Utilitarian Distribution of Scarce Surgical Capacity During the COVID-19 Crisis and Beyond: A Modelling Study

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1. NEJM (advice to try the COVID-19 special, because NEJM is not that into decision models - maybe for COVID they are) How about we also talk about “1. Emanuel EJ, Persad G, Upshur R, et al. Fair Allocation of Scarce Medical Resources in the Time of Covid-19. N Engl J Med 2020;1–7.” in the cover letter
2. Lancet
3. BMJ

# Abstract

## Background

COVID-19 has put unprecedented pressure on health care systems worldwide. This has led to a reduction of the health care capacity available for non-emergency surgical interventions. As a result, an accumulating number of patients is waiting for vital surgeries and societies face dilemmas about prioritization of patients. Therefore, our objective was to develop a decision model to estimate the effects of delay of surgical interventions on health and quality of life that can be used for prioritization.

Methods

A cohort state-transition model was developed to simulate long-term implications of delaying surgery. The model was applied to 34 semi-elective (not necessarily performed within 3 days, but ideally performed within 3 weeks) surgeries on adults commonly performed in one of the eight Dutch academic hospitals. We compared scenarios of delaying surgery from two weeks up to one year (with 10-week intervals) and no surgery at all. Model parameters were based on Dutch and American registries, literature, and the global burden of disease study by the World Health Organization. For each surgical indication, we estimated the average expected Quality-Adjusted Life-Years (QALYs) for the different scenarios. Urgency was defined as expected health loss due to surgical delay, expressed in QALY loss per month (QALY/month). A probabilistic sensitivity analysis was performed to incorporate parameter uncertainty in the model estimates.

## Results

The maximum QALYs gained varied between procedures, from 0.54 QALYs (95%-CI 0.48 – 0.61) for resection of high-grade glioma to 10.3 QALYs (8.7 - 11.9) for kidney transplantation. The three most urgent interventions were surgically repairing an abdominal aorta aneurysm (-0.11 QALY/month, -0.13 – -0.09), pacemaker implantation (-0.11 QALY/month, -0.22 - -0.04), and resecting a peri-hilar cholangiocarcinoma (-0.09 QALY/month, -0.12 - -0.06). The three least urgent interventions were the placing of a shunt for dialysis (-0.01 QALY/month, -0.01 – -0.005), resecting thyroid carcinoma (-0.01 QALY/month, -0.02 - -0.01), and resecting mild salivary gland carcinoma (-0.01 QALY/month, -0.03 - -0.01).

## Conclusion

Expected health loss due to surgical delay could be quantified with our decision model and can guide prioritization of surgical care from a utilitarian perspective (i.e. minimizing health loss for the total population) in times of scarcity (due to for example COVID-19). Placing this tool in the context of different ethical perspectives and combining it with capacity management tools is key to achieve large-scale implementation.

## Background

COVID-19 has put unprecedented pressure on health care systems worldwide. The health care demand of the pandemic supersedes total usual health care capacity, far beyond the demand that was imposed by the 2017 influenza pandemic.1,2 This pressure on the available health care capacity impacts the continuity of usual care.

We can identify multiple causes of the disruption of usual care. At first, because wards and operating theaters are converted to COVID-19 care facilities, fewer non-COVID-19 patients can be admitted or undergo surgery.3 Second, because physicians are deployed to care for COVID-19 patients, fewer patients were seen and referred.4,5In the Netherlands, we observed a 90% decrease in referrals during the first part of the crisis compared to previous years.6 Finally, fear of the virus may leave sick people reluctant to seek the care they need 4,5, as has been seen in similar health crises like the SARS epidemic.7

Delay in surgical care may impose complex health care problems. In the first part of the crisis in the Netherlands, 75-90% fewer surgical procedures were performed compared to previous years.6 The impact on health care logistics of these delays can be substantial. A modeling study has evaluated the consequences of delay of orthopedic surgical procedures. They showed that it would take 7-16 months until the health-care system would perform at 90% of the expected value of surgery in case they resume elective orthopedic surgery in June 2020 in the USA.8 Because an accumulating group of patients is waiting for vital surgeries, our society is facing dilemmas about which patients should be prioritized.

Experts in the field of medical ethics recently proposed that the distribution of scarce (surgical) resources can be evaluated by the following four ethical values: 1) The scarce resources are used to maximize the benefits; 2) People are treated equally; 3) Instrumental value is promoted and rewarded; 4) The worst off (sickest or youngest) are prioritized.2 In the context of a pandemic, it justifiable to focus on maximizing the benefits (first value).9–13 This is consistent with utilitarian ethical perspectives, which emphasize population outcomes over individual outcomes.14

As stated by Emanuel et al., “*The question is not whether to set priorities, but how to do so ethically and consistently, rather than basing decisions on individual institutions’ approaches or a clinician’s intuition in the heat of the moment*”.2 In reality, however, surgical patients are most often triaged by experts from the respective surgical fields.15 Experts, for which it is known that the agreement of prioritization is low.16 Additionally, prioritization across different disciplines is complicated by the high degree of specialization in modern medicine. To our knowledge, no objective, quantitative, evidence-based approach has yet been developed to assist in prioritization of surgical care in times of scarcity.

Therefore, this study aims is to develop a decision model to estimate the impact of postponing surgical intervention on health. This measure of urgency might be used to guide prioritization of surgical intervention form a utilitarian perspective. Although this strategy was conceived during the COVID-19 pandemic, our secondary aim is to ensure applicability to the context of upcoming pandemics, possibly even to the context of usual care and economical scarcity.

## Methods

This manuscript is guided by the CHEER guidelines for reporting health-economical evaluations.17 The model was built in R software18 and the code is based on tutorials provided by the DARTH workgroup.19,20 The model code and input data are freely available via a GitHub repository: [https://github.com/erasmusmc-mgz/VB\_OR\_t](https://github.com/erasmusmc-mgz/VB_OR_triage)riage.

### Patients and setting

The procedures evaluated in this study comprised of non-pediatric, semi-elective surgeries in an academic tertiary referring hospital. A semi-elective procedure was defined as a procedure that is non-urgent, but ideally performed within three to six weeks. A selection of semi-elective procedures for this modeling study was based on electronic patient registry data of the Erasmus MC (University Medical Center based in Rotterdam, The Netherlands). From this patient registry, we retrieved the surgery time, length of stay at an intensive care unit (ICU), and length of stay at a non-ICU unit of all non-urgent procedures between July 2017 and May 2020. The extra surgery time associated with re-operations (e.g. due to complications) and the surgery of both donor and receiver of transplants was added to the average surgery time per diagnosis. Procedures that were performed at least 80 times were selected. These selected procedures were consecutively classified by two senior clinicians (JvS – emeritus professor internal medicine, RBdJ – head of the department of head and neck surgery) as a semi-elective procedure based on their experience. Ultimately, 61 semi-elective procedures were selected. Where relevant, we distinguished mild and severe cases undergoing the procedure.

We aimed to collect data about the populations of patients with an indication of one of the 61 selected non-pediatric semi-elective procedure. The average age of the patients was used as the initial age of the simulated cohort in the model. Where possible, survival data from national Dutch registries were used. In this study, we only focus on health benefits.

Because benefits have more “value” in the near than in the distant future, it is common to perform discounting: this is a procedure where benefits later in the time horizon are weighed less. A discount rate of 0.015 per year for health benefits was used, as this is common practice in the Netherlands.21 Discounting is done to make current benefits worth more than those expected in the future because benefits now are enjoyed more than in the future.22 If discounting is not performed, we would value health gains achieved this year similar to those achieved in 30 or 40 years.

### Markov model

To quantify the long-term health effects of surgery delay we made use of a Markov cohort state-transition model (cSTM). This model type is frequently used in clinical decision analysis, because it is relatively simple to build, easy to communicate and can synthesize data from different sources to estimate long-term outcomes.23,24 A cSTM simulates a hypothetical cohort of patients over a defined period in discrete time cycles to estimate the average time individuals spend in the various health states.23,25 Based on the time spent in these states, health benefits can be calculated. Possible health benefits that can be calculated include the expected life years or quality adjusted life years (QALYs) - the surrogate measure of life years with quality of life.25,26

For our aim, we developed a three-state cSTM with a preoperative state, a postoperative state, and a dead state (Figure 1). The entire cohort starts in the preoperative state, and was followed their entire remaining lifespan, until they are 100 years, using weekly cycles. The transition from the preoperative state to the postoperative state was set to a specific week, depending on the scenario. We evaluated scenarios where patients were treated immediately (delay of two weeks) up to a delay of a year using intervals of ten weeks. In addition, we evaluated the scenario where nobody ever received treatment: this was modeled by following patients their remaining lifespan in the preoperative health state. In all scenarios, the transitions from the pre- and postoperative states to the absorbing state dead were based on survival data, as described in the next section.

### Survival

Two types of survival data were required to model the survival in the pre- and postoperative health state, the survival with and without treatment respectively. The survival data with treatment was obtained from national Dutch registries for oncological27 and cardiothoracic28 surgical procedures, and from literature for the other procedures. The survival data without treatment for all procedures is based on data from published studies. If either survival with or without treatment was lacking, the reported treatment effect (preferably evaluated in a randomized controlled trial) was used to calculate the missing survival parameter. An overview of all parameter values and their sources can be found in Appendix A.

The disease specific mortality was added to the overall age-specific background mortality from the Dutch Central Bureau of Statistics.29 All survival data, including the disease specific mortality and age-specific background mortality, had to be converted to mortality risk per week (formulas presented in Appendix C)25.

Since postponing surgery can have consequences on the effectiveness of the procedure, we included an additional parameter to the model reflecting the time until no effect can be expected of treatment on survival. In practice, this means that when this time has passed, we assumed that the surgery did not have any effect on the survival of the patient anymore. This time is often important in oncological surgeries, where after a specific time a tumor becomes inoperable. This was translated in the model by setting the postoperative survival equal to the preoperative survival if the delay was longer than this time. The data for this time to no effect of survival came from literature (Appendix A). For most procedures, only data about the minimal delay not associated with worse survival was evaluated in the literature. For those procedures, we assumed the upper limit of this parameter to be a year (the maximum delay we evaluated), and the mean of the lower and upper limit as average.

### Quality of life

The quality of life (QoL) values in the preoperative and postoperative health states were based on ‘disutility weights’ from the Global Burden of Disease Study 2016.30 This study reports disability weights for nonfatal health outcomes. Disability weights represent the magnitude of health loss associated with specific health state, where 0 represents the value of full health and 1 the value of death. When these weights are multiplied with the duration of the state, one has calculated the weighted ‘years lived with disability’ (YLD).31 The YLD summed with the years of life lost to premature death (YLLs) give the disability adjusted life years (DALY).32 A ‘full DALY’ can be thought of as losing one year in full health. Disability Adjusted Life Years (DALYS) are the complement (the opposite) of the Quality Adjusted Life Years (QALYs), which represents the value of a year spent in full health. For our study, we used the complement (1-x) of the disability weight as QoL values to calculate QALYs.

Where possible, the disability weight of health states was directly based on the GBD 2016 update. For the remaining health states, we estimated additional values following the method described by Stouthard et al.33 We used a visual analogue scale (VAS) calibrated on the basis of the GBD 2016 QoL weights. Stouthard et al. describe how experts can then place (map) the reaming health states on VAS scale with QoL weights. The only deviation from that protocol was that we did not first classify the health states on the EQ-5D. The expert panel consisted of a diverse group of Dutch health care professionals, both surgeons (e.g. cardiothoracic surgeons, neurosurgeons, and gynecologic surgeons) as well as generalists (e.g. internists, geriatricians and GPs). The health states were valued one by one. First the health states were shortly introduced by an expert with the most experience with that health state. The experts were allowed to ask questions and discuss the QoL aspects of the health state. Two to three other experts were then invited to express their estimated QoL value for the health state. After some discussion, the experts wrote down their own estimation of the QoL value. In this way, the expert could use a maximum of information and opinions, but still express their own estimation, and we could also estimate the variance of the estimated values. The mean and 95% confidence interval of the mapped QoL scores were used in the model. We used two session of three hours to collect the QoL values from the experts. As we estimated eight health states in both sessions, we could get an indication of the reliability (test-retest by means of a t-test) of the valuations. For the model, the estimates of the first session were used. Appendix D provided the calibrated VAS used in the exercise as well as summary of the participating health care professionals.

Similar to the parameter for survival, we also included a parameter for the time until no effect of treatment can be expected on QoL. When the delay in surgery is higher than the time indicated by this parameter, the QoL of the postoperative state will be equal to the QoL of the preoperative state.

### Analysis

Parameter uncertainty was incorporated using a probabilistic sensitivity analysis. Instead of simulating all scenarios with one estimate per parameter, we simulated all scenarios with 100 parameter sets. These parameters sets were drawn from the distribution of each parameter described by the 95% confidence interval. We assumed triangle distributions for the survival probabilities, the time to no effect on survival or QoL, and utilities; we assumed lognormal distributions for relative treatment effects; and we assumed normal distributions for age. This procedure results in 100 model estimates per scenario. The 50th, 2.5th, and 97.5th percentile of these estimates were calculated, which correspond to the main estimate and the lower and upper limit of the 95% confidence interval, respectively. To calculate QALY loss due to delay, the QALYs associated with delaying surgery for 52 weeks was subtracted from the QALYs associated with delaying the surgery for 2 weeks. This gives the QALY loss per 50 weeks, which in turn was converted to QALY loss per month. Finally, the model results were visually compared to the capacity requirements, obtained from the electronic patient registry.

# Assumptions

The section above described the design of the model. This design translates to the following core assumptions:

* The health benefit of the surgical procedure for the average patient is evaluated.
* The model does not include complications or a period of recovery, both of which can reduce QoL temporarily.
* Surgical procedures are successful: no increased risk of mortality during surgery is assumed.
* The COVID-19 context does not impact the performance of the surgical procedures.

The output of the model should therefore be interpreted as the maximum health gain associated by performing the procedure successfully for an average patient, in an OR-setting not complicated by COVID-19. As for the QALY loss per month, we assume that complications and harm at various delays are equal and cancel each other out. Therefore, this measure of urgency can be compared across treatments with varying associated harm.

# Results

Full input data was found for 34/61 (56%) selected procedures. These 34 evaluated procedures comprised of 47% of the total semi-elective program in our hospital. We evaluated 8 (24%) cardiothoracic procedures, 19 (56%) oncological procedures, 2 (6%) transplantations (liver and living donor kidney), 4 (11%) vascular procedures, and 1 (3%) other type of procedure.

For 21/34 (62%) procedures, the treatment effect was used to calculate the survival without treatment from the survival with treatment. For 20 (59%) procedures, the QoL of the pre- and postoperative health state was estimated by the expert panel. Out of the eight health states (of three procedures) that were estimated twice by the panel, six health states did not differ significantly between the two sessions (table 3 Appendix B). The only procedure where a “time-to-no-effect-on-QoL” was assumed was the endarterectomy for symptomatic carotid artery stenosis (59 weeks, range: 32 – 94 weeks). For 16 (47%) procedures, we assumed a “time-to-no-effect-of-treatment-on-survival”. All these procedures were oncological procedures. Input parameters varied widely between procedures (Figure 2).

The input parameters, their source27,28,42–51,34,52–61,35,62–71,36,72–81,37,82,38–41, and the corresponding model output for every procedure are presented in Appendix A.

The maximum benefit expected from the evaluated procedures ranged from 0.54 QALYs (95% CI: 0.48 - 0.61) for resection of high-grade glioma to 10.3 QALYs (95% CI: 8.7 - 11.9) for kidney transplantation (Figure 3). The ranking based on QALYs gained by surgery was moderately correlated with the ranking based on LYs gained by surgery:the Spearman rank correlation coefficient between the ranking of procedures based on LYs and QALYs was 0.35 (p=0.045).

The urgency of the procedures ranged from -0.01 QALY/month (95% CI: -0.01 - -0.00) for placing a shunt for dialysis, to -0.11 QALY/month (-0.13 - -0.09) for the surgical repair of an abdominal aneurysm of the aorta (Figure 4, and table 1 Appendix B). Procedures that were associated with a high expected QALY benefit by surgery, did not always lose more QALYs per month as well: The Spearman correlation coefficient between the ranking of health benefit in terms of QALYs and urgency in terms of QALY loss per month was 0.31 (p=0.07). The most urgent procedures after surgical repair of an abdominal aneurysm of the aorta were pacemaker implantation (-0.11 QALY/month, 95% CI: -0.22 - -0.04), and resection of cholangiocarcinoma (-0.09 QALY/month, 95% CI: -0.12 - -0.06). After placing a shunt for end-stage renal disease patients, the least urgent procedures were resection of thyroid cancer (-0.01 QALY/month, 95% CI: -0.02 - -0.01) and the resection of mild salivary gland carcinoma (-0.01 QALY/month, 95% CI: -0.03 - -0.01) (Appendix B). When ordering procedures based on LYs lost per month instead of QALYs lost per month, resection of non-small cell lung carcinoma was ranked substantially lower (from rank 5 to rank 19), while the implantation of a left-ventricle assist device was ranked substantially higher (from rank 8 to rank 1).

Procedures that are ranked high in terms of urgency and had relative short surgery time include repair of atrial septum defects (surgery time: 74 min [IQR: 56-131], urgency: -0.06 QALY/month [95% CI: -0.14 — -0.02]), pacemaker implantations (115 min [82-154],-0.11 QALY/month [-0.22 - -0.04]), and resection of mild larynx carcinoma (70 min [38 – 109], -0.07 [-0.11 - -0.05]) (Figure 5). Liver transplant is relatively urgent, but requires an exceptional amount of OR-time (875 min [797 - 957], -0.08 QALY/month [-0.09 - -0.07]) (table 2 Appendix B).

# Discussion

Our decision model can be used to guide prioritization of surgical interventions from a utilitarian perspective, by estimating urgency based the expected health loss of delay. Our results demonstrate that we can rank semi-elective surgeries based on their urgency using a simple three-states cSTM. Using this approach, we found that repairing an abdominal aneurysm of the aorta, implantation of a pacemaker, and the resection of cholangiocarcinoma were the most urgent procedures. Less urgent procedures were installment of a shunt for dialysis, resection of thyroid cancer, and the resection of mild salivary gland carcinoma. We also identified liver transplantation as being a relatively urgent procedure with an exceptionally long surgery time: based on these findings, it may be argued that liver transplantation should be only limitedly prioritized in times of OR-scarcity, because the procedure pressures OR-capacity.

We propose a prioritization based on QALY loss per month. This strategy is an alternative to the currently most employed approach: triaging by expert teams from the respective surgical fields.15 Because experts weigh each objective characteristic by their own personal values, the agreement in prioritization is low.16 Moreover, prioritization across different disciplines is complicated by the high degree of specialization in modern medicine. Finally, this approach is not object nor transparent, and conflicts of interests at the individual and departmental level may arise. Therefore, we feel our approach is more objective, transparent, and evidence-based, while operationalizing ethical values that are the most appropriate in times of scarcity.2

To illustrate what this measure actually represents, we take the most urgent procedure as an example. Surgically repairing an abdominal aneurysm of the aorta is associated with a QALY loss of 0.11 per month –partly due to the prospect of a potentially life-threatening rupture preoperatively, partly due to the increase in survival after surgery. This implies that if this procedure would be postponed by a month, patients with this surgical indication lose approximately 40 days (0.11\*365) spent in perfect health of their remaining expected QALYs gained by surgery. Although the personal value of a loss of 40 days spent in perfect health can be different for everybody, it is a substantial loss compared to the least urgent surgery: a similar calculation for the placing of a shunt for dialysis is associated with 4 days less spent in perfect health by delaying the procedure by a month.

Although this approach rationalizes and objectively quantifies urgency from a utilitarian perspective, it needs to be complemented by other perspectives to be used effectively in practice. First, an important consideration from the medical perspective may be the availability of alternative treatment strategies. In cancer treatment, (chemo-)radiation or systematic therapy alone may be considered instead of surgery, even when the effectivity would be lower, since waiting lists may be shorter. Second, an important consideration from the logistical perspective might be the impact of procedures on the hospital capacity, which can differ in different phases of crises (e.g. surgery time is scarce in one week, and ICU capacity in the other). Third, a financial perspective might also be explored. This perspective might be less relevant in a crisis such as the COVID-19 pandemic, where the bottleneck in costs is hospital capacity. If this approach would be applied to the context of usual care, this perspective might be of increasing importantance. Finally, other ethical perspectives might be explored to assess the viability of our approach, and to find the scope of procedures where our approach is applicable.

There are practical advantages of comparing “average patients” on urgency, despite the fact that there is no such thing as an “average patient”: It prevents our approach from systematically discriminating against a specific group of patients. Our approach would only discriminate if specific socioeconomic groups would suffer more frequently from diseases that are less urgent. It is known that lower socioeconomic groups are more prone to develop cancers that have clear association with unhealthy behavior, such as lung cancer.83 However, these diseases do not systematically rank low in our approach. Moreover, by comparing the average patients across specialties on urgency, we give way to shared decision making: we feel that next to a quantitative estimation of urgency from a utilitarian perspective, individual patient’s preferences, social contexts, and operability should also be included in the decision making process of prioritization.

Since all models are, by definition, a simplification of reality, our model has several limitations. First, we assume that all surgeries are successful. We do not simulate adverse events, like major bleedings or death due to surgery (although we included extra surgery time due to complications of earlier surgery). We also did not incorporate the potential reduction of QoL due to these adverse events or QoL reduction of a temporary period of recovery after surgery. Because of these assumptions, the overall QALYs associated with the surgery should not be interpreted as absolute estimate. They can be considered the maximum possible QALYs that can be acquired by performing the procedure. However, these assumptions were considered reasonable to achieve the main goal of this study: when surgery without delay is compared to surgery with delay, the harm in both scenarios is similar and therefore cancels out.

Second, we did not take the extra perioperative mortality risk of patients infected with COVID-19 into account. It has already been shown that this risk is increased, especially in male patients older than 70 years84. These findings might be relevant to consider when prioritizing surgical procedures during a pandemic.

Third, we used a linear approximation to quantify urgency by delaying surgery up to a year. Some procedures did show a slightly steeper decrease in the first phase of delay. We have chosen for this pragmatic approach because we did not specifically design the model to validly estimate the curvature in this descend.

Fourth, there are methodological issues with the fact that we calculated QALYs by the disutility weights by the WHO. … There are also multiple methodological, ethical, and contextual disadvantages of using QALYs.85

Fifth, we did not include the potential impact on QoL of delaying a semi-elective surgery. This impact might differ across procedures. It might be hypothesized that procedures performed after already a long disease history (e.g. kidney transplant) might have less “waiting time disutility” than recently diagnosed diseases (e.g. mammacarcinoma).

The model was tailored to the Dutch context by using the Dutch discount rate, and Dutch registry data. However, a substantial amount of the evidence used in the model (most treatment effects, average age, time to no effect of surgery on survival/QoL) originated from various non-Dutch sources. Therefore, with some modifications, and using international data, the model can easily be applied to different contexts. Moreover, the model could be developed further by also modeling complications, recovery periods and the effect of comorbidity on survival. Therefore, this study can be considered the first step towards a triaging strategy which optimizes surgical benefit in times of scarcity in surgical capacity, such as during the COVID-19 pandemic. The next step is to create sufficient support base for this approach. If successful, a wider range of procedures should be considered, implementation strategies should be explored and evaluated, and the model should be applied to a variety of settings.

# Conclusion

Our decision model guides prioritization of surgical care in times of scarcity (due to COVID-19) in surgical capacity from a utilitarian perspective. The expected health loss due to delay could be reliably quantified for semi-elective surgical procedures in our hospital. This observation can help to minimize health losses when trying to overcome delay in surgical procedures. This approach is more transparent, more evidence-based, and more objective than the alternative strategy of triaging based on expert opinion. Placing this tool in the context of different ethical perspectives and combining it with capacity management tools is key to achieve large-scale implementation.



Figure 1, state-transition diagram of the model. The model is a Markov model consisting of three states: a preoperative state (Preop), a postoperative state (Postop), and the absorbing state Dead. All patient eligible of semi-elective surgery start in the Preop health states. From the Preop states they can die, transition to dead, or continue to wait for their surgery. At the time of surgery, which is determined by the scenario analysis, all individuals still alive in the Preop health state transition to the Postop health state. The remaining lifetime the cohort is followed. They can die, transition for the Postop state to dead or stay alive in the Postop health state.



Figure 2, input parameters for the model. For a full list of input parameters per disease and source, see appendix A. **Abbreviations Figure titles**: Qol\_no\_tx: Quality of Life without treatment; QoL\_tx: quality of life with treatment; Surv\_no\_tx: 1-year survival probability without treatment; Surv\_tx: 1-year survival probability with treatment; Time\_noeff\_surv: days until no treatment is effective. **Disease abbreviations:** AAA: aneurysm of the abdominal aorta; AP: angina pectoris; ESRD: end-stage renal disease; ASD: atrial septum defect; ca.: carcinoma; CABG: coronary artery bypass graft; ESHF: end-stage heart failure; ESLD: end-stage liver disease; EVAR: endovascular aortic repair; HIPEC: hyperthermic intraperitoneal chemotherapy; HCC: hepatocellular carcinoma; NSCLC: non-small cell lung carcinoma; PAD: peripheral arterial disease; PCI: percutaneous coronary intervention; UUT: upper urinary track; VATS: video assisted thoracoscopic surgery

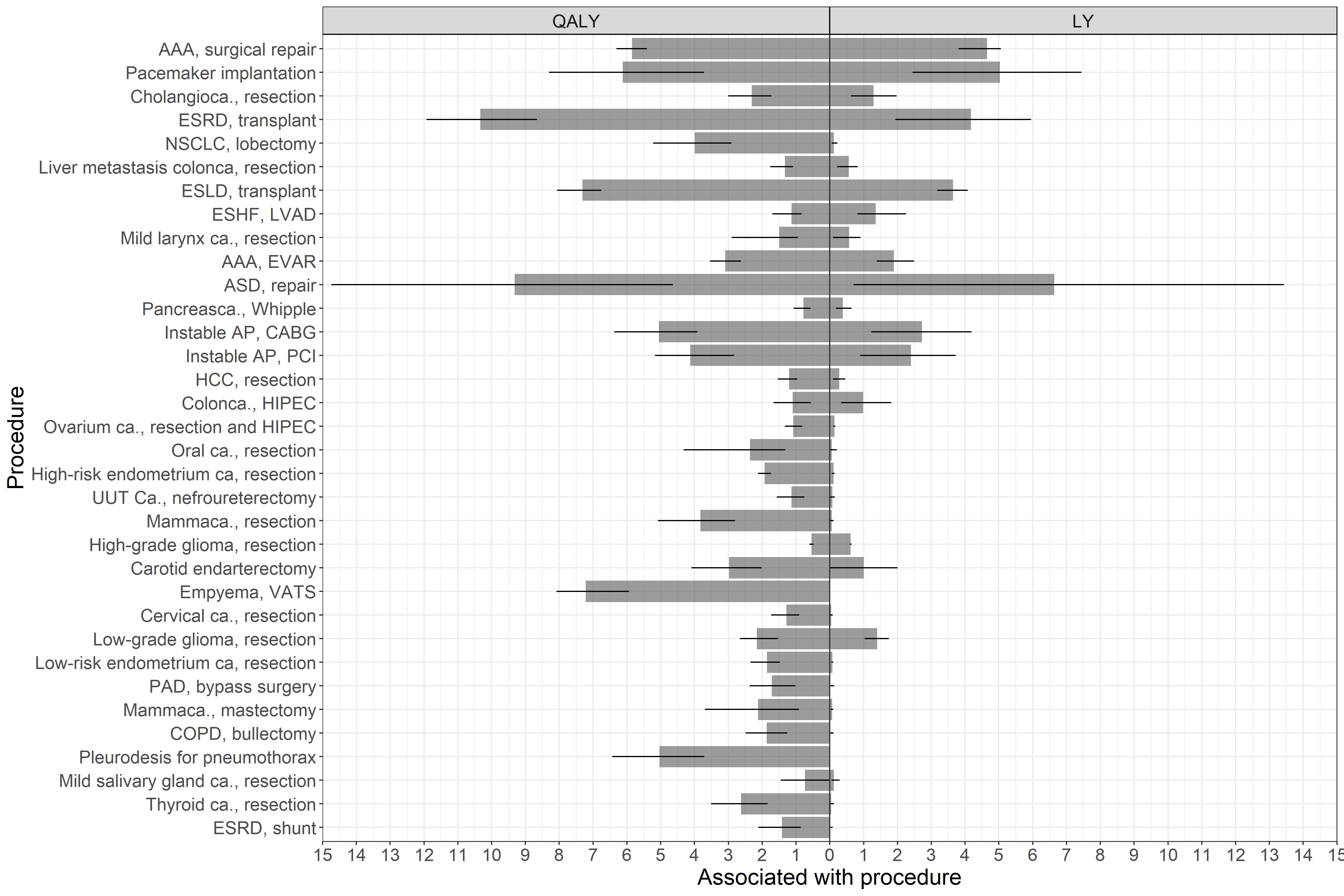


Figure 3, the maximum expected QALYs and LYs per intervention, in descending order of urgency (see figure 4). The estimates (gray bars) and 95% confidence intervals (black lines) are shown. The model output for no surgery was subtracted from the model output for a delay of 2 weeks. The actual data are presented in Appendix B. **Abbreviations Figure titles**: QALY: Quality of Life without treatment; LY: life years. **Disease abbreviations**: AAA: aneurysm of the abdominal aorta; AP: angina pectoris; ESRD: end-stage renal disease; ASD: atrial septum defect; ca.: carcinoma; CABG: coronary artery bypass graft; ESHF: end-stage heart failure; ESLD: end-stage liver disease; EVAR: endovascular aortic repair; HIPEC: hyperthermic intraperitoneal chemotherapy; HCC: hepatocellular carcinoma; NSCLC: non-small cell lung carcinoma; PAD: peripheral arterial disease; PCI: percutaneous coronary intervention; UUT: upper urinary track; VATS: video assisted thoracoscopic surgery

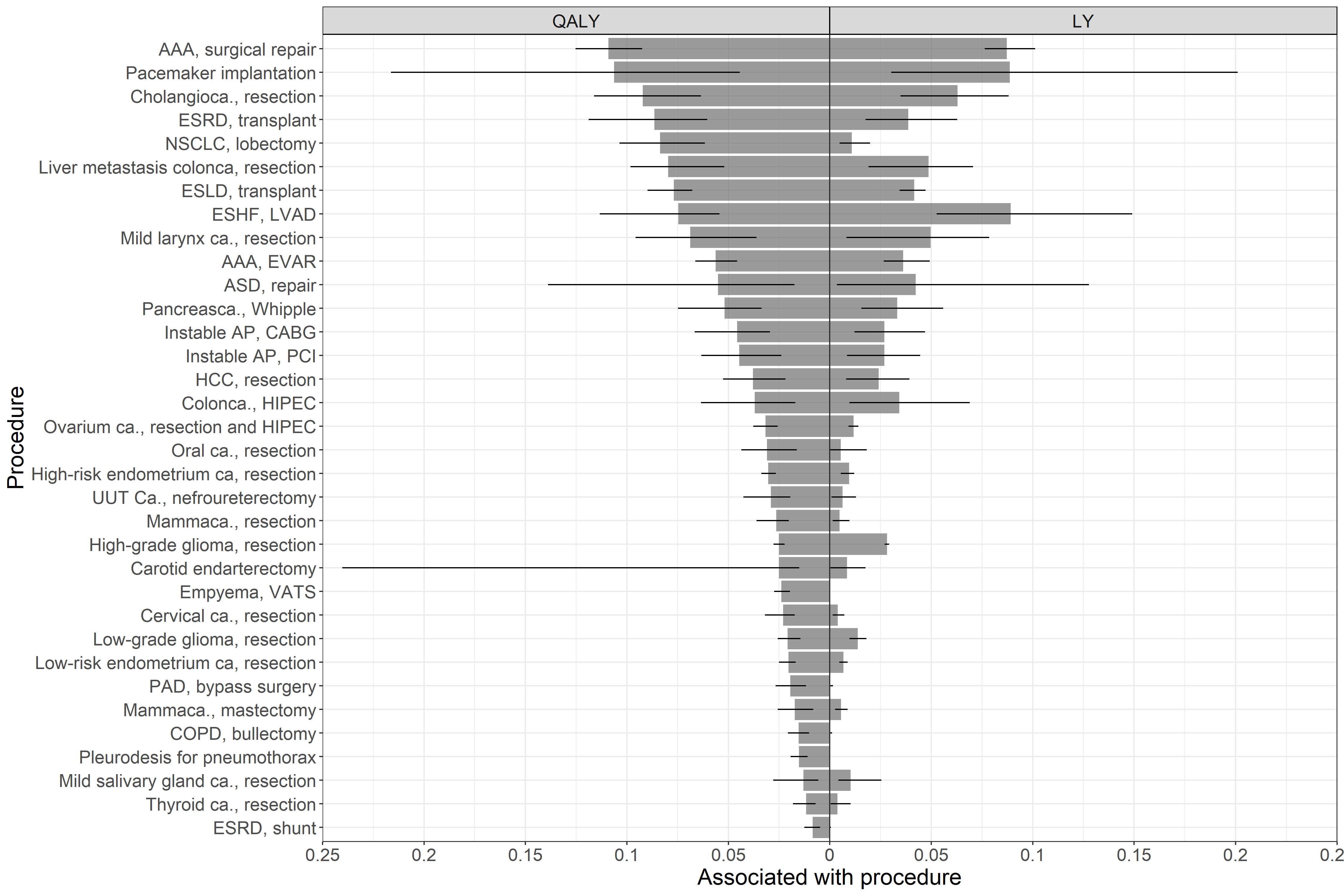


Figure 4, the average loss of QALYs and LYs per month of delay for the investigated interventions based on the simulation of surgery delay of 52 weeks. The estimates (gray bars) and 95% confidence intervals (black lines) are shown. The actual data are presented in appendix B. **Abbreviations Figure titles**: QALY: Quality of Life without treatment; LY: life years **Disease abbreviations**: AAA: aneurysm of the abdominal aorta; AP: angina pectoris; ESRD: end-stage renal disease; ASD: atrial septum defect; ca.: carcinoma; CABG: coronary artery bypass graft; ESHF: end-stage heart failure; ESLD: end-stage liver disease; EVAR: endovascular aortic repair; HIPEC: hyperthermic intraperitoneal chemotherapy; HCC: hepatocellular carcinoma; NSCLC: non-small cell lung carcinoma; PAD: peripheral arterial disease; PCI: percutaneous coronary intervention; UUT: upper urinary track; VATS: video assisted thoracoscopic surgery

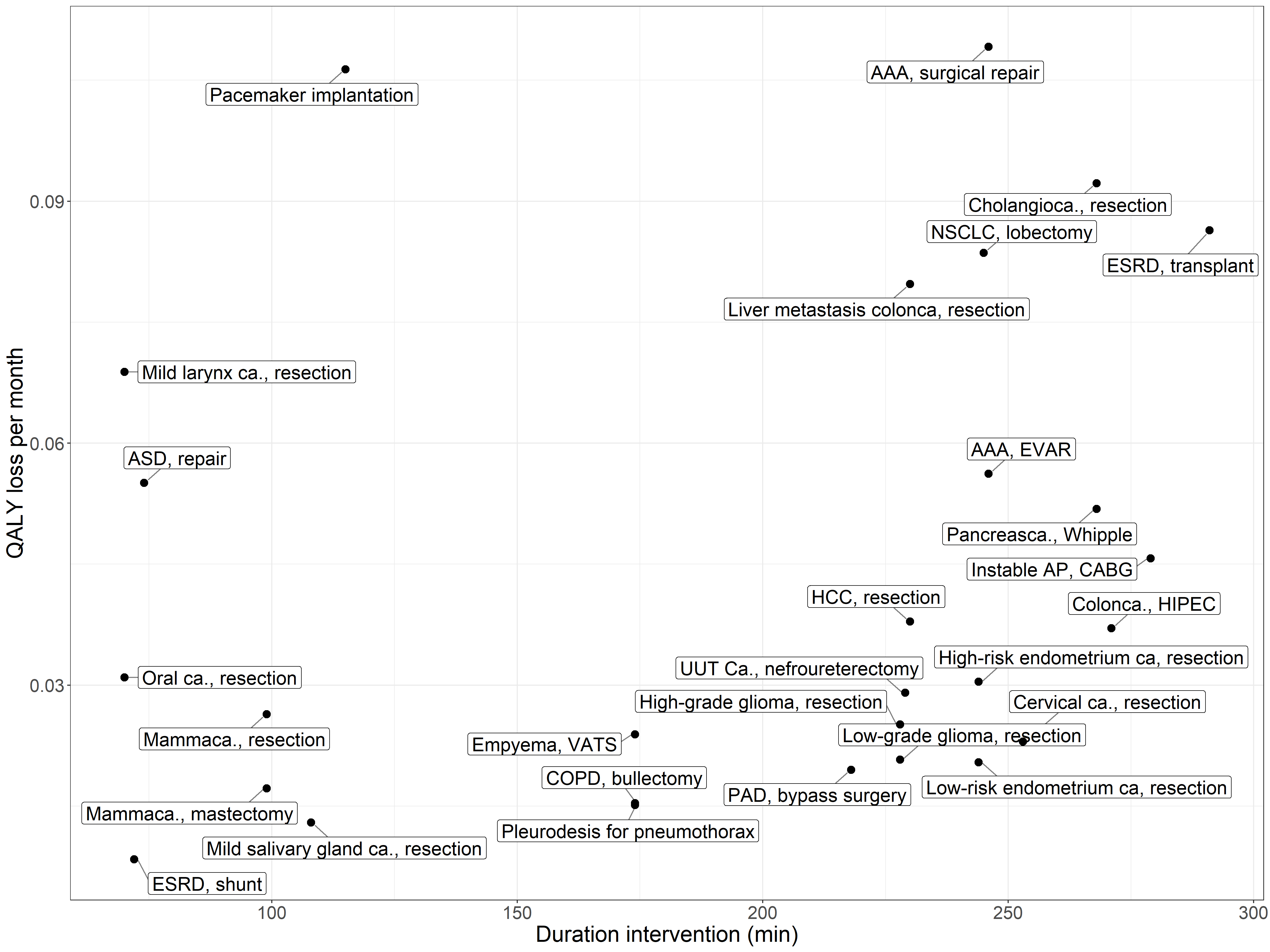


Figure 5, showing the mean duration of the intervention and the urgency in terms of QALY loss per month. Liver transplant was excluded, because it was an outlier in terms of duration of intervention (median: 875 minutes, IQR: 797-957 and -0.08 QALY per month, 95% CI: -0.09 - -0.07). **Abbreviations Figure titles**: QALY: Quality of Life without treatment. **Disease abbreviations**: AAA: aneurysm of the abdominal aorta; AP: angina pectoris; ESRD: end-stage renal disease; ASD: atrial septum defect; ca.: carcinoma; CABG: coronary artery bypass graft; ESHF: end-stage heart failure; ESLD: end-stage liver disease; EVAR: endovascular aortic repair; HIPEC: hyperthermic intraperitoneal chemotherapy; HCC: hepatocellular carcinoma; NSCLC: non-small cell lung carcinoma; PAD: peripheral arterial disease; PCI: percutaneous coronary intervention; UUT: upper urinary track; VATS: video assisted thoracoscopic surgery

Disclosures

**ADD DISCLOSURES (Please add your personal disclosures!)**

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## Appendix A

An overview per disease of the distribution and source of the input parameters and a graphical representation of the output of the model.

## Appendix B

A summary of the estimates of the decision model and an overview of the counts, duration, and length of stay of the included interventions in our hospital.

## Appendix C

Formulas to convert survival data into risk per week.

## Appendix D

Calibrated visual analogue scale based on the Global burden of disease study and description of expert panel that participated.