BMJ Open

Does a virtual hospital save money? Budget impact analysis of providing hospital inpatient care virtually in the home setting

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-051833
Article Type:	Original research
Date Submitted by the Author:	30-Mar-2021
Complete List of Authors:	Peters, Guido; Hospital Rijnstate Arnhem, Rijnstate Research Center; University of Twente Faculty of Behavioural Sciences, Department of Health Technology and Services Research Doggen, Carine J.M.; University of Twente Faculty of Behaviourial Management and Social sciences, Department of Health Technology and Services Research; Hospital Rijnstate Arnhem, Rijnstate Research Center van Harten, Wim; University of Twente, Department of Health Technology and Services Research; Netherlands Cancer Institute, Division of Psychosocial Research and Epidemiology
Keywords:	Telemedicine < BIOTECHNOLOGY & BIOINFORMATICS, HEALTH ECONOMICS, HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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Title page

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Author Information: Guido M Peters [1,2], Carine JM Doggen [1,2], Wim H van Harten [2,3]

1 Rijnstate Research Center, Rijnstate Hospital, Arnhem, The Netherlands

2 Department of Health Technology and Services Research, Technical Medical Centre, University of Twente, Enschede, The Netherlands

3 Division of Psychosocial Research and Epidemiology, Netherlands Cancer Institute, Amsterdam, The Netherlands

Corresponding author:

Prof. Dr. Wim H van Harten

Mailing address: Technical Medical Centre, Department of Health Technology and Services Research, University of Twente, Drienerlolaan 5 7522 NB Enschede, the Netherlands

Phone number: +31-53-489 7475

Email: w.h.vanharten@utwente.nl

Clinical trial number: not applicable

Prior presentations: not applicable

Word and element counts:

Abstract: 247

Main text: 4025

Number of Figures: 1

Number of Tables: 4

Number of appendices: 3

Abbreviated title: Budget impact analysis of virtual care

Keywords: Telemedicine, Wireless Technology, Remote Consultations, Budget Impact Analysis, Economic Evaluation

Does a virtual hospital save money? Budget impact analysis of providing hospital inpatient care virtually in the home setting

Guido M Peters[1,2], Carine JM Doggen[1,2], Wim H van Harten[2,3]

Abstract

Objective: To determine the budget impact of virtual care.

Methods: We conducted a budget impact analysis of virtual care from the perspective of a large teaching hospital in the Netherlands. Virtual care included remote monitoring of vital signs, and three daily remote contacts. Net budget impact over five years and net costs per patient per day (costs/patient/day) were calculated for different scenarios: implementation in one ward, in two different wards, in the entire hospital, and in multiple hospitals. Sensitivity analyses included best and worst case scenarios, and reducing the frequency of daily remote contacts.

Results: None of the scenarios resulted in cost savings. Net budget impact over five years was €2,441,000 for implementation in one ward, €2,235,000 for two wards, and €9,024,000 for the entire hospital. Costs/patient/day in the first year were €374 for implementation in one ward, €258 for two wards, and €82 for the entire hospital, decreasing to €269, €174, and €67, respectively. Projecting implementation in every Dutch hospital resulted in a net budget impact over five years of €634,516,000. For this scenario, costs/patient/day decreased to €58 in the first year, and to €48 in subsequent years in the best case. Reducing daily remote contacts to one per day reduced costs/patient/day to €4 in the first year, and to €−5 in subsequent years.

Conclusions: With present cost levels, virtual care only save money if it can be designed such that the active involvement of health professionals is minimized and a Greenfield approach is taken, involving larger numbers of hospitals.

Article summary

Strengths and limitations of this study

- We deconstructed the cost of hospital inpatient days to more accurately estimate potential cost savings.
- As fixed costs constitute a major component of the cost of hospital inpatient days, we used capacity estimation to assess possible reductions in fixed costs.
- We explored the effect of various levels of scale on the estimated budget impact.
- Many assumptions were made, owing to the novelty of the conceived intervention, and a consequent lack of an evidence base.
- The present study was conducted within the context of the Dutch healthcare system, which may limit the generalizability of the results.

BACKGROUND

Healthcare costs have been rising for decades and are expected to increase even further. Hospital care expenditure comprised more than 30% of total healthcare costs in the US and in 29 out of 31 countries in the European Economic Area.[1,2] To reduce the cost growth of hospital care, attempts are being undertaken to move care for post-operative and comparable patient categories out of hospitals to lower-cost contexts, such as the home situation and primary care.[3-8] Most of these attempts involve provision of in-person care in patients' homes by medical specialists. As a result, medical specialists spend much time on travel between patients. Use of digital technologies may allow more efficient use of healthcare resources, by entirely eliminating travel time, and by enabling nurses to carry out most of the work. One way to move care out of the hospital using digital technology is through telehealth, defined in a systematic review as "the use of information or communication technology as a medium for enabling professional-patient interaction[…]".[8]
Telehealth includes monitoring patients remotely, by telephone calls, store and forward services, or automatic monitoring devices enabling detection of patient deterioration, as well as tele-or videoconsultations, websites, or smartphone apps to provide health advice to patients.
While manufacturers frequently claim that telehealth reduces the use of hospital services and generates cost-savings, thorough evidence for this is lacking.[9,10] Properly designed studies are rare both due to technology push and rapid development of innovative technologies. While the use of telehealth to manage chronic conditions such as heart failure and chronic obstructive pulmonary disease is well studied and is generally positive,[8,11,12] these patient categories are at relatively low risk of complications requiring hospitalization compared to post-surgery patients. Presently, hospitals in the Netherlands are increasingly investing in telehealth to substitute in-hospital care. These investments are typically made by individual hospitals or departments within hospitals. This may not be the most cost-efficient way to organize telehealth, however the effect of scale on telehealth costs have not been studied thoroughly. Furthermore, investments in telehealth are often predicated on the idea that cost savings will be achieved. As a result, payors intend to lower hospital budgets, despite a lack of evidence.
The case we present is a first step in developing a virtual care setting for hospital patients using remote monitoring to enable very early discharge of postoperative and comparable categories of patients who need frequent supervision and who would usually remain in hospital for observation for at least one day. The virtual care center enables patients to be monitored in their homes, aiming to reduce the number of hospital inpatient days. This article presents a budget impact analysis (BIA) of a case at a large teaching hospital in the Netherlands. We consider four scenarios for organizing virtual care: 1) implementation of virtual care in a single ward, 2) virtual care in two wards, 3) providing virtual care in the entire hospital through a hospital-based virtual care center, and 4) providing virtual care for multiple hospitals through a "Greenfield" approach.

METHODS

We conducted a budget impact analysis of virtual care from a hospital perspective with a time horizon of five years, using a cost-calculator approach following ISPOR guidelines.[13] Virtual care includes a wireless wearable sensor that continuously measures vital signs, a relay device that transmits measurements to the hospital, and a number of tele- or videoconsultations. Box 1 describes virtual care in more detail.

Costs taken into account, the four scenarios, and the assumptions made in the calculations are provided below.

Box 1: Virtual care center

The virtual care center is meant to facilitate very early discharge of patients from the hospital, thereby reducing the number of inpatient days. It consists of three main components: 1) technology, 2) infrastructure, and 3) service. Each component is described below.

Technology

The technology component consists of a wireless wearable sensor, referred to as 'biosensor', and a relay device. The biosensor continuously measures patients' health status in terms of respiratory rate, heart rate, heart rate variability, skin temperature, and body posture. It is able to do so for 4 days (96 hours). The relay device receives the biosensor data through Blue Tooth Low Energy and transmits the data to the hospital through wireless internet.

Infrastructure

The infrastructure consists of server hardware and a software solution to process the biosensor data, and a remote monitoring center. The server hardware must be powerful enough to process a large continuous stream of data from several biosensors simultaneously. The software solution processes the data and provides a comprehensible overview of patients' health status. It is also capable of generating automated alerts.

The hospital-based virtual care center is equipped with a number of access points to the software solution, enabling simultaneous monitoring of all patients who are wearing a biosensor, as well as inspection of the complete biosensor measurement history. It is staffed by specially trained telenurses, each of which requires an access point.

Service

Upon discharge, patients are equipped with a biosensor and a relay device. Telenurses contact patients at least three times daily by telephone or videoconferencing for a duration of 4 days. Based on the assessment of patient health status, telenurses decide whether to provide behavioral or medication advice, to conduct a home visit or home treatment, or to contact a specialist. In case of a home visit or home treatment, it is desirable from a practical standpoint that another nurse is available as back-up, meaning there must always be at least two telenurses, regardless of how many patients are under the care of the virtual care center. If a specialist is contacted, they may determine that immediate transfer to the hospital by ambulance is desirable, or otherwise may give instructions to transfer a patient to hospital if symptoms progress to a certain point.

Cost types

To provide insight into how savings could be achieved, costs are separated into investments, fixed costs, and variable costs. Investments are those costs necessary to enable virtual care that only vary with the maximum number of patients expected to receive the intervention. Fixed costs are not directly affected by variation in the number of hospital bed days provided to patients or the number of patients, but may be reduced if hospital bed days are reduced by a sufficient amount. Variable costs vary directly with the number of bed days or the number of patients. Costs are further subdivided into costs related to 1) technology, 2) infrastructure, 3) service, 4) start-up, and 5) inpatient days. Table 1 provides a complete overview of costs.

Investments

Investments need to be made in technology and infrastructure, as well as in start-up costs, including implementation. For the technology component, investments include relay devices, client licenses, mobile client licenses and patient licenses. Relay devices and patient licenses are needed for each patient that is concurrently monitored with a biosensor. A small reserve of relay devices may be needed, as they have to be returned by or picked up from the patient. Client licenses are required for each access point in the remote monitoring center. Mobile client licenses are necessary for each mobile device with access to the server. All infrastructure costs are investments, i.e. server hardware, software license fees, and access points consisting of computers with monitors, tablet computers to enable videoconferencing, and office furniture. The server is capable of monitoring 240 biosensors simultaneously.

All start-up costs are depreciated as investments. These arise from project management to guide implementation, technical implementation to integrate the new technology and all of its components into existing systems such as the Electronic Medical Record (EMR) and ensuring system security and compatibility, external consultancy for various purposes, and training nurses in using the new equipment, as well as training telenurses that staff the virtual care center.

Fixed costs

Fixed costs originate from the infrastructure, service, and hospital inpatient capacity components and are also related to the offices necessary for the remote patient monitoring center. Fixed costs of the service include costs of telenurses, and costs of remote technical support, which enables the vendor of the biosensors and software applications to intervene if necessary. The major part of costs for inpatient days comes from salaries for specialists, physician assistants, and nurses, as well as real estate and overhead. These costs are reported as costs per inpatient day, as this is how they are conventionally quoted and reimbursed. In reality, however, in many countries these costs are fixed on the short- and midterm rather than variable.

Variable costs

Costs for the technology, service, and inpatient days contain variable components. In the case of technology, only the costs of biosensors are variable, as patients need their own biosensor.

As described in Box 1, some patients may require a home visit, home treatment, or ambulance transportation to the hospital, resulting in a variable cost component. Finally, a small proportion of costs for inpatient days is variable, consisting of materials such as medication, bandages, office supplies, and room and board. To estimate changes in nurse costs, capacity estimation is performed (Appendix A) based on a method developed in a different study.[14]

Data sources

Costs of technology, server hardware, the software solution, remote technical support, technical implementation, and education are based on a quotation of the vendor of the telehealth intervention. Costs for access points are based on market prices for equipment currently in use. Project management and external consultancy costs were retrieved from internal documents of the hospital. Costs of inpatient days are based on 2014 weighted average reference prices of general and academic hospitals, retrieved from the supplemental material to the Dutch guideline for economic evaluations in healthcare.[15] After correcting to 2019 values by applying the Consumer Price Index (CPI),[16] these prices were used for the calculations. Telenurses will be responsible for a large number of patients, require a broader knowledge base to deal with a large variety of health conditions, and need to be able to provide care at a distance. Therefore, costs are expected to be higher than for a conventional nurse, but lower than for a nurse working in an Intensive Care Unit. Hospital admissions data needed for capacity estimation were acquired from the hospital's business intelligence department.

Scenarios

The strategy of establishing a hospital-based virtual care center will be explored through four scenarios in which the expected effect is modeled on hospital admissions data from 2018. Box 1 presents the details of the virtual care center. A full description of each scenario is presented below. Because the different scenarios may hinder the comparability of budget impact figures, we additionally present costs of virtual care per patient per day.

Scenario 1: single ward - bariatric surgery

The bariatrics ward is a 16 bed ward. In 2018, bariatric surgery was performed in 1355 unique patients who used 4084 bed days. Additionally, 159 non-bariatric surgery patients used this ward. The average length of stay was approximately 2.5 days.
Patients who undergo surgery in the morning are typically discharged in the afternoon of the next day. With virtual care, bariatric surgeons expect that these patients could be discharged in the evening of the day of surgery, as long as they meet the following criteria: 1) being free from diabetes or sleep apnea, 2) living within 30 minutes of the hospital (by car), 3) not living alone, and 4) they or a caregiver are capable of working with the technology. It is assumed that surgeries are planned in such a way that all patients undergoing surgery in the morning meet eligibility criteria for same-day discharge. Based on this, 423 patients (31.2%) would have been eligible for virtual care in 2018.

Scenario 2: two wards and different patient groups - bariatric and vascular surgery

The vascular ward is a 19 bed ward, which provided services to 1667 unique patients in 2018. Based on expert opinion, it is expected that patients treated for carotid artery pathology (N = 78) or endovascular treated abdominal aortic aneurysm (AAA; N = 189) are eligible for very early discharge with virtual care. The average length of stay for these patients in 2018 was approximately 3.2 and 8 days, respectively. For carotid artery surgery a prolonged hospital stay is due to postoperative hypertension, and for AAA patients due to postoperative fever. Vascular surgery patients must meet the same criteria as bariatric surgery patients to be eligible. We assume again that the planning can be made such that all patients undergoing surgery in the morning meet eligibility criteria. Based on this, 162 patients (9.7%) would have been eligible for virtual care in 2018.
Additional investments in technology will be needed, as an increased number of patients leads to the need for a greater number of relays and patient licenses, and may cause a greater number of client licenses and mobile client licenses to be necessary.

Scenario 3: hospital-wide implementation in one hospital

The hospital in this case had 766 active beds in 2017, and provided care to 33,061 unique patients. We calculated the weighted average of the proportions of eligible patients found in scenarios 1 and 2, resulting in an eligible proportion of 19.4% of all patients. Thus, 6400 patients would have been eligible for virtual care in the whole hospital in 2018. A weighted average is also calculated for the number of days by which length of stay is reduced, to determine the total number of inpatient days that can be saved in this scenario.
In scenario 1 and 2, the number of inpatient days to be saved to reduce the number of nurse shifts by one is calculated. Based on this, a weighted average is calculated, which is used to estimate the number of nurse shifts that can be reduced in this scenario. This is done by dividing the number of

inpatient days that can be saved by the number of inpatient days to be saved to reduce the number of nurse shifts by one.

Scenario 4: multiple hospitals - Greenfield

In this scenario, a virtual care center is established independent of any one hospital, which provides its service to a number of hospitals, in our case the whole of the Netherlands. The proportion of patients who are eligible and the reduction in length of stay are based on findings from the first two scenarios, as for scenario 3.

It is assumed that investments in technology, infrastructure, and start-up costs are only needed once. As not all hospitals use the same systems, however, an exception to this is technical implementation, which is assumed to be needed for each hospital. Additionally, training is necessary at each hospital, as the biosensor has to be applied to patients locally. Finally, it is assumed that the other hospitals are of similar size as the case hospital.

General assumptions

Besides the assumptions described in the scenarios above, some general assumptions were made which may differ in other healthcare systems, namely: 1) the hospital cannot increase its revenue by performing more surgeries per day, due to restrictions imposed by health insurers 2) capacity that becomes available due to early discharge of patients with the biosensor is not used by patients from other wards or hospitals, 3) health outcomes do not change as a result of virtual care, and 4) there is no impact on overhead costs. An overview of all assumptions made is provided in Table 2.

Sensitivity analyses

For scenarios 3 and 4, it is investigated to what extent the budget impact would be affected by changes in the proportion of eligible participants, the reduction in length of stay, and the number of telephone contacts that are performed as part of virtual care. Costs per patient per day and net budget impact are calculated for a best and worst case scenario. In the best case scenario, the greatest proportion of eligible patients as well as the greatest reduction in length of hospital stay of the first two scenarios is taken, rather than the weighted average. For the worst case scenario, the smallest value is taken for both. The effect of changing the number of telephone contacts provided to virtual care patients after discharge from 3 per day to 1 per day is also examined, which changes the ratio of telenurses to patients from 1:12 to 1:36.

Validation

Face validity of the calculations was verified through discussions with a major health insurer in the region, industry partners, and within the hospital with the financial director and business controllers.

Patient and Public Involvement

Patients or the public were not involved in this study. Dissemination to participants or patient groups is not applicable.

RESULTS

This section presents the budget impact over five years, as well as the cost of virtual care per patient per day for each scenario.

Scenario 1 - single ward

If virtual care were implemented in a single ward, the number of nurse shifts during the day could be reduced by 0.5 shifts. The net budget impact is estimated at an additional €633,000 in the first year, followed by €452,000 in subsequent years, resulting in a total net budget impact of €2,441,000 over a period of 5 years. As shown in Figure 1, the majority of additional costs is caused by the service component of virtual care. Variable inpatient day costs provide savings of €41,999 and reductions in nurse shifts provide savings of €53,000. Net costs per patient per day are €374 in the first year and €269 in subsequent years.

Scenario 2 - two wards

Simulating virtual care in two wards, the number of nurse shifts needed is reduced by one. This results in cost savings of €106,000 in fixed costs. The net budget impact is estimated at an additional €604,000 in the first year, followed by €408,000 in subsequent years, resulting in a total net budget impact of €2,235,000 over a period of 5 years. As shown in Figure 1, the majority of additional costs is caused by the service component of virtual care. Cost savings originate fairly equally from variable inpatient day costs and reductions in nurse shifts needed. Net costs per patient per day are €258 in the first year and €174 in subsequent years.

Scenario 3 - hospital wide implementation

Extrapolating the results of the effect of virtual care on capacity to the entire hospital shows that the number of nurse shifts needed is reduced by 12. This results in cost savings of €1,272,000 in terms of fixed inpatient day costs.

The net budget impact is estimated at €2,110,000 in the first year, followed by €1,728,000 in subsequent years, resulting in a total net budget impact of €9,024,000 over a period of 5 years. Cost savings originating from reductions in nurse shifts are almost double that of savings from variable inpatient day costs. Net costs per patient per day are €82 in the first year, and €67 in subsequent years.

Scenario 4 - multiple hospitals

A Greenfield implementation of virtual care always results in a lower net cost per patient per day than if a hospital were to establish its own virtual care center (scenario 3), as shown in Table 3. The extent of the economies of scale is thus also illustrated.

The cost per patient per day ranges from €80 if only two hospitals participate to €72 when all 78 hospitals participate in the first year, and from €67 to €62 in subsequent years, depending on the number of hospitals participating.

It is important to note that while savings are made relative to each hospital establishing their own virtual care center, it is still more expensive than usual care. If one organization were to provide virtual care for all 78 hospitals in the Netherlands, this would result in a net budget impact of €142,820,000 in the first year, and €122,924,000 in subsequent years, for a total of 499,197 unique patients, and 1,996,788 virtual inpatient days. The macro impact for the Netherlands would thus be 0.8%.

Sensitivity analyses

In the worst case scenario only 9.7% of patients are eligible and length of hospital stay is reduced by 0.98 days per patient. The cost of virtual care per patient per day in the Netherlands ranged from €115 for implementation in one hospital to €87 for implementation in all 78 Dutch hospitals in the first year, and from €93 to €75 in subsequent years. The net budget impact ranged from €1,474,000 for one hospital to €86,950,000 for 78 hospitals in the first year, and from €1,197,000 for one hospital to €75,649,000 for 78 hospitals in subsequent years.

In the best case scenario 31.2% of patients are eligible and length of hospital stay is reduced by 1.38 days per patient. The cost of virtual care per patient per day in the Netherlands in the first year ranged from €67 to €58 in the first year, and from €54 to €48 in subsequent years. The net budget impact ranges from €2,750,000 for one hospital to €185,250,000 for 78 hospitals in the first year, and from €2,229,000 for one hospital to €154,789,000 for 78 hospitals in subsequent years.

When the number of telephone contacts per day in virtual care is reduced to one instead of three, the cost per patient per day in the Netherlands ranges from €12 to €4 in the first year, and from €−3 to €−5 in subsequent years. The net budget impact ranges from €300,000 for one hospital to €8,590,000 for 78 hospitals in the first year, and from €−72,000 for one hospital to €−10,393,000 for

78 hospitals in subsequent years. An overview of the results from sensitivity analyses is provided in Table 4 (complete version in Appendix B).

DISCUSSION

Replacing in-hospital care with virtual care does not directly lead to cost savings. This is mainly due to the fact that the virtual care service, in this case remote vital signs monitoring with three daily telephone contacts, apart from investments in IT infrastructure, requires additional telenurses to be available 24/7. Despite reductions in in-hospital nurse shifts, the additional costs of telenurses outweigh the savings made. Even in the best case scenario in terms of eligible patients and reduction in length of stay, as well as through reducing the number of telephone contacts per day, virtual care still incurs additional costs. However, if a Greenfield strategy (involving a large number of hospitals) is employed, and only one daily telephone contact is provided as part of virtual care, cost savings can be realized. These cost savings will not reduce healthcare expenditure with considerable impact, though, at present cost levels. These findings contradict those of communications from industry and prior research, which often found cost savings. In fact, only one prior study, also conducted in the Netherlands, was found to report an increase in costs.[17] Studies reporting cost savings often assumed that inpatient hospital day costs are entirely variable,[18-20] which is in contrast to the finding in this study that inpatient hospital day costs consist of a fixed component (84%) and a variable component (16%). Additionally, some studies reporting cost savings did not account for costs related to the intervention,[9,11] while even implementation of virtual care in only one ward costs €728,000 in the present study. Lastly, it is important to note that the case mix of diagnoses per hospital does not easily allow for a general or large scale reduction of staffs and wards, as digital services also require dedicated infrastructure and staffing; reductions mostly need to be specified per patient group.

This study must be interpreted within the context of several assumptions. First, it is not known with certainty which or how many patients are eligible for early discharge, as this is not common practice. Two eligible patient groups from different wards were identified based on expert opinion. The proportions of eligible patients relative to the total number of patients treated in these wards informed our analysis (9.7% to 31.2% eligibility). Moreover, it is assumed that remote continuous monitoring devices combined with telephone or video contacts is equivalent to in-hospital care in terms of health outcomes. While health outcomes in chronic conditions such as heart failure and Chronic Obstructive Pulmonary Disease (COPD) are generally affected positively,[21,22] little research has been done in directly post-operative or comparable patient populations from a case mix perspective. Nevertheless, the intervention in this case is of such short duration that improved health outcomes cannot realistically be expected. Furthermore, the Greenfield analysis is a linear extrapolation of the findings based on data of a large teaching hospital. In reality, the results may well differ for other types of hospitals, as differences in the number of patients treated per day and length of stay between hospitals, as well as hospital size, were not taken into account. Our hospital is, however, one of the larger Dutch teaching hospitals and we do not have reasons to believe admission patterns are very different in other hospitals. Finally, in the Dutch healthcare system hospitals cannot freely increase the number of patients that are treated due to restrictions imposed by health insurers, and in some cases savings in in-patient days may thus lead to reduced hospital income.[23] Although there are few examples of successful virtual hospitals and their definitions and scope vary per health system, different financing and market environments may lead to different degrees of impact.

This study also has several strengths. First, the cost of inpatient days was deconstructed to determine to what extent it consists of variable costs. Second, we used capacity calculation to establish the amount of fixed costs that could be saved. Third, we explored the effect of various levels of scale on budget impact.

An important implication of the results of this study is that it is essential for the success of virtual care's potential for cost savings that active involvement of health professionals is minimized. If the monitoring process can be automated, and health professionals need only take action when there is clinical necessity, costs can be reduced. Validated algorithms which can detect or even predict deterioration in patients' health status must therefore be developed. Another possibly interesting avenue for future research is to investigate how early discharge can affect waiting lists, as well as optimize throughput from the Emergency Department and Intensive Care Units to general and specialty wards through improved bed availability. Finally, it is important to consider that with virtual care, health professionals are responsible for more patients than with usual care, and increasingly have to deal with technology and data. It is conceivable that these factors influence health professionals' attitude towards their work and their well-being, as their professional environment is changing considerably. The aspect of digitalization of the professional environment merits further research.

CONCLUSIONS

Virtual care using telemonitoring of patients that are currently admitted to the hospital is still far from showing a positive budget impact. It can save money, provided it is deployed at sufficient scale, designed to minimize time spent by health professionals, and the costs of the technology are considerably reduced. Presently, in many European countries with fully or partly capitated budget systems, the financial situation of hospitals might even suffer when venturing into virtual care for postoperative and comparable categories of patients, as a result of higher costs and lower incomes.

Author affiliations
[1] Rijnstate Research Center, Rijnstate Hospital, Arnhem, The Netherlands
[2] Department of Health Technology and Services Research, Faculty of Behavioural, Management, and Social Sciences (BMS), Technical Medical Centre, University of Twente, Enschede, The Netherlands
[3] Division of Psychosocial Research and Epidemiology, Netherlands Cancer Institute, Amsterdam, The Netherlands

Acknowledgement The authors thank Eric Hazebroek and Steven van Sterkenburg for providing input from a clinical perspective; Ron van Kuilenburg, Nicole Hijnen, Murk Westerterp, Ton van Veen, Nicky Nillesen, and Laura Kooij for their critical evaluation of the budget impact calculations; as well as Paul Joustra for providing input on the capacity calculations.

Author Contributions GMP and WHvH had an equal role in the conceptualization of this study, with support from CJMD. GMP took the lead in data curation, formal analysis, developing the methodology, visualizing the results, and writing the original draft. WHvH and CJMD had an equal role in supervision of the research and reviewing the original draft, and both supported visualization of the results. WHvH acquired the funding for this study.

Competing interests GMP and CJMD have nothing to declare. WHvH has received non-restricted research grants form Novartis and Agendia BV.

Transparency statement The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported, and that no important aspects of the study have been omitted.

Ethical approval Ethical approval was not required for this study.

Funding source This study was funded by a non-restricted grant from Menzis, a Dutch insurance company. The funding source was not involved in the design of the study, data analysis, writing of the manuscript, or the decision to submit for publication.

Data sharing statement No additional unpublished data are available.

References

1. Centers for Medicare & Medicaid Services. National Health Expenditures 2017 Highlights. Baltimore: Centers for Medicare & Medicaid Services. Retrieved from https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/Downloads/highlights.pdf last accessed: 13-05-2019.
2. Eurostat. Healthcare expenditure by provider, 2015. Luxembourg: Eurostat. Retrieved from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Healthcare_expenditure_by_provider,_2015_(%25_of_current_healthcare_expenditure)_FP18a.png last accessed: 13-05-2019.
3. Gonçalves-Bradley DC, Ili-e S, Doll HA, et al. Early discharge hospital at home. *Cochrane Database of Systematic Reviews*. 2017; Issue 6. Art. No.: CD000356. DOI: 10.1002/14651858.CD000356.pub4
4. Safavi KC, Ricciardi R, Heng M, et al. A Different Kind of Perioperative Surgical Home. *Annals of Surgery*. 2020; 271 (2): 227-29. DOI: 10.1097/SLA.0000000000003417
5. Handley NR, Bekelman JE. The oncology hospital at home. Journal of Clinical Oncology. 2019; 37 (6): 448-53. DOI: 10.1200/JCO.18.01167
6. Aasen L, Ponton IG, Johannessen AKM. Being in control and striving for normalisation: A Norwegian pilot study on parents' perceptions of hospital-at-home. *Scandinavian Journal of Caring Sciences*. 2019; 33 (1): 102-10. DOI: 10.1111/scs.12606
7. Vesterby MS, Pedersen PU, Laursen M, et al. . Telemedicine support shortens length of stay after fast-track hip replacement. *Acta Orthop* 2017; 88: 41–7. DOI: 10.1080/17453674.2016.1256939
8. McLean S, Chandler D, Nurmatov U, et al. Telehealthcare for asthma: a Cochrane review. *CMAJ*. 2011; 183(11): E733-42. DOI: 10.1503/cmaj.101146
9. Baker LC, Johnson SJ, Macaulay D, et al. Integrated telehealth and care management program for Medicare beneficiaries with chronic disease linked to savings. *Health Affairs*. 2011; 30: 1689–1697.
10. Vitacca M. Telemonitoring in patients with chronic respiratory insufficiency: expectations deluded? *Thorax*. 2016; 71: 299-301. DOI: 10.1136/thoraxjnl-2015-208211
11. Jin K, Khonsari S, Gallagher R et al. Telehealth interventions for the secondary prevention of coronary heart disease: A systematic review and meta-analysis. Eur J Cardiovasc Nurs. 2019; 18(4): 260-71. DOI:10.1177/1474515119826510
12. Haveman ME, Kleiss SF, Ma KF, et al. Telemedicine in patients with peripheral arterial disease: is it worth the effort? *Expert Review of Medical Devices*. 2019; 16(9): 777-86. DOI: 10.1080/17434440.2019.1649595
13. Sullivan SD, Mauskopf JA, Augustovski F, et al. Principles of good practice for budget impact analysis II: report of the ISPOR Task Force on Good Research Practices – Budget Impact Analysis. *Value Health*. 2014;17(1):5-14.
14. De Bruin AM, Bekker R, Van Zanten L, Koole GM. Dimensioning hospital wards using the Erlang loss model. *Ann Oper Res*. 2010; 178: 23-43. DOI: 10.1007/s10479-009-0647-8
15. Zorginstituut Nederland. Richtlijn voor het uitvoeren van economische evaluaties in de gezondheidszorg (verdiepingsmodules). [Internet]. 2016 [cited 2020 Jun 30]. Available from: https://www.zorginstituutnederland.nl/binaries/zinl/documenten/publicatie/2016/02/29/richtlijn-voor-het-uitvoeren-van-economische-evaluaties-in-de-gezondheidszorg/Richtlijn+voor+het+uitvoeren+van+economische+evaluaties+in+de+gezondheidszorg+%28verdiepingsmodules%29.pdf
16. Centraal Bureau voor Statistiek. Consumentenprijzen; prijsindex 2015 = 100. [Internet]. 2020 [cited 2020 Jun 30]. Available from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83131NED/table?ts=1593473618202
17. Balk AHMM, Davidse W, Dommelen P, et al. Tele-guidance of chronic heart failure pateints enhances knowledge about the disease. *European Journal of Heart Failure*. 2008; 10(11): 1136-42.

18. Giordano A, Scalvini S, Zanelli E, et al. Multicentre randomised trial on home-based telemanagement to prevent hospital readmission of patients with chronic heart failure. *International Journal of Cardiology*. 2009; 131(2): 192-9.
19. Kielblock B, Frye Ch, Kottmair S, et al. Impact of telemetric management on overall treatment costs and mortality rate among patients with chronic heart failure [Einfluss einer telemedizinisch unterstützten Betreuung auf Gesamtbehandlungskosten und Mortalität bei chronischer Herzinsuffizienz]. *Deutsche Meizinische Wochenschrift*. 2007; 132 (9): 417-22.
20. Chen YH, Ho YL, Huang HC, et al. Assessment of the clinical outcomes and costeffectiveness of the management of systolic heart failure in Chinese patients using a home-based intervention. *J Int Med Res*. 2010; 38: 242–252.
21. Kitsiou S, Paré G, Jaana M. Effects of Home Telemonitoring Interventions on Patients With Chronic Heart Failure: An Overview of Systematic Reviews. *JMIR*. 2015; 17(3): e63.
22. Murphy LA, Harrington P, Taylor SJC et al. Clinical-effectiveness of self-management interventions in chronic obstructive pulmonary disease: An overview of reviews. *Chronic Respiratory Disease*. 2017; 14 (3): 276-288. DOI: 10.1177/1479972316687208
23. Kroneman M, Boerma W, van den Berg Met al. The Netherlands: health system review. *Health Systems in Transition*. 2016; 18(2):1–239

Figure legends

Figure 1. Budget impact per year for scenarios 1 and 2

Tables

Table 1. Overview of costs.

	Investments		Fixed costs		Variable costs	
	Cost item	Price	Cost item	Price	Cost item	Price
Technology	Relay device	€1150			Biosensor	€120
	Patient license	€520				
	Client license	€130				
	Mobile client license	€170				
Infrastructure	Server hardware	€33,900	Offices*	€1200		
	Software solution	€12,100				
	Access point	€1390				
Service			Telenurse	€65,000	Home visit	€80
			Remote Technical Support	€16,000	Home treatment	€130
					Ambulance transport	€760
Start-up	Project management	€48,400				
	Technical implementation	€20,000				
	External Consultancy	€40,500				
	Education	€25,000				
Inpatient day			Specialists	€30	Materials	€10
			Physician's assistants	€20		
			Nurses	€220	Room and board	€70
			Real estate	€20		
			Overhead	€130		

*Cost is per m² per year. All other prices are unit prices and include 21% VAT

Table 2. Overview of assumptions

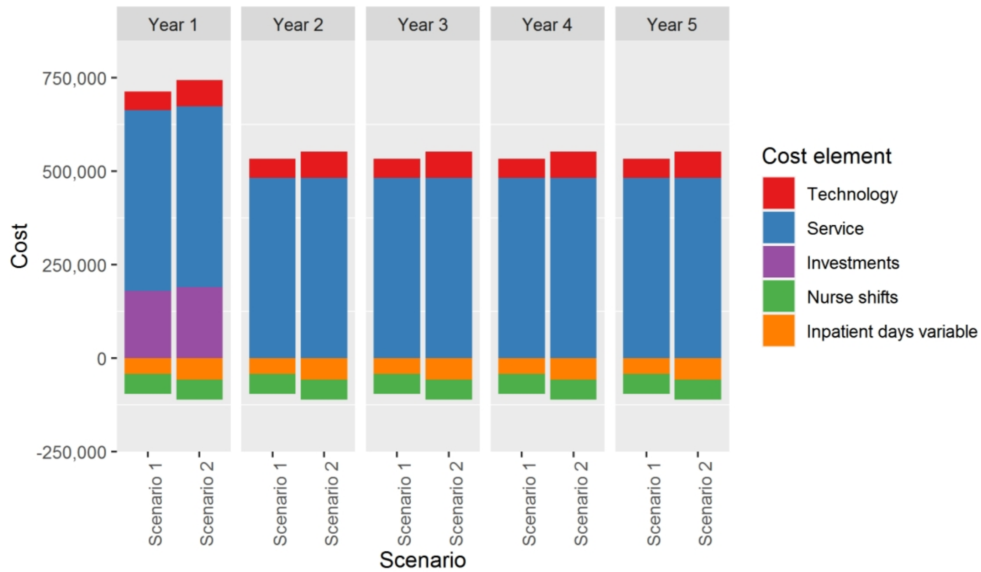
General assumptions
The hospital cannot increase its revenue by performing more surgeries per day, due to restrictions imposed by health insurers
Capacity that becomes available due to early discharge of patients with the biosensor is not used by patients from other wards or hospitals
There is no impact on overhead costs
Reductions in nurse shifts are possible in increments of 0.5 shifts
Nurses are each responsible for four beds during the day, six in the evening, and ten during the night.
Scenario 1
Surgeries for eligible patients can be planned in the morning
Scenario 2
All patients treated for abdominal aortic aneurysm (AAA) or carotid artery pathology are eligible for virtual care
All surgeries for AAA or carotid artery pathology can be planned in the morning.
Scenario 3 and 4
Proportions of patients eligible for virtual care in scenario 1 and 2 translate linearly to hospital-wide scale
Reductions in nurse shifts are linearly related to reductions in hospital bed days
Other hospitals are similar in size to the case hospital

Table 3. Net budget impact and cost of virtual care per patient per day for a range of numbers of hospitals to which virtual care is provided

Number of hospitals	Budget impact year 1	Budget impact per year years 2-5	Cost per patient per day year 1	Cost per patient per day years 2-5
Scenario 3 - each hospital own virtual care center				
1	€ 2,110,000	€ 1,728,000		
2	€ 4,220,000	€ 3,456,000		
3	€ 6,330,000	€ 5,185,000		
4	€ 8,440,000	€ 6,913,000		
5	€ 10,550,000	€ 8,641,000		
6	€ 12,660,000	€ 10,369,000	€ 82	€ 68
7	€ 14,770,000	€ 12,098,000		
8	€ 16,880,000	€ 13,826,000		
9	€ 18,990,000	€ 15,554,000		
10	€ 21,100,000	€ 17,282,000		
78	€ 164,574,000	€ 134,803,000		
Scenario 4 - one virtual care center for all hospitals				
2	€ 4,070,000	€ 3,440,000	€ 80	€ 67
3	€ 5,910,000	€ 5,017,000	€ 77	€ 65
4	€ 7,710,000	€ 6,571,000	€ 75	€ 64
5	€ 9,550,000	€ 8,151,000	€ 75	€ 64
6	€ 11,510,000	€ 9,862,000	€ 75	€ 64
7	€ 13,010,000	€ 11,114,000	€ 73	€ 62
8	€ 14,980,000	€ 12,824,000	€ 73	€ 63
9	€ 16,810,000	€ 14,404,000	€ 73	€ 63
10	€ 18,620,000	€ 15,958,000	€ 73	€ 62
78	€ 142,820,000	€ 122,924,000	€ 72	€ 62

Table 4. Net budget impact and cost of virtual care per patient per day for a range of numbers of hospitals to which virtual care is provided, stratified by sensitivity analysis

Analysis	Number of hospitals	Net budget impact year 1	Net budget impact per year years 2-5	Cost per patient per day year 1	Cost per patient per day years 2-5
Worst case	1	€ 1,474,000	€ 1,197,000	€ 115	€ 93
	2	€ 2,490,000	€ 2,075,000	€ 97	€ 81
	10	€ 11,460,000	€ 9,894,000	€ 89	€ 77
	78	€ 86,950,000	€ 75,649,000	€ 87	€ 75
Best case	1	€ 2,750,000	€ 2,229,000	€ 67	€ 54
	2	€ 5,190,000	€ 4,286,000	€ 63	€ 52
	10	€ 23,960,000	€ 19,949,000	€ 58	€ 48
	78	€ 185,250,000	€ 154,789,000	€ 58	€ 48
One telephone contact	1	€ 300,000	€ −72,000	€ 12	€ −3
	2	€ 450,000	€ −161,000	€ 9	€ −3
	10	€ 1,390,000	€ −1,157,000	€ 5	€ −5
	78	€ 8,590,000	€ −10,393,000	€ 4	€ −5



Budget impact per year for scenarios 1 and 2

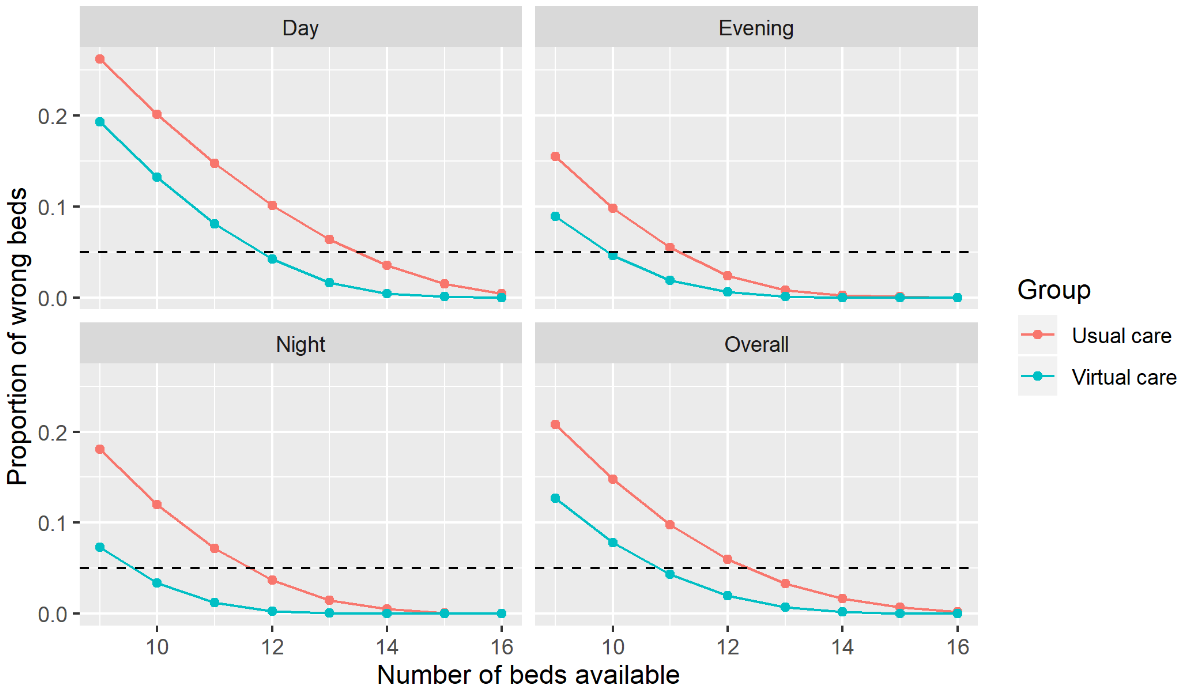
Appendix A: Capacity estimation

A pragmatic approach to capacity estimation is taken, using the method employed at the local hospital. This method requires admissions data of a ward for one year and the number of beds available to that ward as input. It then finds the number of patients treated by a ward for every hour of every day over the previous year, as well as the number of patients admitted to a different ward than the one providing treatment, i.e. the number of patients in "wrong beds". Patients end up in a wrong bed when all beds available to the treating ward are full. The proportion of patient time in wrong beds is computed to determine whether the number of beds available to the ward is appropriate. In this case, the maximum acceptable proportion of wrong beds is set to 0.05. Finally, the number of beds available to a ward is iterated to find the minimum number of beds needed to stay within the maximum acceptable proportion of wrong beds.
The hospital already works at reduced capacity in the months July and August, resulting in inaccurate capacity estimates for the rest of the year. Therefore, these months are excluded from the capacity estimation. Furthermore, for model stability, i.e. to ensure that the year does not start with an empty ward, admissions data for the last two months of the year before the year under investigation are also needed.
Finally, the reduction in number of beds needed is translated to a savings in nurse shifts by dividing the number of beds needed by the number of beds that can be served by a single nurse. During day shifts, one nurse serves 4 beds, during evening shifts one nurse is responsible for 6 beds, and during night shifts a single nurse serves 10 beds.

Scenario 1
As shown in Appendix Table 1, 13 beds are needed to restrict the number of bariatric surgery patients in wrong beds to an acceptable level with usual care, whichis reduced to 11 with virtual care.Therefore, with usual care, 3.5 nurse shifts are needed, while only 3 nurse shifts are needed with virtual care, resulting in a reduction of nurse shifts by 0.5.
As shown in Figure 1, the number of beds needed is reduced by two for each shift: from 14 to 12 during the day, and from 12 to 10 in the evening and the night. For evening and night shifts this does not result in a reduction in the number of nurse shifts needed, however. In the evening this is not possible because the number of beds is not sufficiently reduced, and during the night it is impossible because the ward already works with 1.5 nurse shifts, which is the minimum number of nurse shifts that should be available at any given time.

Appendix Table 1. Number of days bariatric surgery patients spend in wrong beds per year, based on number of beds available overall

	Usual care (3075 Bed days)		Virtual care (2660 Bed days)	
Beds	Wrong bed days	proportion wrong beds	Wrong bed days	proportion wrong beds
16	4,9	0,002	0	0,000
15	20,6	0,007	1,0	0,000
14	51,2	0,017	4,9	0,002
13	102,7	0,033	19,2	0,007
12	184,7	0,060	52,8	0,020
11	302,6	0,098	113,3	0,043
10	455,0	0,148	206,9	0,078
9	640,5	0,208	336,8	0,127

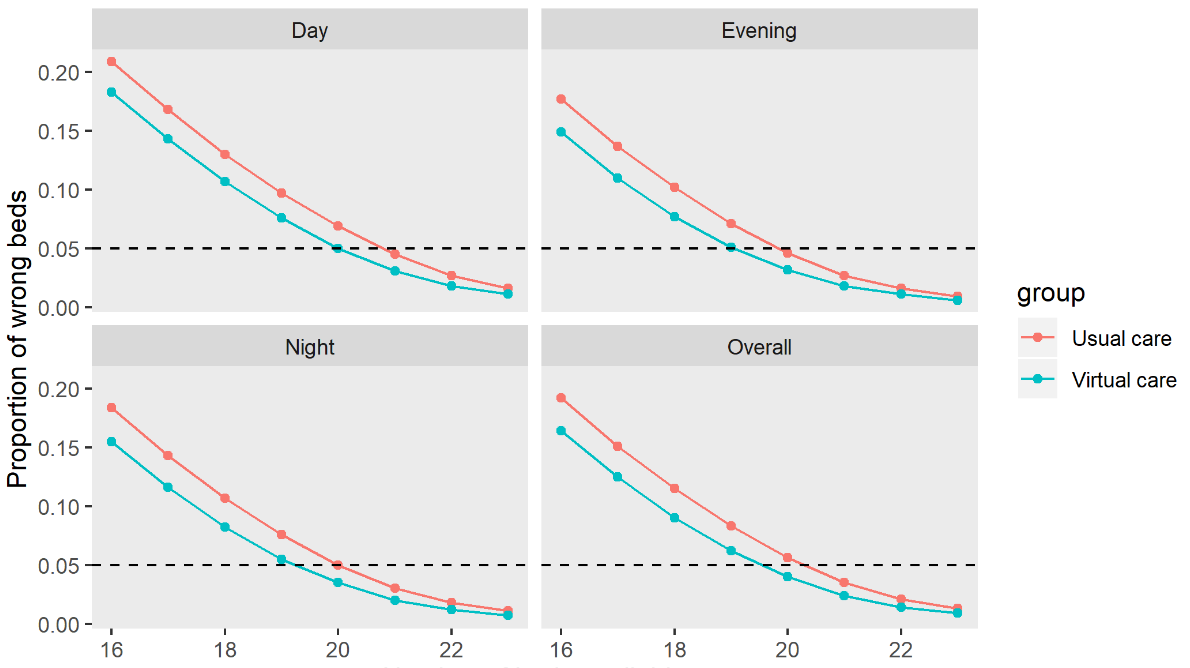


<u>Scenario 2</u>

As shown in Appendix Figure 2, 21 beds are needed to restrict the number of vascular surgery patients in wrong beds to an acceptable level with usual care, which is reduced to 20 with virtual care. Therefore, with usual care, 5.5 nurse shifts are needed, while only 5 nurse shifts are needed with virtual care, resulting in a reduction of nurse shifts by 0.5.

As shown in Figure 1, the number of beds needed is reduced by one for day and evening shifts: from 21 to 20 during the day, and from 20 to 19 in the evening. The number of beds needed during the night shift stays the same at 20. For the evening shift this does not result in a reduction in the number of nurse shifts needed, however, because the number of beds is not sufficiently reduced.

Appendix Figure 2. Number of beds needed for the vascular ward per shift with and without virtual care



Scenario 3

The weighted average percentage of eligible patients is 19.36%, resulting in 6400 eligible patients, and the weighted average reduction in length of stay is 1.20 days, resulting in savings of 7696.8 inpatient days. The weighted average number of saved inpatient days needed to reduce the number of nurse shifts by 1 is 619.28 days. Therefore, the number of nurse day shifts could be reduced by 7696.8 / 619.28 = 12.43 = 12 nurse shifts. Since nurse shifts during the evening and night could not be reduced in either scenario 1 or 2, it is assumed that this scenario also does not allow for this.

Appendix B: Complete sensitivity analysis

Table 1. Budget impact and cost of virtual care per patient per year, stratified by sensitivity analysis

Analysis	Number of hospitals	Net budget impact year 1	Net budget impact per year years 2-5	Cost per patient per day year 1	Cost per patient per day years 2-5
Worst case	1	€ 1,474,000	€ 1,197,000	€ 115	€ 93
	2	€ 2,490,000	€ 2,075,000	€ 97	€ 81
	3	€ 3,680,000	€ 3,125,000	€ 96	€ 81
	4	€ 4,830,000	€ 4,134,000	€ 94	€ 80
	5	€ 6,040,000	€ 5,184,000	€ 94	€ 81
	6	€ 7,050,000	€ 6,063,000	€ 91	€ 79
	7	€ 7,920,000	€ 6,785,000	€ 88	€ 75
	8	€ 9,240,000	€ 7,965,000	€ 90	€ 77
	9	€ 10,260,000	€ 8,844,000	€ 89	€ 76
	10	€ 11,460,000	€ 9,894,000	€ 89	€ 77
	78	€ 86,950,000	€ 75,649,000	€ 87	€ 75
Best case	1	€ 2,750,000	€ 2,229,000	€ 67	€ 54
	2	€ 5,190,000	€ 4,286,000	€ 63	€ 52
	3	€ 7,470,000	€ 6,171,000	€ 60	€ 50
	4	€ 9,910,000	€ 8,228,000	€ 60	€ 50
	5	€ 12,060,000	€ 9,983,000	€ 58	€ 48
	6	€ 14,660,000	€ 12,196,000	€ 59	€ 49
	7	€ 17,100,000	€ 14,252,000	€ 59	€ 49
	8	€ 19,380,000	€ 16,137,000	€ 59	€ 49
	9	€ 21,700,000	€ 18,064,000	€ 58	€ 49
	10	€ 23,960,000	€ 19,949,000	€ 58	€ 48
	78	€ 185,250,000	€ 154,789,000	€ 58	€ 48
One telephone contact	1	€ 300,000	€ -72,000	€ 12	€ -3
	2	€ 450,000	€ -161,000	€ 9	€ -3
	3	€ 610,000	€ -250,000	€ 8	€ -3
	4	€ 760,000	€ -338,000	€ 7	€ -3
	5	€ 910,000	€ -427,000	€ 7	€ -3
	6	€ 1,060,000	€ -515,000	€ 7	€ -3
	7	€ 1,080	€ -734,000	€ 6	€ -4
	8	€ 1,240,000	€ -823,000	€ 6	€ -4
	9	€ 1,390,000	€ -911,000	€ 6	€ -4
	10	€ 1,390,000	€ -1,157,000	€ 5	€ -5
	78	€ 8,590,000	€ -10,393,000	€ 4	€ -5

Reporting checklist for economic evaluation of health interventions.

Based on the CHEERS guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the CHEERSreporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title			
	#1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	1, 3
Abstract			
	#2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions	3
Introduction			
Background and objectives	#3	Provide an explicit statement of the broader context for the study. Present the study question and its relevance for health policy or practice decisions	4
Methods			

Target population and subgroups	#4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	6
Setting and location	#5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	4, 7
Study perspective	#6	Describe the perspective of the study and relate this to the costs being evaluated.	5
Comparators	#7	Describe the interventions or strategies being compared and state why they were chosen.	5, 6, Appendix A
Time horizon	#8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	5
Discount rate	#9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate	n/a
Choice of health outcomes	#10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed	n/a
Meaurement of effectiveness	#11a	Single study-based estimates: Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data	n/a
Measurement of effectiveness	#11b	Synthesis-based estimates: Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data	n/a
Measurement and valuation of preference based outcomes	#12	If applicable, describe the population and methods used to elicit preferences for outcomes.	n/a
**Estimating resources and costs **			
	#13a	Single study-based economic evaluation: Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs	n/a

Methods			
Estimating resources and costs	#13b	Model-based economic evaluation: Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	5-7, Appendix B
Currency, price date, and conversion	#14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	6
Choice of model	#15	Describe and give reasons for the specific type of decision analytical model used. Providing a figure to show model structure is strongly recommended.	n/a
Assumptions	#16	Describe all structural or other assumptions underpinning the decision-analytical model.	6, 7
Analytical methods	#17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	7
Results			
Study parameters	#18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	6, 7
Incremental costs and outcomes	#19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	n/a
Characterising uncertainty	#20a	Single study-based economic evaluation: Describe the effects of sampling uncertainty for the estimated incremental cost and	n/a

		incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	
Characterising uncertainty	#20b	Model-based economic evaluation: Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	8
Characterising heterogeneity	#21	If applicable, report differences in costs, outcomes, or cost effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	n/a
Discussion			
Study findings, limitations, generalisability, and current knowledge	#22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	9, 10
Other			
Source of funding	#23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support	2, 11
Conflict of interest	#24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations	2, 11

Notes:

- 7: 5, 6, Appendix A
- 13b: 5-7, Appendix B This checklist was completed on 29. March 2021 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai

BMJ Open

Budget impact analysis of providing hospital inpatient care at home virtually, starting with two specific surgical patient groups

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-051833.R1
Article Type:	Original research
Date Submitted by the Author:	17-Jan-2022
Complete List of Authors:	Peters, Guido; Hospital Rijnstate Arnhem, Rijnstate Research Center; University of Twente Faculty of Behavioural Sciences, Department of Health Technology and Services Research Doggen, Carine J.M.; University of Twente Faculty of Behaviourial Management and Social sciences, Department of Health Technology and Services Research; Hospital Rijnstate Arnhem, Rijnstate Research Center van Harten, Wim; University of Twente, Department of Health Technology and Services Research; Netherlands Cancer Institute, Division of Psychosocial Research and Epidemiology
Primary Subject Heading:	Health economics
Secondary Subject Heading:	Health services research, Health policy
Keywords:	Telemedicine < BIOTECHNOLOGY & BIOINFORMATICS, HEALTH ECONOMICS, HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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Title page

Article Title: Budget impact analysis of providing hospital inpatient care at home virtually, starting with two specific surgical patient groups.

Author Information: Guido M Peters [1,2], Carine JM Doggen [1,2], Wim H van Harten [2,3]

1 Rijnstate Research Center, Rijnstate Hospital, Arnhem, The Netherlands

2 Department of Health Technology and Services Research, Technical Medical Centre, University of Twente, Enschede, The Netherlands

3 Division of Psychosocial Research and Epidemiology, Netherlands Cancer Institute, Amsterdam, The Netherlands

Corresponding author:

Prof. Dr. Wim H van Harten

Mailing address: Technical Medical Centre, Department of Health Technology and Services Research, University of Twente, Drienerlolaan 5 7522 NB Enschede, the Netherlands

Phone number: +31-53-489 7475

Email: w.h.vanharten@utwente.nl

Clinical trial number: not applicable

Prior presentations: not applicable

Word and element counts:

Abstract: 244

Main text: 4858

Number of Figures: 1

Number of Tables: 4

Number of appendices: 3

Abbreviated title: Budget impact analysis of virtual care

Keywords: Telemedicine, Wireless Technology, Remote Consultations, Budget Impact Analysis, Economic Evaluation

Budget impact analysis of providing hospital inpatient care at home virtually, starting with two specific surgical patient groups

Guido M Peters[1,2], Carine JM Doggen[1,2], Wim H van Harten[2,3,4]

Abstract

Objective: To determine the budget impact of virtual care.

Methods: We conducted a budget impact analysis of virtual care from the perspective of a large teaching hospital in the Netherlands. Virtual care included remote monitoring of vital signs, and three daily remote contacts. Net budget impact over five years and net costs per patient per day (costs/patient/day) were calculated for different scenarios: implementation in one ward, in two different wards, in the entire hospital, and in multiple hospitals. Sensitivity analyses included best and worst case scenarios, and reducing the frequency of daily remote contacts.

Results: Net budget impact over five years was €2,090,000 for implementation in one ward, €410,000 for two wards, and €-6,206,000 for the entire hospital. Costs/patient/day in the first year were €303 for implementation in one ward, €94 for two wards, and €11 for the entire hospital, decreasing in subsequent years to a mean of €259 (SD=€72), €17 (SD=€10), and €-55 (SD=€44), respectively. Projecting implementation in every Dutch hospital resulted in a net budget impact over five years of €-445,698,500. For this scenario, costs/patient/day decreased to €-37 in the first year, and to €54 in subsequent years in the base case.

Conclusions: With present cost levels, virtual care only saves money if it is deployed at sufficient scale or if it can be designed such that the active involvement of health professionals is minimized. Taking a Greenfield approach, involving larger numbers of hospitals, further decreases costs compared with implementing virtual care in one hospital alone.

Strengths and limitations of this study

- We deconstructed the cost of hospital inpatient days to more accurately estimate potential cost savings.
- As fixed costs constitute a major component of the cost of hospital inpatient days, we used capacity estimation to assess possible reductions in fixed costs.
- We explored the effect of various levels of scale on the estimated budget impact.
- Many assumptions were made, owing to the novelty of the conceived intervention, and a consequent lack of an evidence base.
- The present study was conducted within the context of the Dutch healthcare system, which may limit the generalizability of the results.

BACKGROUND

Healthcare costs have been rising for decades and are expected to increase even further. Hospital care expenditure comprised more than 30% of total healthcare costs in the US and in 29 out of 31 countries in the European Economic Area.[1,2] To reduce the cost growth of hospital care, attempts are being undertaken to move care for post-operative and comparable patient categories out of hospitals to lower-cost contexts, such as the home situation and primary care.[3-7] Most of these attempts involve provision of in-person care in patients' homes by medical specialists. As a result, medical specialists spend much time on travel between patients. Use of digital technologies may allow more efficient use of healthcare resources, by entirely eliminating travel time, and by enabling nurses to carry out most of the work. One way to move care out of the hospital using digital technology is through telehealth, defined in a systematic review as “the use of information or communication technology as a medium for enabling professional-patient interaction”.[8] Telehealth includes monitoring patients remotely, by telephone calls, store and forward services, or automatic monitoring devices enabling detection of patient deterioration, as well as tele-or videoconsultations, websites, or smartphone apps to provide health advice to patients.

While manufacturers frequently claim that telehealth reduces the use of hospital services and generates cost-savings, thorough evidence for this is lacking.[9,10] Properly designed studies are rare both due to technology push and rapid development of innovative technologies. While the use of telehealth to manage chronic conditions such as heart failure and chronic obstructive pulmonary disease is well studied and is generally positive,[11-13] these patient categories are at relatively low risk of complications requiring hospitalization compared to post-surgery patients. Presently, hospitals in the Netherlands are increasingly investing in telehealth to substitute in-hospital care. These investments are typically made by individual hospitals or departments within hospitals. This may not be the most cost-efficient way to organize telehealth, however the effect of scale on telehealth costs have not been studied thoroughly. Furthermore, investments in telehealth are often predicated on the idea that cost savings will be achieved. As a result, payors intend to lower hospital budgets, despite a lack of evidence.

The case we present is a first step in developing a virtual care setting for hospital patients using remote monitoring to enable very early discharge of postoperative and comparable categories of patients who need frequent supervision and who would usually remain in hospital for observation for at least one day. The virtual care center enables patients to be monitored in their homes, aiming to reduce the number of hospital inpatient days. This article presents a budget impact analysis (BIA) of a case at a large teaching hospital in the Netherlands. We consider four scenarios for organizing virtual care: 1) implementation of virtual care in a single ward, 2) virtual care in two wards, 3) providing virtual care in an entire 766 bed hospital through a hospital-based virtual care center, and 4) providing virtual care for all Dutch hospitals, i.e. 39,900 beds, through a “Greenfield” approach.

METHODS

Patient and Public Involvement Patients or the public were not involved in this study. Dissemination to participants or patient groups is not applicable.

We conducted a budget impact analysis of virtual care from a hospital perspective with a time horizon of five years, using a cost-calculator approach following ISPOR guidelines.[14] Virtual care includes a wireless wearable sensor that continuously measures vital signs, a relay device that transmits measurements to the hospital, and a number of tele- or videoconsultations. Appendix A describes virtual care in more detail.

Box 1: Virtual care center

The virtual care center is meant to facilitate very early discharge of patients from the hospital, thereby reducing the number of inpatient days. It consists of three main components: 1) technology, 2) infrastructure, and 3) service. Each component is described below.

Technology

The technology component consists of a wireless wearable sensor, referred to as 'biosensor', and a relay device. The biosensor continuously measures patients' health status in terms of respiratory rate, heart rate, heart rate variability, skin temperature, and body posture. It is able to do so for 4 days (96 hours). The relay device receives the biosensor data through Blue Tooth Low Energy and transmits the data to the hospital through wireless internet.

Infrastructure

The infrastructure consists of server hardware and a software solution to process the biosensor data, and a remote monitoring center. The server hardware must be powerful enough to process a large continuous stream of data from several biosensors simultaneously. The software solution processes the data and provides a comprehensible overview of patients' health status. It is also capable of generating automated alerts.

The hospital-based virtual care center is equipped with a number of access points to the software solution, enabling simultaneous monitoring of all patients who are wearing a biosensor, as well as inspection of the complete biosensor measurement history. It is staffed by specially trained telenurses, each of which requires an access point.

Service

Upon discharge, patients are equipped with a biosensor and a relay device. Telenurses contact patients at least three times daily by telephone or videoconferencing for a duration of 4 days. Based on the assessment of patient health status, telenurses decide whether to provide behavioral or medication advice, to conduct a home visit or home treatment, or to contact a specialist. In case of a home visit or home treatment, it is desirable from a practical standpoint that another nurse is available as back-up, meaning there must always be at least two telenurses, regardless of how many patients are under the care of the virtual care center. If a specialist is contacted, they may determine that immediate transfer to the hospital by ambulance is desirable, or otherwise may give instructions to transfer a patient to hospital if symptoms progress to a certain point.

Costs taken into account, the four scenarios, and the assumptions made in the calculations are provided below.

Cost types

To provide insight into how savings could be achieved, costs are separated into investments, fixed costs, and variable costs. Investments are those costs necessary to enable virtual care that only vary with the maximum number of patients expected to receive the intervention. Fixed costs are not directly affected by variation in the number of hospital bed days provided to patients or the number of patients, but may be reduced if hospital bed days are reduced by a sufficient amount. Variable costs vary directly with the number of bed days or the number of patients. Costs are further subdivided into costs related to 1) technology, 2) infrastructure, 3) service, 4) start-up, and 5) inpatient days. Table 1 provides a complete overview of costs.

Investments

Investments need to be made in technology and infrastructure, as well as in start-up costs, including implementation. For the technology component, investments include relay devices, client licenses, mobile client licenses and patient licenses. Relay devices and patient licenses are needed for each patient that is concurrently monitored with a sensor. A small reserve of relay devices may be needed, as they have to be returned by or picked up from the patient. Client licenses are required for each access point in the remote monitoring center. Mobile client licenses are necessary for each mobile device with access to the server. All infrastructure costs are investments, i.e. server hardware, software license fees, and access points consisting of computers with monitors, tablet computers to enable videoconferencing, and office furniture. The server is capable of monitoring 240 sensors simultaneously.

All start-up costs are depreciated as investments. These arise from project management to guide implementation, technical implementation to integrate the new technology and all of its components into existing systems such as the Electronic Medical Record (EMR) and ensuring system security and compatibility, external consultancy for various purposes, and training nurses in using the new equipment, as well as training telenurses that staff the virtual care center.

Fixed costs

Fixed costs originate from the infrastructure, service, and hospital inpatient capacity components and are also related to the offices necessary for the remote patient monitoring center. Fixed costs of the service include costs of telenurses, and costs of remote technical support, which enables the vendor of the sensors and software applications to intervene if necessary. The major part of costs for inpatient days comes from salaries for specialists, physician assistants, and nurses, as well as real estate and overhead. These costs are reported as costs per inpatient day, as this is how they are conventionally quoted and reimbursed. In reality, however, in many countries these costs are fixed on the short- and midterm rather than variable.

Variable costs

Costs for the technology, service, and inpatient days contain variable components. In the case of technology, only the costs of sensors are variable, as patients need their own sensor.

As described in Box 1, some patients may require a home visit, home treatment, or ambulance transportation to the hospital, resulting in a variable cost component. Finally, a small proportion of costs for inpatient days is variable, consisting of materials such as medication, bandages, office supplies, and room and board. To estimate changes in nurse costs, capacity estimation is performed (Appendix A) based on a method developed in a different study.[15]

Data sources

Costs of technology, server hardware, the software solution, remote technical support, technical implementation, and education are based on a quotation of the vendor of the telehealth intervention. Costs for access points are based on market prices for equipment currently in use. Project management and external consultancy costs were retrieved from internal documents of the hospital. Costs of inpatient days are based on 2014 weighted average reference prices of general and academic hospitals, retrieved from the supplemental material to the Dutch guideline for economic evaluations in healthcare.[16] After correcting to 2019 values by applying the Consumer Price Index (CPI),[17] these prices were used for the calculations. Telenurses will be responsible for a large number of patients, require a broader knowledge base to deal with a large variety of health conditions, and need to be able to provide care at a distance. Therefore, costs are expected to be higher than for a conventional nurse, but lower than for a nurse working in an Intensive Care Unit. Hospital admissions data needed for capacity estimation were acquired from the hospital's business intelligence department.

Scenarios

The strategy of establishing a hospital-based virtual care center will be explored through four scenarios in which the expected effect is modeled on hospital admissions data from 2015 to 2019. Box 1 presents the details of the virtual care center. A full description of each scenario is presented below. Because the different scenarios may hinder the comparability of budget impact figures, we additionally present costs of virtual care per patient per day.

Scenario 1: single ward - bariatric surgery

The bariatrics ward is a 16 bed ward. From 2015 to 2019, bariatric surgery was performed in 1295 (SD=72) unique patients per year, who used an average of 3897 (SD=202) bed days. Additionally, 380 (SD=91) non-bariatric surgery patients used this ward per year. The average length of stay was approximately 2.5 days.

Patients who undergo surgery in the morning are typically discharged in the afternoon of the next day. With virtual care, bariatric surgeons expect that these patients could be discharged in the evening of the day of surgery, as long as they meet the following criteria: 1) being free from diabetes or sleep apnea, 2) living within 30 minutes of the hospital (by car), 3) not living alone, and 4) they or a caregiver are capable of working with the technology. It is assumed that surgeries are planned in such a way that all patients undergoing surgery in the morning meet eligibility criteria for same-day discharge. Based on this, an average of 402 patients (SD=83) would have been eligible for virtual care per year.

Scenario 2: two wards and different patient groups - bariatric and vascular surgery

The vascular ward is a 19 bed ward, which provided services to 927 (SD=63) unique patients per year from 2015 to 2019, on average. Based on expert opinion, it is expected that patients treated for carotid artery pathology (mean N=71, SD=6) or endovascular treated abdominal aortic aneurysm (AAA; mean N = 156, SD=18) are eligible for very early discharge with virtual care. The average length of stay for these patients was approximately 3.2 and 8 days, respectively. For carotid artery surgery a prolonged hospital stay is due to postoperative hypertension, and for AAA patients due to postoperative fever. Vascular surgery patients must meet the same criteria as bariatric surgery patients to be eligible. We assume again that the planning can be made such that all patients undergoing surgery in the morning meet eligibility criteria. Based on this, an average of 196 patients (SD=21) would have been eligible for virtual care per year.

Additional investments in technology will be needed, as an increased number of patients leads to the need for a greater number of relays and patient licenses, and may cause a greater number of client licenses and mobile client licenses to be necessary.

Scenario 3: hospital-wide implementation in one hospital

The hospital in this case had 766 active beds from 2015 to 2019, and provided care to 33,295 (SD=427) unique patients per year. We calculated the weighted average of the proportions of eligible patients found in scenarios 1 and 2 for each year, resulting in an eligible proportion ranging from 19%

to 32% of all patients. Thus, an average of 8517 (SD=1640) patients would have been eligible for virtual care in the whole hospital per year. A weighted average is also calculated for the number of days by which length of stay is reduced, to determine the total number of inpatient days that can be saved in this scenario.
In scenario 1 and 2, the number of inpatient days to be saved to reduce the number of nurse shifts by one is calculated. Based on this, a weighted average is calculated. This is done by dividing the number of inpatient days that can be saved by the number of inpatient days to be saved to reduce the number of nurse shifts by one. As the wards studied in scenarios 1 and 2 turned out to be relatively close to being able to reduce the number of nurse shifts, we further took the average of the theoretical production per nurse shift and the weighted average (Appendix X) to produce a less optimistic estimate for the base case.

Scenario 4: multiple hospitals - Greenfield
In this scenario, a virtual care center is established independent of any one hospital, which provides its service to a number of hospitals, in our case the whole of the Netherlands. The proportion of patients who are eligible and the reduction in length of stay are based on findings from the first two scenarios, as for scenario 3. To account for differences in hospital size, we calculated the average number of patients receiving virtual care per bed per year in scenario 3, which we multiplied by the total number of hospital beds in the Netherlands in 2018 (N=39,900)[18] to arrive at the number of patients receiving virtual care in all Dutch hospitals combined per year.
It is assumed that investments in technology, infrastructure, and start-up costs are needed once per hospital.

General assumptions
Besides the assumptions described in the scenarios above, some general assumptions were made which may differ in other healthcare systems, namely: 1) the hospital cannot increase its revenue by performing more surgeries per day, as health insurers impose volume restrictions on all DRGs,[19] 2) capacity that becomes available due to early discharge of patients with the sensor is not used by patients from other wards or hospitals, 3) health outcomes do not change as a result of virtual care, and 4) there is no impact on overhead costs. It should be noted that the volume restrictions per DRG can be renegotiated. However, as health insurers are tasked with keeping costs low, it is nevertheless questionable to what extent increased revenues could be achieved. An overview of all assumptions made is provided in Table 2.

Sensitivity analyses
For scenarios 3 and 4, it is investigated to what extent the budget impact would be affected by changes in the proportion of eligible participants, the reduction in length of stay, and the number of telephone contacts that are performed as part of virtual care. Additionally, the effect of allowing repurposing of saved inpatient days such that they can be utilised by patients from other wards or hospitals is explored.
Costs per patient per day and net budget impact are calculated for a best and worst case scenario. In the best case scenario, the greatest proportion of eligible patients as well as the greatest reduction in length of hospital stay of the first two scenarios is taken, rather than the weighted average. For the worst case scenario, the smallest value is taken for both. The effect of changing the number of telephone contacts provided to virtual care patients after discharge from 3 per day to 1 per day is also examined, which changes the ratio of telenurses to patients from 1:12 to 1:36. The effect of repurposing capacity is calculated for 20%, 50%, and 80% of saved inpatient days. Capacity that is repurposed directly leads to savings of the total costs of an inpatient day, i.e. €500 per day saved (Table 1). As capacity is intended to be used in these cases, savings from reducing nurse shifts do not apply.

Validation

Face validity of the calculations was verified through discussions with a major health insurer in the region, industry partners, and within the hospital with the financial director and business controllers.

RESULTS

This section presents the budget impact over five years, as well as the cost of virtual care per patient per day for each scenario.

Scenario 1 - single ward

If virtual care were implemented in a single ward, the number of nurse shifts during the day and the evening could be reduced by 0.5 shifts. Night shifts could not be reduced. The net budget impact is estimated at an additional €580,000 in the first year, followed by €377,500 (SD=€10,900) in subsequent years, resulting in a total net budget impact of €2,090,000 over a period of 5 years. As shown in Figure 1, the majority of additional costs is caused by the service component of virtual care. Variable inpatient day costs provide average savings of €42,320 (SD=€15,850) per year and reductions in nurse shifts provide savings of €116,600. Net costs per patient per day are €303 in the first year and €259 (SD=72) in subsequent years.

Scenario 2 - two wards

Simulating virtual care in two wards, the number of nurse day and evening shifts needed is reduced by 1.5 each, while the number of night shifts needed is reduced by 0.5. This results in cost savings of €419,760 in fixed costs. The net budget impact is estimated at an additional €262,000 in the first year, followed by €37,500 (SD=€28,700) in subsequent years, resulting in a total net budget impact of €410,000 over a period of 5 years. As shown in Figure 1, the majority of additional costs is caused by the service component of virtual care. Net costs per patient per day are €94 in the first year and €17 (SD=€10) in subsequent years.

Scenario 3 - hospital wide implementation

Extrapolating the results of the effect of virtual care on capacity to the entire hospital shows that the number of nurse day shifts needed is reduced by 17.1 (SD=3.1), evening shifts by 12.9 (SD=2.4), and night shifts by 7.7 (SD=1.5) per year. This results in average cost savings of €4,531,000 per year in terms of fixed inpatient day costs.

The net budget impact is estimated at €474,500 in the first year, followed by €-1,670,000 (SD=€1,249,500) in subsequent years, resulting in a total net budget impact of €-6,206,000 over a period of 5 years. Net costs per patient per day are €11.1 in the first year, and €-55 (SD=€44) in subsequent years.

Scenario 4 - all Dutch hospitals

Implementing virtual care in all Dutch hospitals, the number of nurse day shifts could be reduced by 933, evening shifts by 702, and night shifts by 423. This results in cost savings of €247,457,000 per year in terms of fixed inpatient day costs.

The net budget impact is estimated at €-65,824,500 in the first year, followed by €-94,968,500 in subsequent years, resulting in a total net budget impact of €-445,698,500 over a period of five years, providing virtual care to 2,218,045 patients, for a total of 8,872,180 virtual inpatient days. The macro impact for the Netherlands would thus be -0.1%. Net costs per patient per day are €-37 in the first year, followed by €-54 in subsequent years.

Sensitivity analyses

An overview of the results from sensitivity analyses is provided in Table 3 and Table 4.

If capacity could be repurposed so that it could be used by patients from other wards or other hospitals, costs of virtual care per patient per day in the first year for one hospital ranged from €107 for 20% capacity repurposed to €-31 for 80% capacity repurposed. In subsequent years, this range was from €81 (SD=€14) to €114.6 (SD=€57.7). For implementation in all hospitals, costs of virtual care per patient per day ranged from €93 to €-90 in the first year, and from €77 to €-107 in subsequent years. The net budget impact in one hospital ranged from €4,569,000 to €-1,346,000 in the first year, and from €2,592,000 (SD=€709,000) to €-3,546,500 (SD=€1,578,000) in subsequent years. For all hospitals, the net budget impact ranged from €165,462,500 to €-160,409,000 in the first year, and from €136,318,500 to €-189,553,000 in subsequent years.

In the worst case scenario only 19% of patients are eligible and length of hospital stay is reduced by 1 day per patient. The costs of virtual care per patient per day in the Netherlands were €100 for implementation in one hospital and €93 for implementation in all 69 Dutch hospitals in the first year. In subsequent years costs per patient per day were €85 (SD=€1) for implementation in one hospital, and €74 for implementation in all Dutch hospitals. The net budget impact was €€2,542,000 for one hospital and €122,095,000 for all hospitals in the first year. Net budget impact in subsequent years was €2,157,500 for one hospital and €96,823,500 for all hospitals.

In the best case scenario 32% of patients are eligible and length of hospital stay is reduced by 3 days per patient. The cost of virtual care per patient per day in the Netherlands in the first year ranged from €-226 to €-228 for all hospitals, and from €-232 (SD=€3) to €-243 in subsequent years. The net budget impact ranges from €-9,692,500 for one hospital to €-505,760,000 for all hospitals in the first year, and from €-7,392,500 (SD=€1,141,500) for one hospital to €-538,675,000 for 78 hospitals in subsequent years.

When the number of telephone contacts per day in virtual care is reduced to one instead of three, the cost per patient per day in the Netherlands ranges from €-55 to €-104 in the first year, and from €−122 (SD=€47) to €–-120 in subsequent years. The net budget impact ranges from €-2,351,000 for one hospital to €-184,881,000 for all hospitals in the first year, and from €-3,800,000 (SD=€1,299,000) for one hospital to €-213,262,500 for all hospitals in subsequent years.

DISCUSSION

Replacing in-hospital care with virtual care does not directly lead to cost savings. This is mainly due to the fact that the virtual care service, in this case remote vital signs monitoring with three daily telephone contacts, apart from investments in IT infrastructure, requires additional telenurses to be available 24/7. Despite reductions of in-hospital nurse shifts, the additional costs of telenurses outweigh the savings made, until sufficient scale is reached. Although the two wards that were used as a basis for the analysis showed a level of utilization that enabled nurse shifts to be reduced relatively quickly, this was insufficient to result in cost savings. In the base case we start seeing savings over a period of five years once virtual care is implemented in the whole hospital. Employing a Greenfield strategy, in this case involving all Dutch hospitals, does not show a much lower cost per patient per day than implementing virtual care in one hospital (Table 3, Table 4). This indicates that the cost floor can be reached with fewer participating hospitals. In the best case scenario, if virtual care is implemented in all Dutch hospitals, cost savings would be €538,675,000 per year. These cost savings will not reduce healthcare expenditure with considerable impact, though, as the macro impact would be approximately -0.1% of the total healthcare expenditure of the Netherlands. It must be noted, however, that we did not include indirect costs such as coordinating virtual care between all hospitals, relationship management, or redesign of healthcare pathways. Especially when implemented at the scale of an entire country, these costs may have a significant impact on the savings that can be realised, which could reduce the macro impact to below -0.1%. As such, if the goal is to save money, it is questionable whether this is the approach that should be taken. Since the approximately 1 million bed days that could be saved under the assumptions in the base case equate to saving around 4000 beds (at 70% utilisation), it may instead be more interesting to consider virtual care as a way of increasing hospital capacity at relatively low cost.. Our findings contradict those of communications from industry and prior research, which often found cost savings, also at smaller scales. In fact, only one prior study, also conducted in the Netherlands, was found to report an increase in costs.[20] Studies reporting cost savings often assumed that inpatient hospital day costs are entirely variable,[21-23] which is in contrast to the finding in this study that inpatient hospital day costs consist of a fixed component (84%) and a variable component (16%). Additionally, some studies reporting cost savings did not account for costs related to the intervention,[9,11] while even implementation of virtual care in only one ward costs €728,000 in the present study. Lastly, it is important to note that the case mix of diagnoses per hospital does not easily allow for a general or large scale reduction of staffs and wards, as digital services also require dedicated infrastructure and staffing; reductions mostly need to be specified per patient group.

This study must be interpreted within the context of several assumptions. First, it is not known with certainty which or how many patients are eligible for early discharge, as this is not common practice. Two eligible patient groups from different wards were identified based on expert opinion. The proportions of eligible patients relative to the total number of patients treated in these wards informed our analysis (19% to 32% eligibility). Moreover, it is assumed that remote continuous monitoring devices combined with telephone or video contacts is equivalent to in-hospital care in terms of health outcomes. While health outcomes in chronic conditions such as heart failure and Chronic Obstructive Pulmonary Disease (COPD) are generally affected positively,[24,25] little research has been done in directly post-operative or comparable patient populations from a case mix perspective. Nevertheless, the intervention in this case is of such short duration that improved health outcomes cannot realistically be expected. Furthermore, the Greenfield analysis is a linear extrapolation of the findings based on data of a large teaching hospital. In reality, the results may well differ for other types of hospitals, as differences in the number of patients treated per day and length of stay between hospitals, were not taken into account. Our hospital is, however, one of the larger Dutch teaching hospitals and we do not have reasons to believe admission patterns are very different in other hospitals. Furthermore, in the Dutch healthcare system hospitals cannot freely increase the number of patients that are treated, as health insurers impose volume restrictions on all DRGs. To assess the impact of this assumption on the results, we conducted a sensitivity analysis on the base case, where 20%, 50% or 80% of saved inpatient days could be repurposed to lead to cost savings directly, rather than through reducing the number of nurse shifts needed. This analysis showed that being able to repurpose 80% of inpatient days saved would result in a lower net budget impact than the base case. Setting this parameter to 50% instead results in a greater net budget impact than the base case. Break-even between the two is likely to be somewhere in the middle between 50% and 80%. Finally, in the Dutch implementation of DRGs hospitals are reimbursed based on a category of length of stay, rather than being reimbursed for every actual inpatient day. Examples of categories are <5 days, 5-10 days, 11-25 days, and >25 days. If a patient moves from the category 5-10 days to <5 days, savings in in-patient days may thus lead to reduced hospital income.[19] Although there are few examples of successful virtual hospitals and their definitions and scope vary per health system, different financing and market environments may lead to different degrees of impact.

This study also has several strengths. First, the cost of inpatient days was deconstructed to determine to what extent it consists of variable costs. Second, we used capacity calculation to establish the amount of fixed costs that could be saved. Third, we explored the effect of various levels of scale on budget impact.

An important implication of the results of this study is that it is essential for the success of virtual care's potential for cost savings that it is implemented at sufficient scale. Furthermore, it is notable that limiting active involvement of health professionals in virtual care also makes cost savings more achievable. If the monitoring process can be automated, and health professionals need only take action when there is clinical necessity, costs can be reduced by an amount comparable to repurposing 80% of saved inpatient days. Validated algorithms which can detect or even predict deterioration in patients' health status must therefore be developed. Another possibly interesting avenue for future research is to investigate how early discharge can affect waiting lists, as well as optimize throughput from the Emergency Department and Intensive Care Units to general and specialty wards through improved bed availability. Finally, it is important to consider that with virtual care, health professionals are responsible for more patients than with usual care, and increasingly have to deal with technology and data. It is conceivable that these factors influence health professionals' attitude towards their work and their well-being, as their professional environment is changing considerably. The aspect of digitalization of the professional environment merits further research.

CONCLUSIONS

Virtual care using telemonitoring of patients that are currently admitted to the hospital can save money, provided it is deployed at sufficient scale, designed to minimize time spent by health professionals, or the costs of the technology are considerably reduced. Presently, in many European countries with fully or partly capitated budget systems, the financial situation of hospitals might even suffer when venturing into virtual care for postoperative and comparable categories of patients if the aforementioned aspects are not taken into account, as a result of higher costs and lower incomes.

Author affiliations
[1] Rijnstate Research Center, Rijnstate Hospital, Arnhem, The Netherlands
[2] Department of Health Technology and Services Research, Faculty of Behavioural, Management, and Social Sciences (BMS), Technical Medical Centre, University of Twente, Enschede, The Netherlands
[3] Executive Board, Rijnstate Hospital, Arnhem, The Netherlands
[4] Division of Psychosocial Research and Epidemiology, Netherlands Cancer Institute, Amsterdam, The Netherlands; Chairman Executive Board at Rijnstate Hospital, Arnhem, The Netherlands.

Acknowledgement The authors thank Eric Hazebroek and Steven van Sterkenburg for providing input from a clinical perspective; Ron van Kuilenburg, Nicole Hijnen, Murk Westerterp, Ton van Veen, Nicky Nillesen, and Laura Kooij for their critical evaluation of the budget impact calculations; as well as Paul Joustra for providing input on the capacity calculations.

Contributorship GMP and WHvH had an equal role in the conceptualization of this study, with support from CJMD. GMP took the lead in data curation, formal analysis, developing the methodology, visualizing the results, and writing the original draft. WHvH and CJMD had an equal role in supervision of the research and reviewing the original draft, and both supported visualization of the results. WHvH acquired the funding for this study.

Competing interests GMP and CJMD have nothing to declare. WHvH has received non-restricted research grants form Novartis and Agendia BV.

Transparency statement The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported, and that no important aspects of the study have been omitted.

Ethical approval The study was approved by the Insitutional Review Board of Rijnstate Hospital with reference number 2021-1947.

Funding source This study was funded by a non-restricted grant from Menzis, a Dutch insurance company. The funding source was not involved in the design of the study, data analysis, writing of the manuscript, or the decision to submit for publication.

Data sharing statement No additional unpublished data are available.

Captions

Figure 1. Budget impact per year for scenarios 1 and 2

References

1. Centers for Medicare & Medicaid Services. National Health Expenditures 2017 Highlights. Baltimore: Centers for Medicare & Medicaid Services. Retrieved from https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/Downloads/highlights.pdf last accessed: 13-05-2019.
2. Eurostat. Healthcare expenditure by provider, 2015. Luxembourg: Eurostat. Retrieved from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Healthcare_expenditure_by_provider,_2015_(%25_of_current_healthcare_expenditure)_FP18a.png last accessed: 13-05-2019.
3. Gonçalves-Bradley DC, Ili-e S, Doll HA, et al. Early discharge hospital at home. *Cochrane Database of Systematic Reviews*. 2017; Issue 6. Art. No.: CD000356. DOI: 10.1002/14651858.CD000356.pub4
4. Safavi KC, Ricciardi R, Heng M, et al. A Different Kind of Perioperative Surgical Home. *Annals of Surgery*. 2020; 271 (2): 227-29. DOI: 10.1097/SLA.0000000000003417
5. Handley NR, Bekelman JE. The oncology hospital at home. Journal of Clinical Oncology. 2019; 37 (6): 448-53. DOI: 10.1200/JCO.18.01167
6. Aasen L, Ponton IG, Johannessen AKM. Being in control and striving for normalisation: A Norwegian pilot study on parents' perceptions of hospital-at-home. *Scandinavian Journal of Caring Sciences*. 2019; 33 (1): 102-10. DOI: 10.1111/scs.12606
7. Vesterby MS, Pedersen PU, Laursen M, et al. . Telemedicine support shortens length of stay after fast-track hip replacement. *Acta Orthop* 2017; 88: 41–7. DOI: 10.1080/17453674.2016.1256939
8. Haveman ME, Kleiss SF, Ma KF, et al. Telemedicine in patients with peripheral arterial disease: is it worth the effort? *Expert Review of Medical Devices*. 2019; 16(9): 777-86. DOI: 10.1080/17434440.2019.1649595
9. Baker LC, Johnson SJ, Macaulay D, et al. Integrated telehealth and care management program for Medicare beneficiaries with chronic disease linked to savings. *Health Affairs*. 2011; 30: 1689–1697.
10. Vitacca M. Telemonitoring in patients with chronic respiratory insufficiency: expectations deluded? *Thorax*. 2016; 71: 299-301. DOI: 10.1136/thoraxjnl-2015-208211
11. Backman W, Bendel D, Rakhit R. The telecardiology revolution: improving the management of cardiac disease in primary care. *J R Soc Med.* 2010; 103: 442–446. DOI: 10.1258/jrsm.2010.100301
12. McLean S, Chandler D, Nurmatov U, et al. Telehealthcare for asthma: a Cochrane review. *CMAJ*. 2011; 183(11): E733-42. DOI: 10.1503/cmaj.101146
13. Peters GM, Kooij L, Lenferink A, et al. The Effect of Telehealth on Hospital Services Use: Systematic Review and Meta-analysis. *J Med Internet Res*. 2021; 23(9): e25195. DOI: 10.2196/25195
14. Sullivan SD, Mauskopf JA, Augustovski F, et al. Principles of good practice for budget impact analysis II: report of the ISPOR Task Force on Good Research Practices – Budget Impact Analysis. *Value Health*. 2014;17(1):5-14.
15. De Bruin AM, Bekker R, Van Zanten L, Koole GM. Dimensioning hospital wards using the Erlang loss model. *Ann Oper Res*. 2010; 178: 23-43. DOI: 10.1007/s10479-009-0647-8
16. Zorginstituut Nederland. Richtlijn voor het uitvoeren van economische evaluaties in de gezondheidszorg (verdiepingsmodules). [Internet]. 2016 [cited 2020 Jun 30]. Available from: https://www.zorginstituutnederland.nl/binaries/zinl/documenten/publicatie/2016/02/29/richtlijn-voor-het-uitvoeren-van-economische-evaluaties-in-de-gezondheidszorg/Richtlijn+voor+het+uitvoeren+van+economische+evaluaties+in+de+gezondheidszorg+%28verdiepingsmodules%29.pdf
17. Centraal Bureau voor Statistiek. Consumentenprijzen; prijsindex 2015 = 100. [Internet]. 2020 [cited 2020 Jun 30]. Available from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83131NED/table?ts=1593473618202

18. Rijksinstituut voor Volksgezondheid en Milieu. Aantal ziekenhuisbedden en IC-bedden. [Internet]. 2021 [cited 2021 Dec 09]. Available from: https://www.volksgezondheidenzorg.info/onderwerp/ziekenhuiszorg/cijfers-context/aanbod#node-aantal-ziekenhuisbedden-en-ic-bedden
19. Balk AHMM, Davidse W, Dommelen P, et al. Tele-guidance of chronic heart failure pateints enhances knowledge about the disease. *European Journal of Heart Failure*. 2008; 10(11): 1136-42.
20. Giordano A, Scalvini S, Zanelli E, et al. Multicentre randomised trial on home-based telemanagement to prevent hospital readmission of patients with chronic heart failure. *International Journal of Cardiology*. 2009; 131(2): 192-9.
21. Kielblock B, Frye Ch, Kottmair S, et al. Impact of telemetric management on overall treatment costs and mortality rate among patients with chronic heart failure [Einfluss einer telemedizinisch unterstützten Betreuung auf Gesamtbehandlungskosten und Mortalität bei chronischer Herzinsuffizienz]. *Deutsche Meizinische Wochenschrift*. 2007; 132 (9): 417-22.
22. Chen YH, Ho YL, Huang HC, et al. Assessment of the clinical outcomes and costeffectiveness of the management of systolic heart failure in Chinese patients using a home-based intervention. *J Int Med Res*. 2010; 38: 242–252.
23. Kitsiou S, Paré G, Jaana M. Effects of Home Telemonitoring Interventions on Patients With Chronic Heart Failure: An Overview of Systematic Reviews. *JMIR*. 2015; 17(3): e63.
24. Murphy LA, Harrington P, Taylor SJC et al. Clinical-effectiveness of self-management interventions in chronic obstructive pulmonary disease: An overview of reviews. *Chronic Respiratory Disease*. 2017; 14 (3): 276-288. DOI: 10.1177/1479972316687208
25. Kroneman M, Boerma W, van den Berg Met al. The Netherlands: health system review. *Health Systems in Transition*. 2016; 18(2):1–239

Tables

Table 1. Overview of costs.

	Investments		Fixed costs		Variable costs	
	Cost item	Price	Cost item	Price	Cost item	Price
Technology	Relay device	€1150			Biosensor	€120
	Patient license	€520				
	Client license	€130				
	Mobile client license	€170				
Infrastructure	Server hardware	€33,900	Offices*	€1200		
	Software solution	€12,100				
	Access point	€1390				
Service			Telenurse	€65,000	Home visit	€80
			Remote Technical Support	€16,000	Home treatment	€130
					Ambulance transport	€760
Start-up	Project management	€48,400				
	Technical implementation	€20,000				
	External Consultancy	€40,500				
	Education	€25,000				
Inpatient day			Specialists	€30	Materials	€10
			Physician's assistants	€20		
			Nurses	€220	Room and board	€70
			Real estate	€20		
			Overhead	€130		

*Cost is per m^2 per year. All other prices are unit prices and include 21% VAT

Table 2. Overview of assumptions

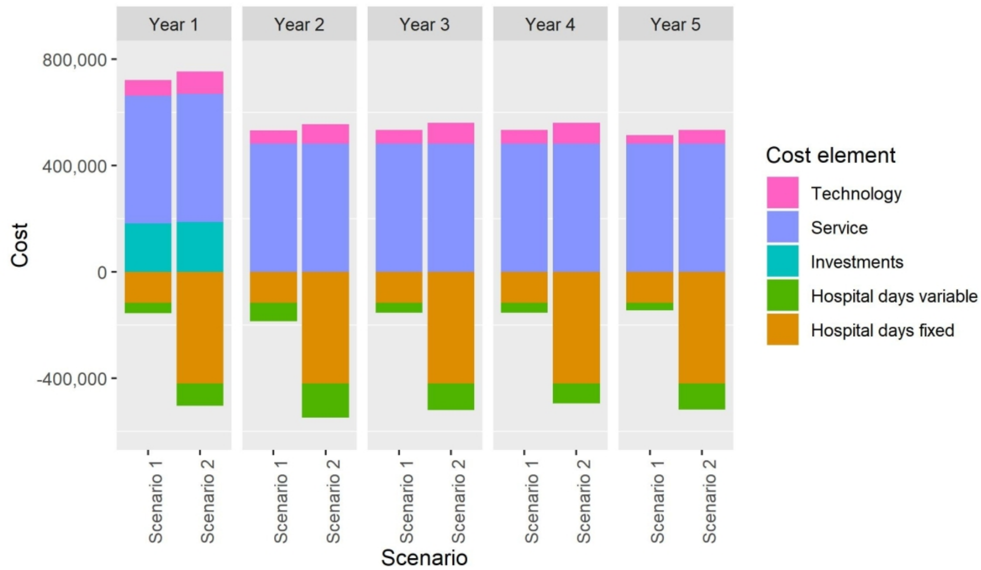
General assumptions
The hospital cannot increase its revenue by performing more surgeries per day, due to restrictions imposed by health insurers
Capacity that becomes available due to early discharge of patients with the biosensor is not used by patients from other wards or hospitals
There is no impact on overhead costs
Reductions in nurse shifts are possible in increments of 0.5 shifts
Nurses are each responsible for four beds during the day, six in the evening, and ten during the night.
Scenario 1
Surgeries for eligible patients can be planned in the morning
Scenario 2
All patients treated for abdominal aortic aneurysm (AAA) or carotid artery pathology are eligible for virtual care
All surgeries for AAA or carotid artery pathology can be planned in the morning.
Scenario 3 and 4
Proportions of patients eligible for virtual care in scenario 1 and 2 translate linearly to hospital-wide scale
Reductions in nurse shifts are linearly related to reductions in hospital bed days
Other hospitals are similar in size to the case hospital

Table 3. Sensitivity analysis for implementation of virtual care in a single hospital

		Year 1	Year 2	Year 3	Year 4	Year 5
Net budget impact	Base case	€474.355	€-2.823.290	€-1.342.786	€-2.020	€-2.462.412
	20% Capacity repurposed	€4.569.241	€2.397.105	€3.259.670	€3.030.186	€1.680.108
	50% Capacity repurposed	€1.611.687	€-1.331.605	€-52.075	€805.791	€-1.331.518
	80% Capacity repurposed	€-1.345.866	€-5.060.315	€-3.363.820	€-1.418.603	€-4.343.144
	Worst case	€2.542.258	€2.164.298	€2.151.054	€2.157.333	€2.156.383
	Best case	€-9.692.469	€-7.864.258	€-8.482.822	€-7.410.863	€-5.811.811
	One telephone contact	€-2.351.096	€-5.046.923	€-3.894.347	€-1.989.368	€-4.269.629
Costs/patient/day	Base case	€11,05	€-83,83	€-36,27	€-1,65	€-97,62
	20% Capacity repurposed	€106,47	€71,17	€88,04	€ 96,25	€66,61
	50% Capacity repurposed	€37,55	€-39,54	€-1,41	€ 25,59	€-52,79
	80% Capacity repurposed	€-31,36	€-150,25	€-90,86	€ -45,06	€-172,18
	Worst case	€99,79	€84,17	€86,58	€ 85,31	€85,60
	Best case	€-225,85	€-233,50	€-229,12	€ -235,39	€-230,41
	One telephone contact	€-54,78	€-149,85	€-105,18	€ -63,19	€-169,27

Table 4. Sensitivity analysis for implementation of virtual care in all 69 Dutch hospitals

	Net budget impact Year 1	Net budget impact Years 2-5	Cost/patient/day Year 1	Cost/patient/day Years 2-5
Base case	€-65.824.447	€-94.968.481	€-37,10	€-53,52
20% Capacity repurposed	€165.462.691	€136.318.657	€93,25	€76,82
50% Capacity repurposed	€2.526.775	€-26.617.259	€1,42	€-15,00
80% Capacity repurposed	€-160.409.142	€-189.553.176	€-90,40	€-106,82
Worst case	€122.094.790	€96.823.446	€92,64	€73,46
Best case	€-505.760.201	€-538.675.005	€-227,83	€-242,66
One telephone contact	€-184.881.086	€-213.262.360	€-104,19	€-120,19



Budget impact per year for scenarios 1 and 2

177x104mm (300 x 300 DPI)

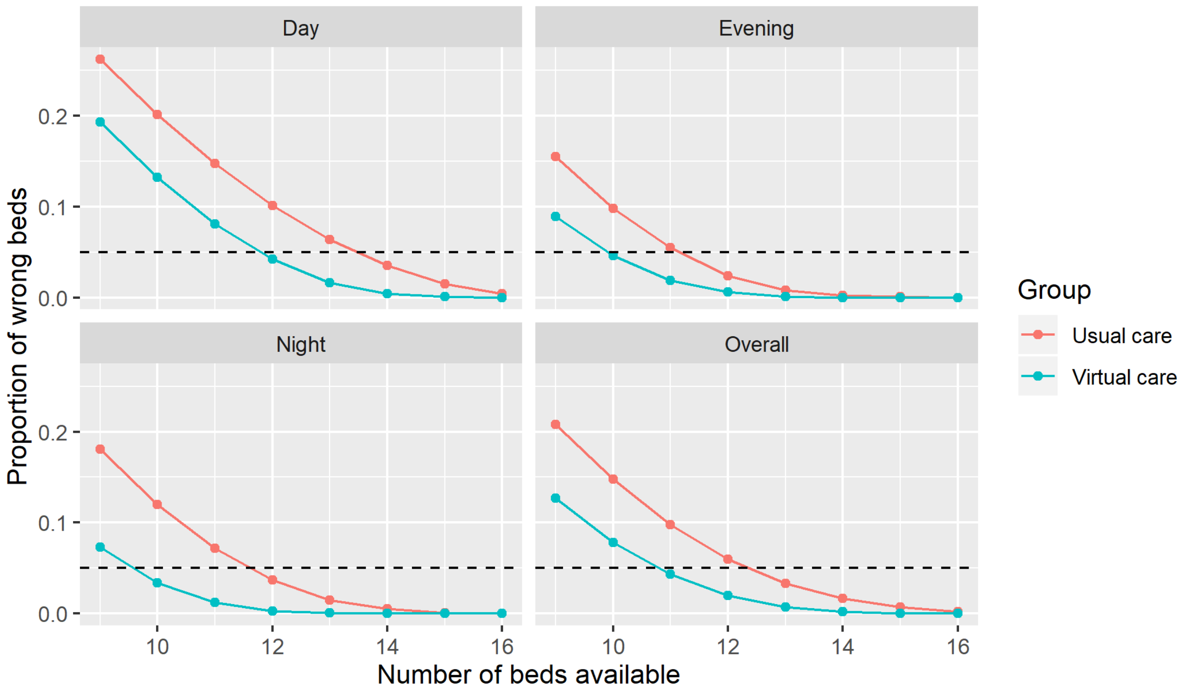
Appendix A: Capacity estimation

A pragmatic approach to capacity estimation is taken, using the method employed at the local hospital. This method requires admissions data of a ward for one year and the number of beds available to that ward as input. It then finds the number of patients treated by a ward for every hour of every day over the previous year, as well as the number of patients admitted to a different ward than the one providing treatment, i.e. the number of patients in “wrong beds”. Patients end up in a wrong bed when all beds available to the treating ward are full. The proportion of patient time in wrong beds is computed to determine whether the number of beds available to the ward is appropriate. In this case, the maximum acceptable proportion of wrong beds is set to 0.05. Finally, the number of beds available to a ward is iterated to find the minimum number of beds needed to stay within the maximum acceptable proportion of wrong beds.
The hospital already works at reduced capacity in the months July and August, resulting in inaccurate capacity estimates for the rest of the year. Therefore, these months are excluded from the capacity estimation. Furthermore, for model stability, i.e. to ensure that the year does not start with an empty ward, admissions data for the last two months of the year before the year under investigation are also needed.
Finally, the reduction in number of beds needed is translated to a savings in nurse shifts by dividing the number of beds needed by the number of beds that can be served by a single nurse. During day shifts, one nurse serves 4 beds, during evening shifts one nurse is responsible for 6 beds, and during night shifts a single nurse serves 10 beds.

Scenario 1
As shown in Appendix Table 1, 13 beds are needed to restrict the number of bariatric surgery patients in wrong beds to an acceptable level with usual care, whichis reduced to 11 with virtual care.Therefore, with usual care, 3.5 nurse shifts are needed, while only 3 nurse shifts are needed with virtual care, resulting in a reduction of nurse shifts by 0.5.
As shown in Figure 1, the number of beds needed is reduced by two for each shift: from 14 to 12 during the day, and from 12 to 10 in the evening and the night. For evening and night shifts this does not result in a reduction in the number of nurse shifts needed, however. In the evening this is not possible because the number of beds is not sufficiently reduced, and during the night it is impossible because the ward already works with 1.5 nurse shifts, which is the minimum number of nurse shifts that should be available at any given time.

Appendix Table 1. Number of days bariatric surgery patients spend in wrong beds per year, based on number of beds available overall

	Usual care (3075 Bed days)		Virtual care (2660 Bed days)	
Beds	Wrong bed days	proportion wrong beds	Wrong bed days	proportion wrong beds
16	4,9	0,002	0	0,000
15	20,6	0,007	1,0	0,000
14	51,2	0,017	4,9	0,002
13	102,7	0,033	19,2	0,007
12	184,7	0,060	52,8	0,020
11	302,6	0,098	113,3	0,043
10	455,0	0,148	206,9	0,078
9	640,5	0,208	336,8	0,127

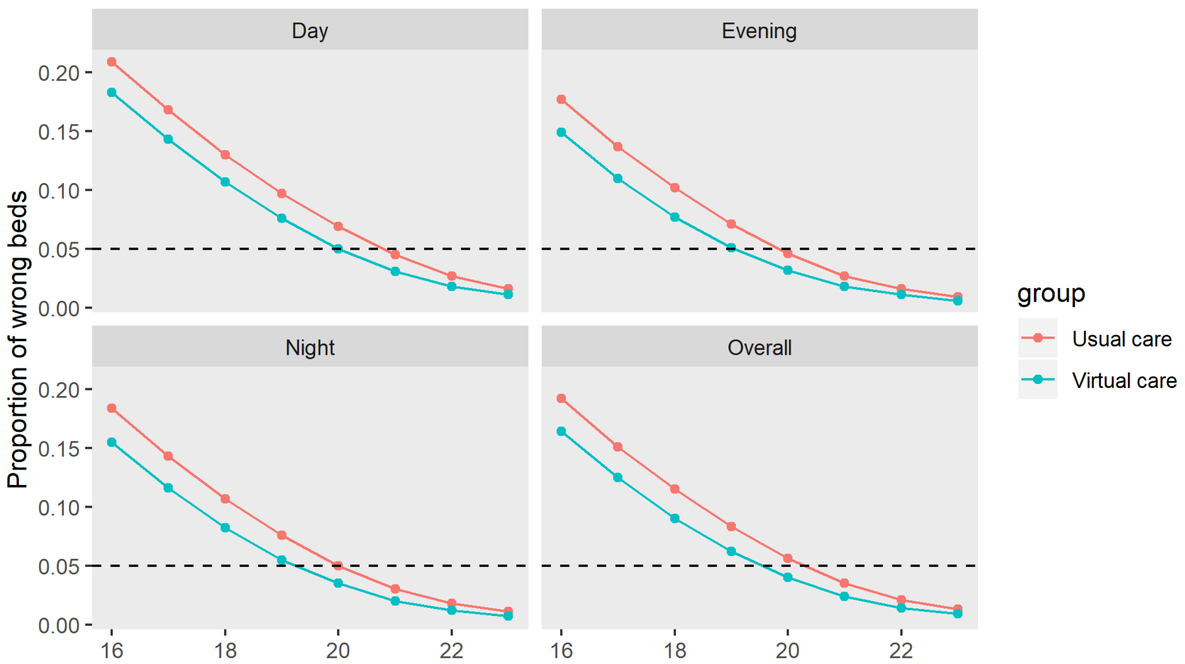


<u>Scenario 2</u>

As shown in Appendix Figure 2, 21 beds are needed to restrict the number of vascular surgery patients in wrong beds to an acceptable level with usual care, which is reduced to 20 with virtual care. Therefore, with usual care, 5.5 nurse shifts are needed, while only 5 nurse shifts are needed with virtual care, resulting in a reduction of nurse shifts by 0.5.

As shown in Figure 1, the number of beds needed is reduced by one for day and evening shifts: from 21 to 20 during the day, and from 20 to 19 in the evening. The number of beds needed during the night shift stays the same at 20. For the evening shift this does not result in a reduction in the number of nurse shifts needed, however, because the number of beds is not sufficiently reduced.

Appendix Figure 2. Number of beds needed for the vascular ward per shift with and without virtual care



Scenario 3

The weighted average percentage of eligible patients is 19.36%, resulting in 6400 eligible patients, and the weighted average reduction in length of stay is 1.20 days, resulting in savings of 7696.8 inpatient days. The weighted average number of saved inpatient days needed to reduce the number of nurse shifts by 1 is 619.28 days. Therefore, the number of nurse day shifts could be reduced by 7696.8 / 619.28 = 12.43 = 12 nurse shifts. Since nurse shifts during the evening and night could not be reduced in either scenario 1 or 2, it is assumed that this scenario also does not allow for this.

Reporting checklist for economic evaluation of health interventions.

Based on the CHEERS guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the CHEERSreporting guidelines, and cite them as:

Husereau D, Drummond M, Petrou S, Carswell C, Moher D, Greenberg D, Augustovski F, Briggs AH, Mauskopf J, Loder E. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement.

		Reporting Item	Page Number
Title			
	#1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	1, 3
Abstract			
	#2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions	3
Introduction			
Background and objectives	#3	Provide an explicit statement of the broader context for the study. Present the study question and its relevance for health policy or practice decisions	4
Methods			

Target population and subgroups	#4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	6
Setting and location	#5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	4, 7
Study perspective	#6	Describe the perspective of the study and relate this to the costs being evaluated.	5
Comparators	#7	Describe the interventions or strategies being compared and state why they were chosen.	5, 6, Appendix A
Time horizon	#8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	5
Discount rate	#9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate	n/a
Choice of health outcomes	#10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed	n/a
Meaurement of effectiveness	#11a	Single study-based estimates: Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data	n/a
Measurement of effectiveness	#11b	Synthesis-based estimates: Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data	n/a
Measurement and valuation of preference based outcomes	#12	If applicable, describe the population and methods used to elicit preferences for outcomes.	n/a
**Estimating resources and costs **			
	#13a	Single study-based economic evaluation: Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs	n/a

Methods

Estimating resources and costs	#13b	Model-based economic evaluation: Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	5-7, Appendix B
Currency, price date, and conversion	#14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	6
Choice of model	#15	Describe and give reasons for the specific type of decision analytical model used. Providing a figure to show model structure is strongly recommended.	n/a
Assumptions	#16	Describe all structural or other assumptions underpinning the decision-analytical model.	6, 7
Analytical methods	#17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	7

Results

Study parameters	#18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	6, 7
Incremental costs and outcomes	#19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	n/a
Characterising uncertainty	#20a	Single study-based economic evaluation: Describe the effects of sampling uncertainty for the estimated incremental cost and	n/a

		incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	
Characterising uncertainty	#20b	Model-based economic evaluation: Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	8
Characterising heterogeneity	#21	If applicable, report differences in costs, outcomes, or cost effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	n/a
Discussion			
Study findings, limitations, generalisability, and current knowledge	#22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	9, 10
Other			
Source of funding	#23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support	2, 11
Conflict of interest	#24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations	2, 11

Notes:

- 7: 5, 6, Appendix A
- 13b: 5-7, Appendix B This checklist was completed on 29. March 2021 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai