 2 groups, as shown in figure 6: four experts estimate the prevalence to be around [REDACTED]. Adverse events and re-operations were even less homogeneous, with estimated prevalence between [REDACTED]. A bigger sample group would give more insight in the overall estimation and the outliers.

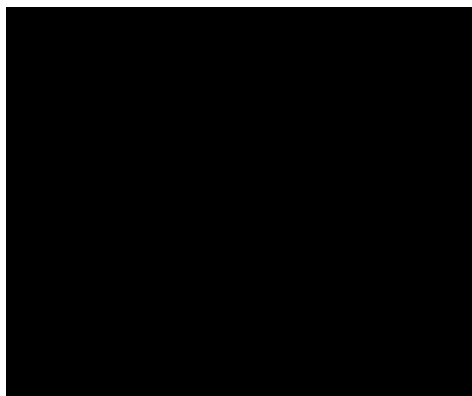


Figure 6: Expert estimations. Occurrence of unsuccessful valve implementation

The linear pooling method was used to combine the experts' answers into an overall probability distribution function (PDF). The red line in figure 6 shows this overall, pooled PDF, [REDACTED]. Perhaps other pooling methods are more efficient, in which all experts estimations are individually used in the model, and the weight could assign the times one expert is used (i.e.: an expert with a weight of 0.3 will be used twice as much as one with a weight of 0.15)

A calibration method was applied, but the weights chosen are arbitrary; there is probably a connection between TAVI performance, experience with 3D-imaging and the ability to correctly estimate procedural and clinical outcomes, but whether - and to what extent - is unclear. Shifting the scores of the weight and assessing the changes in heterogeneity could provide more insight into the calibration method used in this study.

From the 10 experts included in the expert elicitation, [REDACTED]. TAVI procedures should be

assessed individually, and they could [REDACTED]. How certain the other experts are with their answers is unclear. To provide more certainty, an alternative behavioural approach where experts will come together and try to achieve consensus about the effect, instead of expert estimating individually, could be used. By consulting with other experts, this approach could potentially lead to less difficulty in estimating the parameters and more confidence in the answers.

The DES model used for this study is a simplification of reality. The expert elicitation was only used to estimate the prevalence of multiple parameters, but it did not look at every possible outcome. The MST data was used to assess current outcomes, but with [REDACTED], not every possible outcomes was prevalent. Aortic dissection, cardiac tamponade and coronary occlusion were not included in the model, even though these are important adverse events (36).

Practical implications

Even though results from this cost-benefit study implicates that using 3D-imaging prior to TAVI procedures could lead to a decrease in procedural costs, there are numeral factors which could affect this outcome.

3D-systems are not yet used within MST. System errors and usability are not yet assessed. When these are too bothersome, adequate implementation of the system will not start and the system will not be (fully) used. Furthermore, the system is unlikely to be used solely for TAVI procedures, since the versatility of the system is such that it could easily be used before other difficult operations; both in cardio-thoracic and other surgery types, decreasing the overall costs of the system. Retrospective studies have showed that having better images of the patient could improve preoperative choices made in difficult cases (15, 41, 42). Therefore, the deployment of the system will probably be most beneficial in cases where the conventional imaging is unsatisfactory and more information is needed to safely perform surgery. Isolating the

use of 3D-imaging towards those cases is an important step towards using the 3D-imaging system as efficiently as possible, both in TAVI procedures as well as in other operation types.

Besides surgical planning, the system could be used for educational purposes. Radiologists are able to 'read' 2D-images, but for the untrained these images are difficult to interpret. Students and professionals from all kind of specialisms, or even patients, can use 3D-images of anatomical structures/pathologies to improve knowledge about the inside of the human body. Special cases can be explained to patients and made more understandable in case reports, which is something currently done with 3D-prints (43).

Limitations of the 3D-imaging system are the learning curve and the time it takes to adjust the 3D-images so the specialist sees what is of actual interest in. These are limitations that could lead to specialists not using the system, and should be accounted for when deploying the system.

Recommendations

As summarized by Fineberg: "The ultimate value of the diagnostic test is that difference in health outcome resulting from the test: in what ways, to what extent, with what frequency, in which patients is health outcome improved because of this test?" (44). This study looked at the expected cost-savings when using 3D-imaging in general TAVI patients, and with Fineberg in mind, this study could be used as a starting point to more specifically address the advantages of using 3D-imaging in terms of health outcomes.

Uncertainty surrounding the model inputs show that, for 3D-imaging in TAVI procedures, the estimated cost-benefit is not conclusively greater than 1. It should therefore be used as an indication of cost-benefit and as a starting point for further research. When more data is available, these could be used to assess the external validity of this study and to get a more accurate model outcome (45). Further studies could also focus on the use of 3D-imaging in specific cases; when conventional imaging is unsatisfactory and more pre-operative imaging is necessary. For the most

accurate results, these studies must be done with access to a 3D-system, to compare conventional imaging with 3D-imaging, and study the changes in preoperative planning, procedural success and clinical outcomes.

As for the clinical use, a solid implementation plan must be made when deploying the 3D-imaging system. Groel and Wensing (2004) looked at the different incentives and barriers when trying to achieve change (46). Their ten-step model – in combination with the results of this study – could be followed to make sure that there is a platform for using 3D-imaging to its full capacity and that no practical implications will limit the use or benefits of 3D-imaging.

5. Conclusion

When using 3D-imaging prior to TAVI procedures, the conclusion is that 3D-imaging has a favourable Cost-Benefit ratio. Deployment of the 3D-systems in patients where conventional images is unsatisfactory, and where more preoperative imaging is necessary to safely perform the procedure, could lead to larger cost savings as estimated in this study.

6. Acknowledgements

In the making of this master thesis, multiple acknowledgements are in place. At first I would like to thank my supervisors, Erik Koffijberg and Marjan Hummel from the University of Twente, and Jan Grandjean and Frank Halfwerk from Medisch Spectrum Twente. I'm thankful for all input, feedback and help they gave to me.

Furthermore, I would like to thank all radiologist, cardiologist and surgeons within MST and ZGT who took the time to fill in my survey and helped with the expert elicitation. Special thanks to dr. Meijs, who took the time to show me the conventional imaging techniques and introduced me to a lot of other experts, Ben Fransen and Ton Dijkhuis for providing the MST data, and Ps-Medtech for taking 2 days to demonstrate their 3D-imaging system within MST.

7. References

- Hartnell GG. Imaging of aortic aneurysms and dissection: CT and MRI. *J. Thorac. Imaging* 2001;16:35–46. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/11149691>.
- Vahanian A, Alfieri O, Andreotti F, et al. Guidelines on the management of valvular heart disease (version 2012). *Eur. Heart J.* 2012;33:2451–2496.
- Bradley SM, Spertus J a, Kennedy KF, et al. Patient selection for diagnostic coronary angiography and hospital-level percutaneous coronary intervention appropriateness: insights from the national cardiovascular data registry. *JAMA Intern. Med.* 2014;174:1630–9. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/25156821>.
- Lamata P, Casero R, Carapella V, et al. Images as drivers of progress in cardiac computational modelling. *Prog. Biophys. Mol. Biol.* 2014;115:198–212.
- Iribarne a, Easterwood R, Chan EY, et al. The golden age of minimally invasive cardiothoracic surgery: current and future perspectives. *Futur. Cardiol* 2011;7:333–346. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/21627475>npapers3://publication/doi/10.2217/fca.11.23.
- Schmauss D, Haeberle S, Hagl C, Sodan R. Three-dimensional printing in cardiac surgery and interventional cardiology: a single-centre experience. *Eur. J. Cardiothorac. Surg.* 2014;1–9.
- Backer CL, Mongé MC, Russell HM, Popescu AR, Rastatter JC, Costello JM. Reoperation after vascular ring repair. *Semin. Thorac. Cardiovasc. Surg. Pediatr. Card. Surg. Annu.* 2014;17:48–55.
- Said SM, Dearani JA. Strategies for high-risk reoperations in congenital heart disease. *Semin. Thorac. Cardiovasc. Surg. Pediatr. Card. Surg. Annu.* 2014;17:9–21.
- Jacobs S, Grunert R, Mohr FW, Falk V. 3D-Imaging of cardiac structures using 3D heart models for planning in heart surgery: a preliminary study. *Interact Cardiovasc Thorac Surg* 2008;7:6–9. Available at: <http://icvts.oxfordjournals.org/content/7/1/6.full.pdf>.
- Valverde I, Gomez G, Gonzalez A, et al. Three-dimensional patient-specific cardiac model for surgical planning in Nikaidoh procedure. *Cardiol. Young* 2014;1–7. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/24809416>.
- Kim MS, Hansgen AR, Wink O, Quaife RA, Carroll JD. Rapid Prototyping: A New Tool in Understanding and Treating Structural Heart Disease. *Circulation* 2008;117:2388–2394. Available at: <http://circ.ahajournals.org/cgi/doi/10.1161/CIRCULATIONAHA.107.740977>.
- Karatas OH, Toy E. Three-dimensional imaging techniques: A literature review. *Eur. J. Dent.* 2014;8:132–140.
- Sahu D, Mathew MJ, Reddy PK. 3D laparoscopy - Help or hype; initial experience of a tertiary health centre. *J. Clin. Diagnostic Res.* 2014;8.
- Akiba T. Utility of three-dimensional computed tomography in general thoracic surgery. *Gen. Thorac. Cardiovasc. Surg.* 2013;61:676–684.
- Heuts S, Maessen JG, Sardari Nia P. Preoperative planning of left-sided valve surgery with 3D computed tomography reconstruction models: sternotomy or a minimally invasive approach? *Interact. Cardiovasc. Thorac. Surg.* 2016;ivv408. Available at: <http://icvts.oxfordjournals.org/lookup/doi/10.1093/icvts/ivv408>.
- Song BG, Choi JH, Choi SM, Park JH, Park YH, Choe YH. Coronary Artery Graft Dilatation Aided by Multidetector Computed Tomography. *Asian Cardiovasc. Thorac. Ann.* 2010;18:177–179. Available at: <http://aan.sagepub.com/content/18/2/177.abstract>.
- Dankowski R, Baszko A, Sutherland M, et al. 3D heart model printing for preparation of percutaneous structural interventions: Description of the technology and case report. *Kardiol. Pol.* 2014;72:546–551.
- Redekop K, Mikudina B. Early medical technology assessments of medical devices and tests. *J. Heal. Policy Outcomes Res.* 2013;1:26–37.
- Trikalinos T a, Siebert U, Lau J. Decision-analytic modeling to evaluate benefits and harms of medical tests: uses and limitations. *Med. Decis. Making* 2009;29:E22–E29.
- Davis S, Stevenson M, Tappenden P, Wailoo AJ. Technical Support Document 15: Cost-effectiveness modelling using patient-level simulation. NICE DSU 2014. Available at: <http://www.nicedseu.org.uk>.
- Karnon J, Haji Ali Afzali H. When to use Discrete Event Simulation (DES) for the economic evaluation of health technologies? A review and critique of the costs and benefits of DES. *Pharmacoeconomics* 2014;32:547–558.
- Cooper K, Davies R, Roderick P, Chase D, Raftery J. The Development of a Simulation Model of the Treatment of Coronary Heart Disease. *Health Care Manag. Sci.* 5:259–267. Available at: <http://dx.doi.org/10.1023/A:1020378022303>.
- Cremer J, Teebken OE, Simon A, Hutzelmann A, Heller M, Haverich A. Thoracic computed tomography prior to redo coronary surgery. *Eur. J. Cardio-thoracic Surg.* 1998;13:650–654.
- Morgan-Hughes GJ, Marshall AJ, Roobottom CA. Multislice computed tomography cardiac imaging: Current status. *Clin. Radiol.* 2002;57:872–882.
- Leon MB, Piazza N, Nikolsky E, et al. Standardized endpoint definitions for transcatheter aortic valve implantation clinical trials: A consensus report from the Valve Academic Research Consortium. *Eur. Heart J.* 2011;32:205–217.
- Karnon J, Stahl J, Brennan A, Caro JJ, Mar J, M??ller J. Modeling using discrete event simulation: A report of the ISPOR-SMDM modeling good research practices task force-4. *Value Heal.* 2012;15:821–827.
- Byrne MD. How many times should a stochastic model be run? An approach based on confidence

- intervals. In: *Proceedings of the 12th International Conference on Cognitive Modeling.*, 2013:445–450.
28. Sullivan W, Payne K. The appropriate elicitation of expert opinion in economic models. *Pharmacoeconomics* 2011;29:455–459.
29. Haakma W, Steuten LMG, Bojke L, IJzerman MJ. Belief elicitation to populate health economic models of medical diagnostic devices in development. *Appl. Health Econ. Health Policy* 2014;12:327–334.
30. Knol AB, Slottje P, van der Sluijs JP, Lebre E. The use of expert elicitation in environmental health impact assessment: a seven step procedure. *Environ. Health* 2010;9:19. Available at: <http://www.ehjournal.net/content/9/1/19>.
31. Van Dorp JR, Kotz S. A novel extension of the triangular distribution and its parameter estimation. *J. R. Stat. Soc. Ser. D Stat.* 2002;51:63–79.
32. Bojke L, Claxton K, Bravo-Vergel Y, Sculpher M, Palmer S, Abrams K. Eliciting distributions to populate decision analytic models. *Value Heal.* 2010;13:557–564.
33. Andronis L, Barton P, Bryan S. Sensitivity analysis in economic evaluation: an audit of NICE current practice and a review of its use and value in decision-making. *Health Technol. Assess.* 2009;13.
34. Briggs AH, Goeree R, Blackhouse G, O'Brien BJ. Probabilistic Analysis of Cost-Effectiveness Models: Choosing between Treatment Strategies for Gastroesophageal Reflux Disease. *Med. Decis. Mak.* 2002;22:290–308. Available at: <http://mdm.sagepub.com/cgi/doi/10.1177/0272989X0202200408>.
35. Chevreul K, Brunn M, Cadier B, et al. Cost of transcatheter aortic valve implantation and factors associated with higher hospital stay cost in patients of the FRANCE (FRench Aortic National CoreValve and Edwards) registry. *Arch. Cardiovasc. Dis.* 2013;106:209–219.
36. Box GEP, Draper NR. *Empirical Model-Building and Response Surfaces.* 1987. Available at: <http://psycnet.apa.org/psycinfo/1987-97236-000>.
37. Schymik G, Lefèvre T, Bartorelli AL, et al. European experience with the second-generation Edwards SAPIEN XT transcatheter heart valve in patients with severe aortic stenosis: 1-year outcomes from the SOURCE XT Registry. *JACC Cardiovasc. Interv.* 2015;8:657–669.
38. Lefèvre T, Kappetein AP, Wolner E, et al. One year follow-up of the multi-centre European PARTNER transcatheter heart valve study. *Eur. Heart J.* 2011;32:148–157.
39. Smith CR, Leon MB, Mack MJ, et al. Transcatheter versus surgical aortic-valve replacement in high-risk patients. *N. Engl. J. Med.* 2011;364:2187–98. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/21639811>.
40. Haussig S, Schuler G, Linke A. Worldwide TAVI registries: What have we learned? *Clin. Res. Cardiol.* 2014;103:603–612.
41. Rajiah P, Schoenhagen P. The role of computed tomography in pre-procedural planning of cardiovascular surgery and intervention. *Insights Imaging* 2013;4:671–689.
42. Schoenhagen P, Hausleiter J, Achenbach S, Desai MY, Tuzcu EM. Computed tomography in the evaluation for transcatheter aortic valve implantation (TAVI). *Cardiovasc. Diagn. Ther.* 2011;1:44–56. Available at: <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3839132&tool=pmcentrez&rendertype=abstract>.
43. Jongbloed M. 3D models for education. In: *Heart disease in 3D and 4D.* Leiden, 2016.
44. Fineberg H V. Evaluation of computed tomography: Achievement and challenge. *Am. J. Roentgenol.* 1978;131:1–4.
45. Debray TPA, Vergouwe Y, Koffijberg H, Nieboer D, Steyerberg EW, Moons KGM. A new framework to enhance the interpretation of external validation studies of clinical prediction models. *J. Clin. Epidemiol.* 2015;68:279–289.
46. Grol R, Wensing M. What drives change? Barriers to and incentives for achieving evidence-based practice. *Med. J. Aust.* 2004;180.

8. Appendix

Index

Figures:	List of figures.....	Page 2
Appendix I:	Preliminary survey.....	Page 3
Appendix II:	Results survey.....	Page 8
Appendix III:	Making the DES model.....	Page 12
Appendix IV:	Expert Elicitation.....	Page 17
Appendix V:	Expert Elicitation questionnaire.....	Page 19
Appendix VI:	Results Expert Elicitation.....	Page 23

List of figures

Example 3D-imaging system



Appendix I

Preliminary survey

3D-Beeldvorming bij cardio-thoracale ingrepen

Inleiding

UNIVERSITEIT TWENTE.



Geachte Heer/Mevrouw,

Mijn naam is Max Analbers, master student Health Sciences aan de Universiteit Twente. Op dit moment ben ik bezig met mijn masterthesis, waarbij ik onderzoek of het gebruik van 3D-beeldvorming bijdraagt aan beter uitkomsten voor patiënten van cardio-thoracale operaties en wat de kosteneffectiviteit van deze techniek is. Dit onderzoek vindt plaats binnen Thorax Centrum Twente.

De techniek die onderzocht wordt maakt gebruik van 2D beelden gemaakt via CT, MRI en echografie, waarbij de data automatisch omgezet wordt naar een 3D weergave, zodat deze data direct te beoordelen is. Het voordeel van dit systeem is dat meerdere soorten data omgezet kunnen worden naar 3D, en dat deze allemaal via 1 systeem te bekijken en te beoordelen zijn.

Voordat mijn praktijk onderzoek begint wil ik het huidige proces in kaart brengen, onderzoeken welke mogelijkheden er voor dit systeem liggen en welke voordelen het invoeren van 3-D beeldvorming kan hebben. Daarom wil ik u vragen om deel te nemen aan deze enquête.

De enquête bestaat uit 3 onderdelen:

- 1) Huidige beeldvormende technieken en beperkingen
- 2) Het gebruik van automatische 3D-weergave beeldvorming
- 3) Het effect van het gebruik van automatische 3D-weergave beeldvorming en het effect hiervan op de uitkomst van verschillende operaties

Het invullen van de enquête zal ongeveer 5 tot 10 minuten duren. Indien u geen ervaring heeft met 3D-beeldvorming vraag ik u onderstaand filmpje te bekijken (1 minuut). Op deze wijze kunt u een idee krijgen over het systeem en de mogelijkheden.

[URL youtube: <https://www.youtube.com/watch?v=RulkoN-JPjw>]

Mocht u interesse hebben in de uitkomsten van ons onderzoek dan kunt u dit aangeven en zal ik u het eindrapport te zijner tijd toesturen. Voor vragen kunt u altijd mailen naar m.analbers@mst.nl.

De enquête begint op de volgende pagina. Alvast hartelijk dank voor uw hulp!

3D-Beeldvorming bij cardio-thoracale ingrepen

Basisvragen

1. Wat is uw naam?

2. Wat is uw beroep?

- ☐ Cardioloog
☒ Thoraxchirurg
☐ Radioloog
☐ Overige (geef nadere toelichting)

3. Hoeveel ervaring heeft u met 3D-beeldvorming vanuit CT of MRI beelden?

- ☐ Geen ervaring (nog nooit gebruikt)
☐ Weinig ervaring (enkele malen gebruikt)
☐ Redelijke ervaring (regelmatig gebruik)
☐ Veel ervaring (bijna dagelijks gebruik)

3D-Beeldvorming bij cardio-thoracale ingrepen

Deel 1: Huidige beeldvorming technieken:

4. Welke beeldvorming technieken worden er gebruikt bij de diagnosestelling/planning van operaties?

meerdere antwoorden zijn mogelijk.

	CABG	PVI	AVR	MVR	TAVI
CT	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
MRI	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TTE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TEE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CAG	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Overige (geef toelichting indien nodig)

5. Waarin liggen beperkingen van de verschillende typen beeldvorming?

Meerdere antwoorden zijn mogelijk

	Interpretatie van beelden	Sensitiviteit	Specificiteit	Veiligheid/comfort van de patiënt	Inzetbaarheid
CT	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
MRI	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TTE	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Interpretatie van beelden	Sensitiviteit	Specificiteit	Veiligheid/comfort van de patiënt	Inzetbaarheid
TEE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CAG	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Overige (Geef toelichting indien nodig)	<input type="text"/>				

6. Wat is de invloed van de beperkingen van de beeldvorming technieken:

In het diagnostische proces?

Bij het pre-operatief plannen van operaties?

Tijdens het uitvoeren van de operatie?

Bij het postoperatief proces?

3D-Beeldvorming bij cardio-thoracale ingrepen

Deel 2: Het gebruik van automatische 3D-beeldvorming systemen

**7. Waar in het proces kan automatische 3D-beeldvorming toegevoegde waarde hebben?
Meerdere antwoorden zijn mogelijk**

- ☐ In het diagnostische proces
- ☐ Bij het pre-operatief plannen en voorbereiden van operaties
- ☐ Bij het uitvoeren van de operatie
- ☐ In het postoperatief proces
- ☐ Overige (geef nadere toelichting)

[Redacted]
[Redacted]

[Redacted]

[Redacted] [Blue bar]

[Redacted]

Appendix II

Results survey

Question 1:

Wat is uw naam?

Opmerkingen: [REDACTED]

[REDACTED]

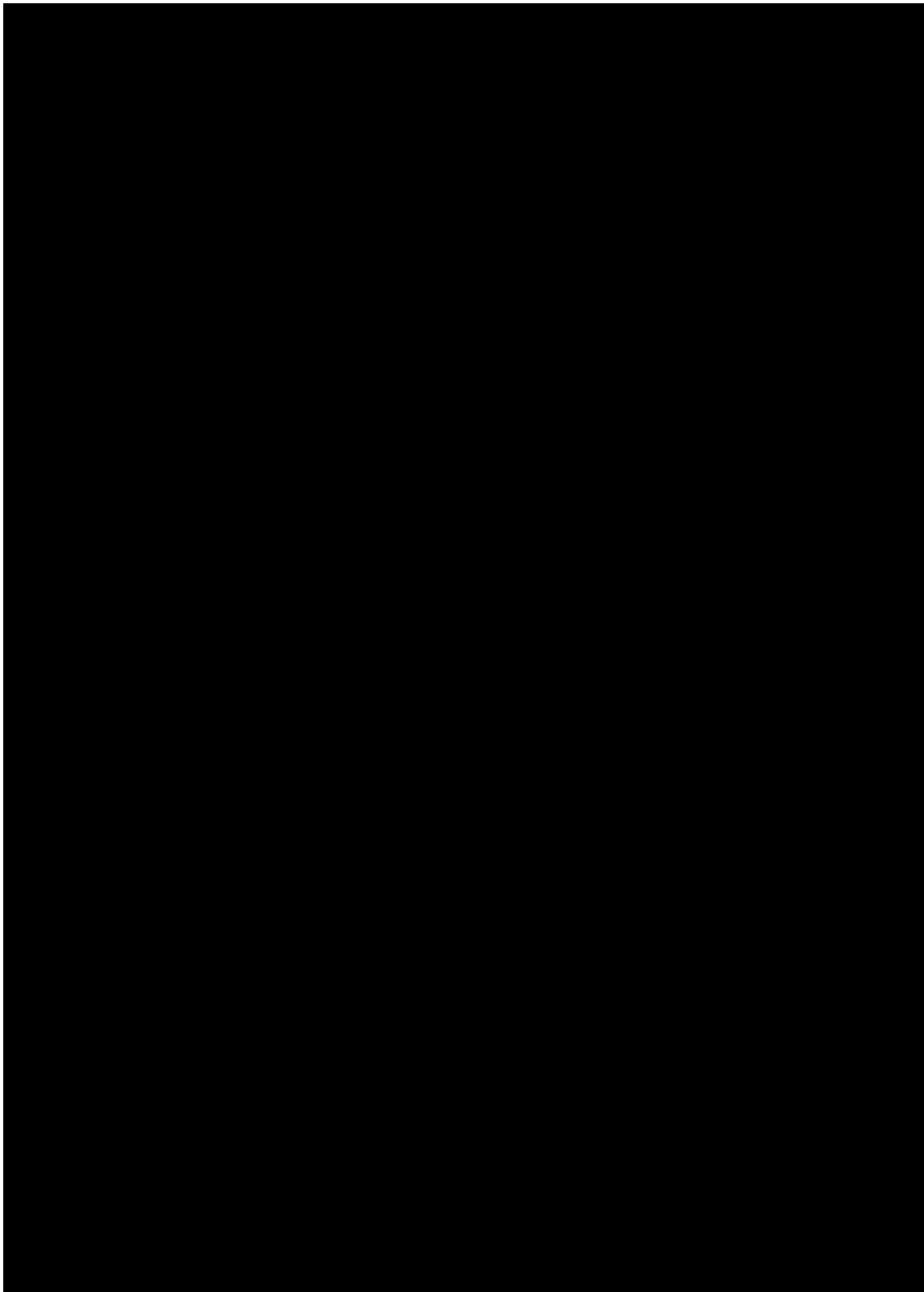
[REDACTED]

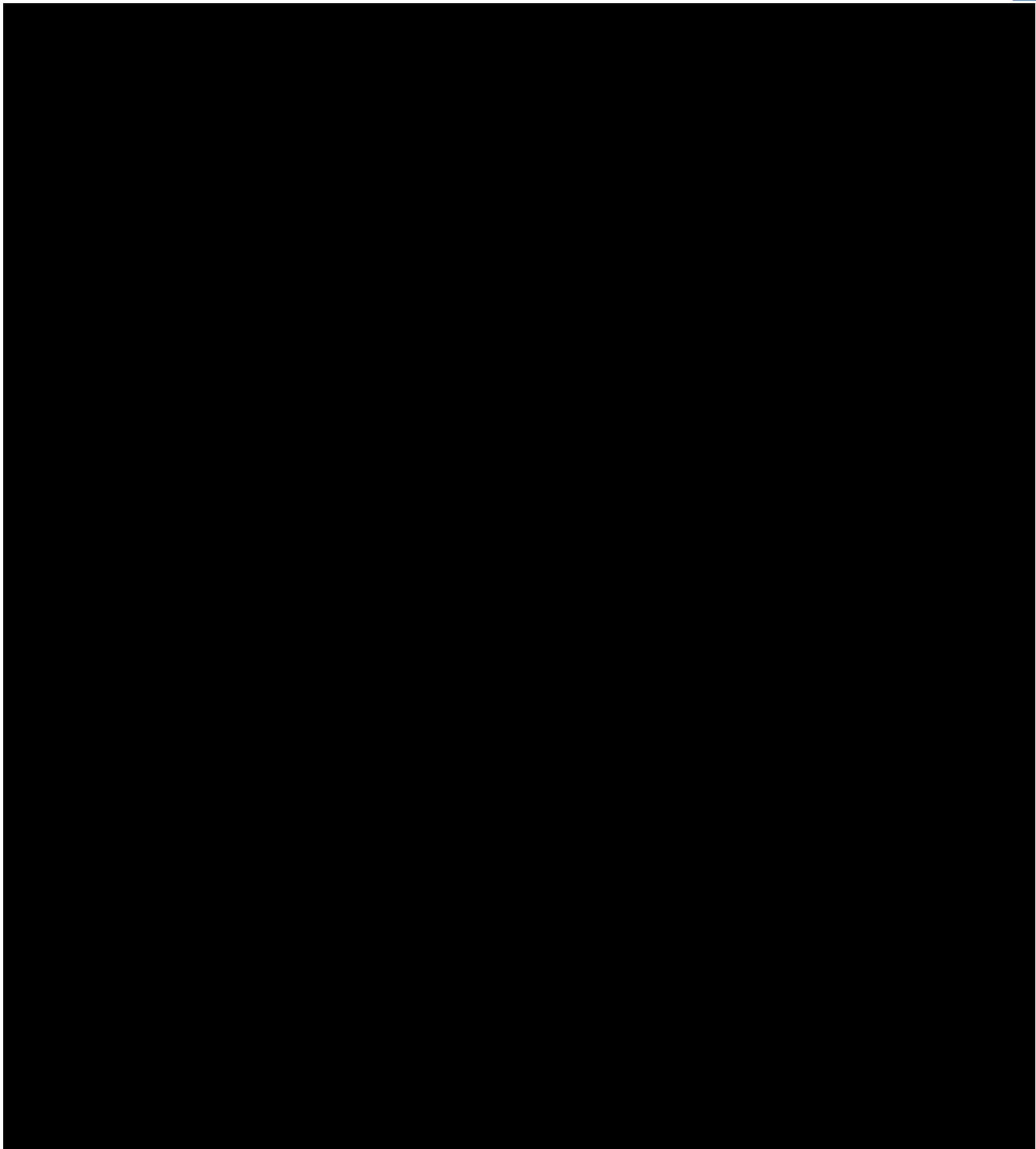
[REDACTED]

Question 6:

Wat is de invloed van de beperkingen van de beeldvorming technieken:

[REDACTED]





Appendix III

Making the DES model

The framework for the DES model in this study is based on a report from the ISPOR-SMDM Modeling Good Research Practices Task Force-41). The model itself will be made in R (R version 3.2.3 (2015-12-10)) with the use of R-Studio. Data about how such a model can be made in R-Studio is obtained from a support document from NICE: Cost-Effectiveness Modelling Using Patient-Level Simulation²⁾.

The making of the model exists of different stages in the modeling process: (1) the structural development of the model, (2) the parameter estimation, (3) the model implementation, (4) the model analysis and lastly, (5) representation and reporting.

Introduction

Discrete Event Simulation can be used to simulate an environment or a system, like a hospital environment or a particular disease in a defined population. All DES have six different 'core concepts', which are entities, attributes, events, resources, queues, and time.

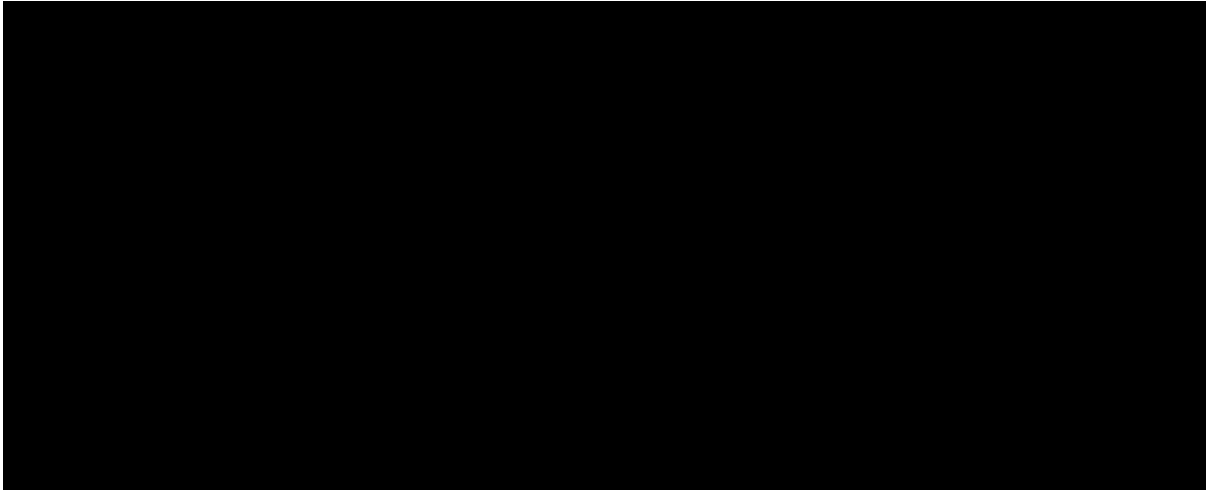
Entities are objects that run through the model. In patient-level simulation, this will most likely be the patient. The patient can experiences events, use resources and enter queues, all over time. Attributes, like gender or age, are given to each entity. These attributes can be used to assess how an entity reacts to certain events. If, for instance, a patient is female, it could have a higher risks of mortality after surgery. Events are, very broadly, things that can happen to the entity. It could be the occurrence of adverse events after surgery, or something simple like having an appointment with a specialist. When events occur, resources can be assigned to certain events. A resource is an object that provides a service to an entity (a specialist or an operation room). This may require time, and when a resource is not available, a queue is formed. Time itself is an important component of DES. Since DES is not time-based, but event-based, the model itself keeps track of when certain events happen and how long these events take. By using the time, it is possible to keep track of time periods like operation time, length of stay or survival.

1. The structural development of the model

The first step in making the model is converting the clinical pathway into a series of sequential events. Not all events in this pathway must change the health status of a patients, they can also change the probability of occurrence from other outcomes. The model should identify where decisions are made (i.e.: where is the decision made which surgical approach is most fitting), and consider whether alternative decisions should be represented. The flowchart below shows the events. At first, the patient and their attributes are created. After that, the first step of the patient in the model is the operation. The operation exists of two parts: the part where they access the heart and the part where they implement the inflatable heart valve. After the operation, the patient will recover in the IC and the nursery ward. From there, the patient can either stay alive, get re-operated or develop adverse events (in which they can either stay alive, die or get re-admitted). After running the model, the patient can either be 'alive', 'alive after adverse events' or 'death'.

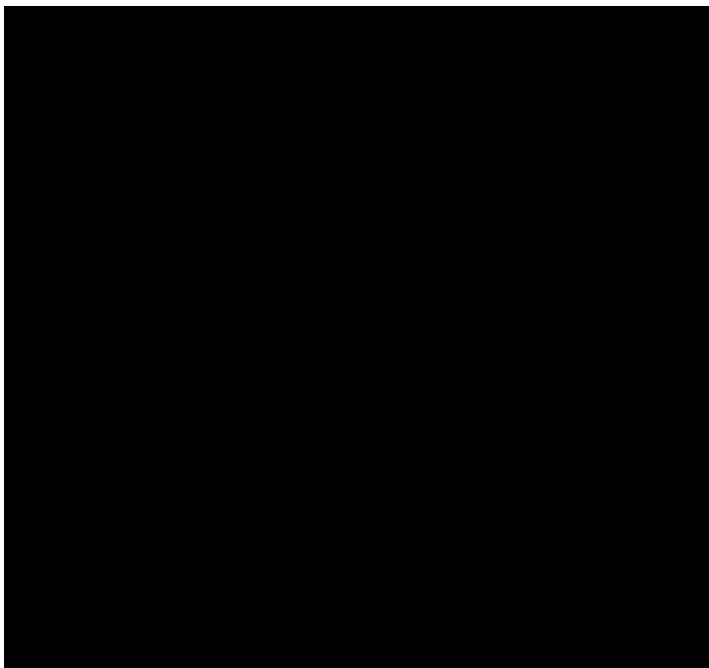
¹⁾: Karnon J, Stahl J, Brennan A, Caro JJ, Mar J, Müller J. Modeling using discrete event simulation: *A report of the ISPOR-SMDM modeling good research practices task force-4*. Value Heal. 2012;15(6):821–7.

²⁾: Davis S, Stevenson M, Tappenden P, Wailoo AJ. Technical Support Document 15: Cost-Effectiveness modelling using patient-level simulation. NICE DSU. 2014.



Attributes are patient specific variables, like their state or history. Global variables are not specific for patients, but remain the same for all entities (like the costs of a TAVI-procedure). Events are used to update both patient attributes and global variables.

Patients attributes are:



be run. When the simulation starts, patients attributes are set for that patient. The patient will go through the model and at each event that the patient experiences, the different costs will be updated. This will continue until no more new events happen. In the next patient, patient attributes will be chosen again and the patient will experience events. When all patients are run through the model, the average costs can be calculated.

2. Parameter Estimation

The parameters that will be included in the model must be estimated. A trade-off between structure and parameter estimation must be made. When data from different parameters is not available, a choice must be made: the model can be adjusted and parameters with lacking data can be removed, or the data gap will be filled with the use of expert elicitation/calibration to find missing parameters. With regards to this study, no representative data for 3D-imaging in TAVI-procedures exists. Data

about the conventional imaging techniques will be found from MST patient data, and expert elicitation will be used to fill in the data gaps for the 3D-imaging pathway of the model.

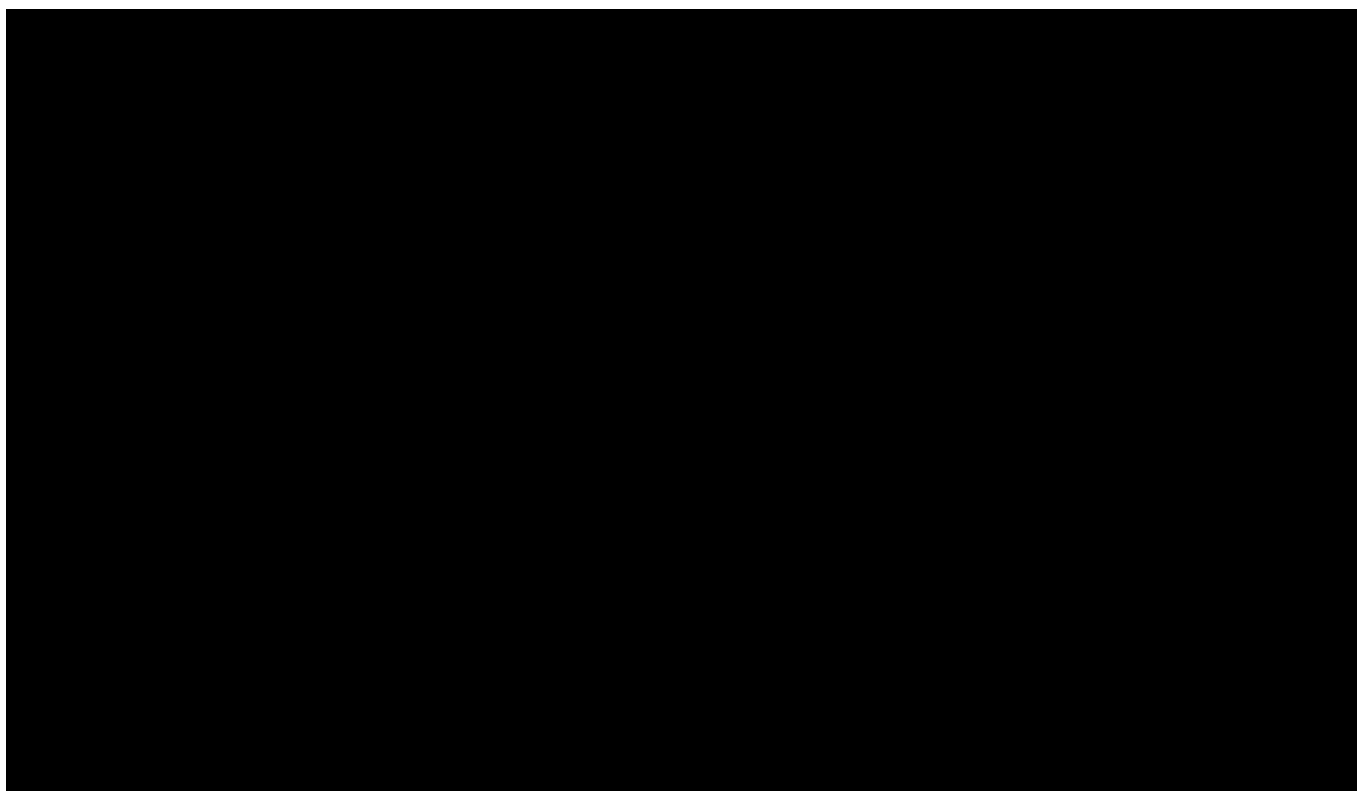
Current input can be found in the table shown below:

General variables

Patients attributes:



Post-operative, short-term:



3. The model implementation

In the model implementation, the defined structure needs to be transferred into a computer program. The computer program used is R. The flowchart above will be converted into a series of assignments which the program will execute.

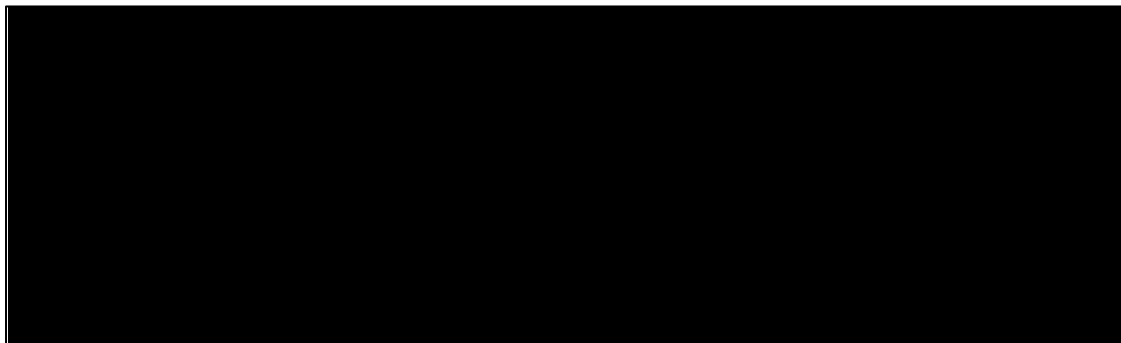
The implementation usually exists of Read data, Create Entities, Main Section, Remove entities, and Present Results. To simplify the modelling, multiple submodels were created. The multiple submodels are shown in the figure below. At first, an empty data frame is created for every simulated patient. In the following steps, the data frame will be updated according to the different events the patients goes through.



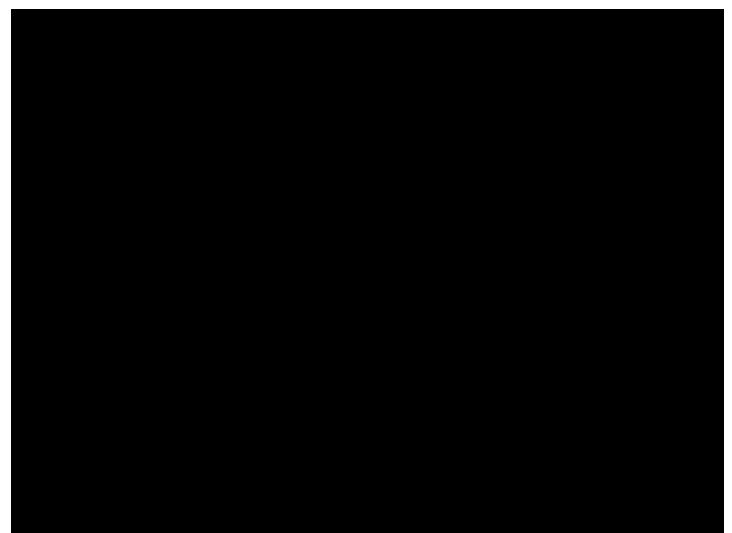
Figuur 1

Eventually, the data frame will be updated in every event. The main section exists of the multiple submodels, which are shown in the figure above. All different steps of the model are shown: first, the empty data frame is made, after which the patient attributes are loaded in. The patient will experience the different events, and in the end the data frame shows the cost of that patient, with or without 3D-imaging.

The most important outcome for every patient is the amount of QALYs and the costs. After the model is run, R gives back an updated data frame in which the data for all individual patient is shown (see the figure below).



The whole data frame is split into two smaller frames, based on whether or not 3D imaging was used for the patient or not. In the data frame, a “0” means that conventional imaging was used, and a “1” means that 3D-imaging was used next to the conventional imaging techniques. From those 2 smaller data frames, the mean of the different costs are calculated. See the figure on the right.



Appendix IV

Expert Elicitation

Introduction

Three-Dimensional imaging could be beneficial to the outcome of TAVI procedures. However, no data exists about TAVI procedures in combination with 3D-imaging techniques. The main objective of this study is to determine the cost-effectiveness of using 3D-imaging prior to TAVI procedures. Determining the clinical performance of the 3D-imaging techniques is difficult. Specificity, sensitivity and usability are one of the many features of the system that influence the impact of the system on the outcome of TAVI surgery.

To establish the clinical performance, a 'belief-elicitation method' can be used to determine the priors. Using expert elicitation to fill in the data gaps must be done correctly, in order to have as little bias as possible. The framework from Haakma et. al. (2014) will be used in order to minimize bias.

Method

Selected Experts

In this study, experts included are interventional cardiologist and thoracic surgeons from the Netherlands, preferably with experiences in TAVI procedures. The aim is to include 15 experts in this study, since it has been argued that after 12 experts, the benefit of adding more experts starts to decrease (Haakma et. al., 2014). All 15 experts will receive an invitation to attend a demonstration of a 3D-imaging system from Ps-Medtech (Amsterdam, the Netherlands), to make sure every expert understands the system and all have equal information.

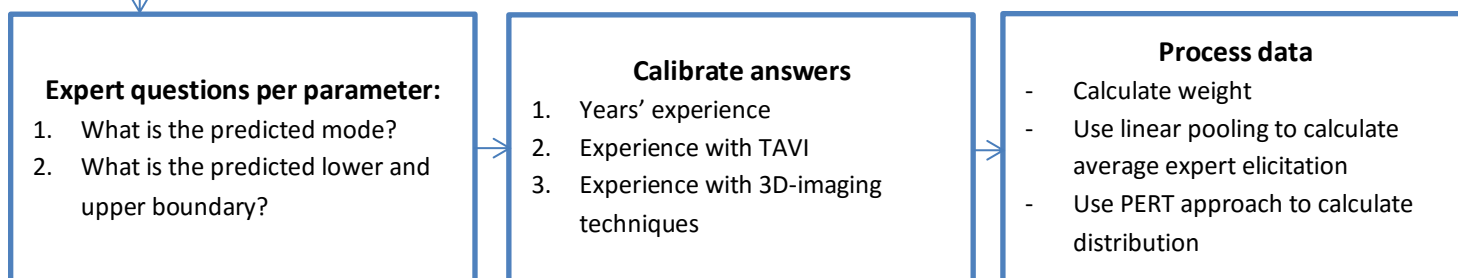
Elicitation procedure overview

The experts included in this study will be asked to estimate the procedural differences and the changes in outcome when using 3D-imaging prior to TAVI procedures. [REDACTED]

[REDACTED]. Experts will be asked to give the most likely value for a parameter (the mode), followed by the lowest and highest likely value. These distributions will be plotted as a Probability Density Function (PDF). All estimations derived will then be compared to the conventional imaging data. When all data is collected, a calibration procedure is applied in order to account for heterogeneity between experts

After the calibration questions are answered, data can be processed. The weight of each expert will be calculated, and by using the linear pooling function the average probability distribution is calculated. To graphically display the data, the PERT approach is used.

A schematic overview of the procedure can be found in the figure below.



The Expert Elicitation procedure

Direct elicitation

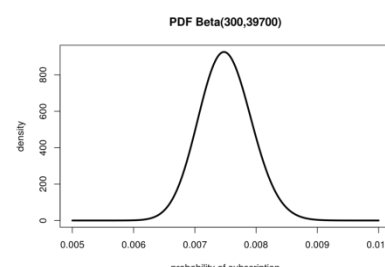
At first, the panel will be invited to attend a demonstration. Ps-Medtech will give a demo in which they show their product and where experts are invited to use the product in practical cases that they have experienced. If experts are not able to attend the demo, a movie will be shown in which the product is explained to provide insight in the product. Whether an expert has seen the movie or attended the demo will influence the weight of the answer.

When the expert is familiar with the system, a questionnaire will be provided. For each parameter, the expert is asked to give a prediction about what they think the outcome will be. This is, of course, not simple. Based on previous studies, the mode (most likely value) is expected to be the most intuitive parameter to estimate for experts¹⁾.

The value is not directly asked, but starts with a broad question and will be more specified until a value (the mode) and lower/upper boundaries can be given to ensure that the answer of the expert will be correspondent to what they actually think.

For every parameter, the expert is first asked whether using 3D-imaging influences the parameter negatively, positively or not at all. After that, an estimation of the impact is made by assessing how big the effect would be (for example: in the death <30 days parameter, would the amount of casualties within 30 days change with: 0-10%, 10-20% etc.). In the last question, the predicted value and the lower and upper 95% confidence interval must be given.

When the expert gives the mode and the lower/upper boundaries, their answer will be graphically represented in a Probability Density Function (PDF) (figure ADF). Answers can be adjusted after seeing the PDF and disagreeing.



¹⁾: Haakma W, Steuten LMG, Bojke L, IJzerman MJ. Belief elicitation to populate health economic models of medical diagnostic devices in development. Appl Health Econ Health Policy. 2014;12(3):327-34.

The PDF is calculated with the Project Evaluation and Review Technique ²⁾.

With PERT, the mean (eq. 1), standard deviation (eq. 2), alpha (eq. 3) and beta (eq. 4) will be used to represent the PDF.

The following equations are used:

$$(1) \quad \text{Mean} = \frac{\min + 4 * \text{mode} + \max}{6}$$

$$(2) \quad \text{Standard Deviation} = \frac{\max - \min}{6}$$

$$(3) \quad \text{Alpha } (\alpha) = \left(\frac{\text{mean} - \min}{\max - \min} \right) * \left(\frac{\text{mean} - \min * (\max - \text{mean})}{\text{standard deviation}^2} \right)$$

$$(4) \quad \text{Beta } (\beta) = \left(\frac{\max - \text{mean}}{\max - \min} \right) * \alpha$$

The elicitation of the experts and their weights were combined using the linear pooling method³⁾. The weights are established and used to get an overall weighted distribution, as shown in equation 5.

Where $\rho(\theta)$ is the probability distribution and w_i is the weight of the expert.

$$(5) \quad \rho(\theta) = \sum_{i=1}^n w_i p_i(\theta)$$

Calibration procedure

Experts will be given weights to assess their expertise, in order to account for the heterogeneity of the results. More experienced experts will have greater influence than the experts with less experience. The calibration will be based on two aspects that is believed to influence the answers of the expert: the experience with TAVI procedures, and the experience with 3D-imaging techniques. See table XDFSAD below.

Experience with TAVI procedures	score	Experience with 3D-imaging techniques	score
No experience whatsoever	1	None	1
Involved in the planning of TAVIs	2	Attended the demo	2
Involved in the performance of TAVIs	3	Work with 3D-imaging technology	3

The score of the experts is used when calculating the pooled data. The minimal score is 2, and the maximum score is 6.

²⁾: van Dorp RJ, Kotz S. A novel extension of the triangular distribution and its parameter estimation. J R Stat Soc Ser d-Sta. 2002;51(1):62-79.

³⁾: Bojke L, Claxton K, Bravo-Vergel Y, et al. Eliciting distributions to populate decision analytic models. Val Health. 2010;13(5):557-64



Geachte,

Mijn naam is Max Analbers en onder begeleiding van dr. Grandjean doe ik onderzoek naar het potentiële effect van 3D-beeldvorming bij TAVI procedures.

Via het 'Vesalius 3D' systeem, in combinatie met het 'C-Station', heeft Ps-Medtech uit Amsterdam een product ontwikkeld welke CT-, MRI- en Echobeelden om kan vormen naar een 3D beeld. Dit beeld kan vervolgens intuïtief onderzocht worden om zo betere keuzes te maken voorafgaand aan operaties. U kunt hiervoor op youtube zoeken naar Ps-Medtech om in verschillende (korte) filmpjes te zien hoe dit werkt.

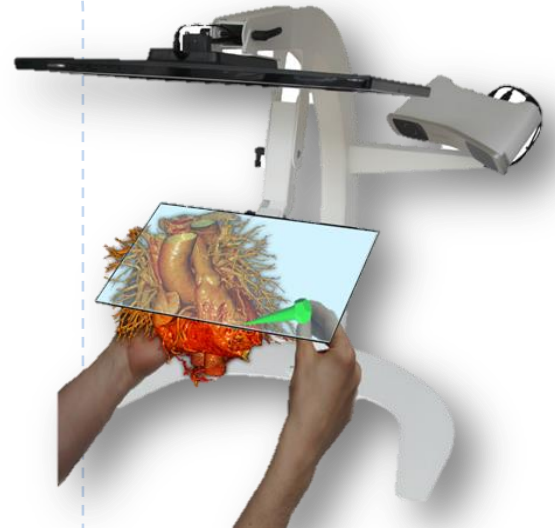
Het systeem van Ps-Medtech wordt momenteel al ingezet in meerdere ziekenhuizen in Nederland, bij onder andere cardio-thoracale en gynaecologische ingrepen.

Voor dit onderzoek wil ik u vragen om de volgende enquête in te vullen. Het is mogelijk dat u hiervoor ook al een mail heeft ontvangen.

Hou er bij het invullen rekening mee dat dit niet de werkelijkheid kan zijn! Het is een schatting, en probeer een zo goed mogelijke schatting te maken. Ook als u denkt dat u het niet weet wil ik u vragen toch een antwoord op te schrijven. Hiermee kan ook een verwachtingspatroon van het 3D-systeem opgesteld worden; een belangrijk deel van het onderzoek. Het invullen kost maximaal 5 minuten. Ook als u persoonlijk niet betrokken bent bij TAVI's hoop ik op uw medewerking.

Graag hoop ik deze enquête zsm op te kunnen halen bij uw bureau, of mag u hem afgeven aan dr. Grandjean.

Namens mijzelf en dr. Grandjean: Bedankt!



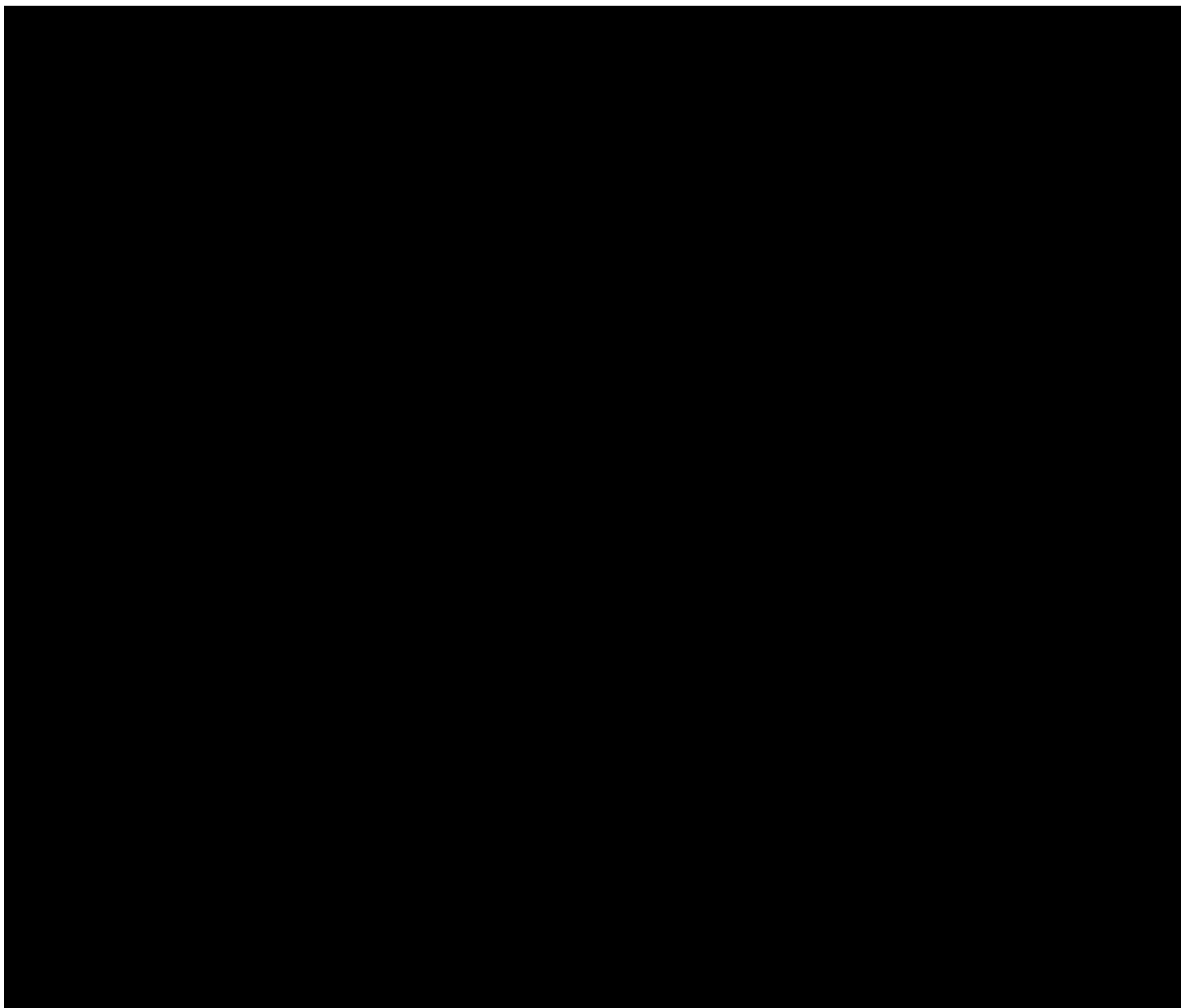
Effect van 3D-beeldvorming bij TAVI procedures

Dit gedeelte is opgesteld om te onderzoeken wat het nut is van 3D-beeldvorming binnen uw specialisme. U wordt gevraagd om uw mening omtrent de inzetbaarheid en potentiële effect van het gebruik van 3D-beeldvorming

Alvast bedankt voor uw deelname!

Naam:

Functie:





Effect van 3D-beeldvorming bij TAVI procedures

Dit deel is opgesteld om te onderzoeken wat het potentiële effect is van 3D-beeldvorming bij TAVI procedures. U wordt gevraagd om bij verschillende onderwerpen in te schatten hoe 3D-beeldvorming de operatie uitkomst beïnvloed. Niet alles is even goed in te schatten, maar probeer overal een antwoord te geven waarbij u denkt dat dit overeen zal komen met de werkelijkheid. Alvast bedankt voor uw deelname!

Wat is uw ervaring met TAVI procedures?

- ☐ Geen ervaring
- ☐ Ik ben betrokken bij de planning en bespreking van TAVIs
- ☐ Ik ben betrokken bij de uitvoering van TAVIs

Wat is uw ervaring met 3D-beeldvorming?

- ☐ Geen ervaring
- ☐ Ik heb de demo bijgewoond en ben bekend met het systeem
- ☐ Ik werk met het 3D-beeldvorming systeem



Thorax Centrum Twente

Waarbij verwacht wordt dat dit maximaal is en waarbij dit minimaal is.

Appendix VI

Results Expert Elicitation.

