

Economic Evaluation of Telemedicine: Review of the Literature and Research Guidelines for Benefit–Cost Analysis

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Abstract

Telemedicine programs provide specialty health services to remote populations using telecommunications technology. This innovative approach to medical care delivery has been expanding for several years and currently covers various specialty areas such as cardiology, dermatology, and pediatrics. Economic evaluations of telemedicine, however, remain rare, and few of those conducted have accounted for the wide range of economic costs and benefits. Rigorous benefit–cost analyses of telemedicine programs could provide credible and comparative evidence of their economic viability and thus lead to the adoption and/or expansion of the most successful programs. To facilitate more advanced economic evaluations, this article presents research guidelines for conducting benefit–cost analyses of telemedicine programs, emphasizing opportunity cost estimation, commonly used program outcomes, and monetary conversion factors to translate outcomes to dollar values. The article concludes with specific recommendations for future research.

Key words: *telemedicine, economic evaluation, benefit–cost analysis*

Introduction

One of the most pressing challenges facing the United States today is the increasing cost of healthcare. Public and private organizations are actively seeking strategies to slow the growth of healthcare spending without compromising access, effectiveness, and safety. One such strategy may be found in telemedicine, whereby healthcare providers use telecommunications technology to deliver healthcare services to patients who are remotely located or have limited access to specialty care. Telemedicine has been implemented, for instance, to monitor and care for patients with heart conditions or diabetes through the transmission of echocardiograms for faster expert diagnosis and the frequent monitoring of patients with diabetes or heart failure via telephone or videoconference. In dermatology and ophthalmology, videoconferencing and image transmission allow for long-distance consultations with experts for faster diagnosis and treatment while also avoiding travel costs for patients and their families. Although telemedicine programs have expanded faster in advanced economies, the use of telemedicine in developing countries, particularly in remote and rural areas, has great potential to increase access to healthcare and technology, enhance knowledge transfer to local practitioners, and make healthcare more affordable for impoverished populations.

Although telemedicine programs were initiated several decades ago and have experienced rapid growth ever since, the rigorous economic evaluation of such programs remains rare. This research gap has contributed to a lack of reliable, comparative economic data for policy makers, program administrators, and other stakeholders. In particular, a dearth of benefit–cost analyses, among other classes of

economic evaluation studies (e.g., cost–utility analysis and cost-effectiveness analysis), stands out in the telemedicine literature.

Given this background, the objective of the present article is to provide research guidelines for conducting benefit–cost analyses in telemedicine, with a particular emphasis on converting program outcomes into monetary values. First, the article briefly describes economic evaluation methods and reviews their use in telemedicine, and identifies current research gaps, limitations, and challenges. Second, we present standardized guidelines for benefit–cost analyses in telemedicine, including the estimation of economic (i.e., opportunity) costs and the application of monetary conversion factors to translate program outcomes into dollar values. Finally, we offer conclusions and provide specific recommendations for future research.

Materials and Methods

ECONOMIC EVALUATION OF TELEMEDICINE

A comprehensive review of the literature suggests that there is a lack of concrete evidence with which to fully assess the economic impact of telemedicine. The absence of a cohesive body of rigorous economic evaluation studies is a key obstacle to the widespread adoption, proliferation, and funding of telemedicine programs.^{1–3} Hersh and colleagues² argue that limited information on the efficacy and costs of telemedicine is a key obstacle for the coverage and reimbursement of telemedicine services by most insurance providers. Bashshur and colleagues⁴ attribute the dearth of rigorous economic studies to the multidimensionality of telemedicine, the lack of funding for large-scale programs, experimental problems (e.g., multi-outcome interventions, delayed and unintended effects), and technological issues related to rapid improvement in technologies and their application to telemedicine. In addition, it can be difficult to build a cohesive body of evidence when some of the lessons and conclusions derived from economic evaluations of telemedicine programs can lose validity in a relatively short period of time (e.g., due to the rapid and continuous decline in equipment prices).

BRIEF OVERVIEW OF ECONOMIC EVALUATION METHODS

Three of the most common economic evaluation methods are cost analysis, cost-effectiveness analysis, and benefit–cost analysis. What follows is an overview of each of these techniques. For a detailed description of these and additional methods of economic evaluation in healthcare, see Drummond and colleagues.⁵

Cost analysis. This type of economic evaluation identifies the resources used to deliver the services of a specific program and then values the associated opportunity costs. Economic or opportunity

costs refer to the value of the next best alternative foregone for the use of the resources. A common type of cost analysis is cost-minimization, whereby the costs of a program are compared to the costs of alternative methods of service delivery under the assumption that both approaches result in similar outcomes. Although cost analyses are a good starting point common to all economic evaluation methods, they exclude program outcomes from the analysis, thus limiting the information available to decision makers when deciding which programs should be implemented or expanded.

Cost-effectiveness analysis. Cost-effectiveness analysis (CEA) is a more inclusive economic evaluation method in that it considers both costs and outcomes of a program. Specifically, it compares the economic costs of a program with a nonmonetary outcome such as years of life gained or avoided illnesses, and the findings are generally expressed as cost per unit of outcome. Even though CEA is superior to a simple cost analysis, it poses an important drawback in that it limits the evaluation to a single outcome.

Benefit–cost analysis. Benefit–cost analysis (BCA) is the most comprehensive type of economic evaluation and allows the study of interventions with multiple outcomes. It compares the economic costs and monetized economic benefits of a program to determine whether a program is economically justified and better than alternative uses of the same resources.⁵ Since the costs and benefits of a program are expressed in a common monetary unit (e.g., dollars), BCA makes possible the direct comparison of programs with disparate outcomes. Therefore, to conduct a BCA, a first step is to clearly identify all of the relevant economic costs and outcomes of a program. Second, the economic benefits of a program are calculated by converting the outcomes into monetary values using reliable monetary conversion factors. This article provides detailed guidelines on how to monetize telemedicine outcomes. Once the economic costs and benefits have been estimated (in constant dollars and discounted to account for the present value of future costs and benefits), the net benefit (total economic benefit minus total economic cost) and the benefit–cost ratio (total economic benefit/total economic cost) are calculated. A positive net benefit and a benefit–cost ratio larger than 1 indicate that the economic benefits are larger than the economic costs, which suggests that the program is worth implementing from a societal perspective.

REVIEW OF ECONOMIC EVALUATION METHODS IN TELEMEDICINE

A review of the literature shows that cost analysis is usually the main focus of most economic evaluations of telemedicine. Although

widely employed in economic evaluations of telemedicine, cost analysis alone is significantly limited because it does not incorporate the outcomes or economic benefits of the telemedicine program. Whitten and colleagues⁶ review over 600 articles addressing the costs and effectiveness of telemedicine and find that fewer than 4% contain a legitimate economic evaluation and that the vast majority of those carry out a simple cost analysis without linking costs to program outcomes. For examples of the application of cost analysis to telemedicine, see Stensland and colleagues,⁷ Bergmo,⁸ Harno and colleagues,⁹ McCue and colleagues,¹⁰ and Persaud and colleagues.¹¹

When both costs and outcomes of telemedicine are considered, CEA is the most common, although not widely used, type of full economic evaluation. Hailey¹² provides a useful commentary on the advantages and challenges of conducting a CEA in telemedicine and emphasizes the areas where future research is needed. As examples of implementation of CEA, Jackson and colleagues¹³ study an ophthalmology program for low-birth-weight infants and find that the cost per quality-adjusted life-year (QALY) gained is \$3,193 with telemedicine and \$5,617 with standard ophthalmoscopy. Other examples of CEA include Agha and colleagues,¹⁴ Johnston and colleagues,¹⁵ Barnett and colleagues,¹⁶ and Smith and colleagues.¹⁷ Since multi-outcome interventions are more common in telemedicine, CEA is informative yet somewhat limited.

BCA is a particularly useful approach in telemedicine, where costs and outcomes can vary widely among specialties due to the fact that each specialty area addresses unique illnesses, follows specific clinical guidelines, employs different telemedicine equipment, and confronts different barriers to access. Few telemedicine evaluations have conducted BCAs, perhaps because this type of evaluation is data intensive and technically sophisticated. Another possible explanation for the shortage of BCAs in telemedicine studies could be the reluctance to assign monetary values to outcomes such as health improvements.^{4,18} Moreover, no established guidelines or systematic procedures have been published on how to undertake BCAs of telemedicine. Although some authors claim to have implemented BCA as part of their economic evaluations, their analyses actually constitute simple cost analysis or CEA (see examples mentioned in Roine et al.,¹⁹ and a general comment in Box 7.2 of Drummond et al.⁵).

RESEARCH GAPS, LIMITATIONS, AND CHALLENGES

Based on a comprehensive review of the literature, we identify some of the main gaps, limitations, and challenges within the economic evaluation of telemedicine programs. *Table 1* provides a summary for easy reference.

Table 1. Research Gaps, Limitations, and Challenges with the Economic Evaluation of Telemedicine

- **Limited generalizability:** Given the heterogeneity of telemedicine programs, most of the results cannot be generalized.
- **Disparate estimation methods:** There is no uniform methodology or guidelines to conduct standardized economic evaluation in telemedicine.
- **Few completed BCAs:** Most economic evaluations focus on program costs, and have not deeply researched a broad range of economic benefits from a variety of perspectives.
- **Lack of RCTs:** The use of RCTs in telemedicine is scant.
- **Lack of long-term evaluation studies:** Long-term studies in telemedicine are rare so that sustainability of these initiatives cannot be studied.
- **Absence of quality data and appropriate measures:** Shortage of appropriate data undermines the quality and reliability of economic evaluation.
- **Small sample sizes:** Telemedicine programs usually involve small samples, thus posing important statistical limitations.

BCAs, benefit-cost analyses; RCTs, randomized control trials.

- **Limited generalizability:** The heterogeneity of telemedicine programs in medical specialty, technology, application, objectives, and cultural and geographical context makes it difficult to generalize the results of a particular economic evaluation. Bashshur and colleagues⁴ highlight the diversity of applications in telemedicine and the difficulty of clearly defining what telemedicine comprises. Hailey and Crowe²⁰ find that the majority of studies analyze one specific type of telemedicine program, such as telepsychiatry or teleradiology. Such specialized analyses are making small incremental contributions to these specialty areas, but they do not contain the scope or depth necessary to facilitate broad conclusions. Hakansson and Gavelin²¹ also emphasize that most existing studies cannot be generalized across the range of telemedicine applications.
- **Disparate estimation methods:** Another overarching issue in the telemedicine literature is the lack of a widely accepted and standardized methodology.²² In addition, the type of economic evaluation approach varies across studies, with some electing to conduct CEA and others performing a simple accounting cost analysis. The diversity in technique further inhibits the ability of policy makers to reach a well-grounded conclusion on the economic effects of telemedicine. Whitten and colleagues⁶ find disparate results in terms of methodological uniformity, design, and technical quality. Moreover, the authors find that none of

the reviewed articles included both costs and benefits of the programs they studied, thus preventing other researchers from making direct quantitative comparisons between alternative interventions.

- Few completed BCAs: Bashshur and colleagues⁴ state that a comprehensive BCA is necessary to fully quantify the range of costs and economic benefits of a large-scale telemedicine program. As mentioned above, however, most economic evaluations of telemedicine have focused on cost analysis or CEA and have not deeply researched a broad range of economic benefits of telemedicine from a variety of perspectives. For example, it would be useful and interesting to estimate from the patient's perspective the economic benefits associated with transportation, leisure time, productivity, and quality of life of a program. Similarly, a provider's perspective should include the economic impact of telemedicine on physicians and support staff. Instead, analysts have focused on one group or on a very limited set of outcomes, thus failing to weigh the full range of costs and benefits. A deeper understanding of these issues would offer critical information to policy makers as they contemplate whether and how to promote such programs. Therefore, for comparison purposes, it would be useful to have dollar-dollar assessments for both the costs and the benefits of telemedicine relative to standard medical practices.
- Lack of randomized control trials (RCTs): In terms of methodology, RCTs are the "gold standard" for the analysis of costs and benefits because they allow for the identification of outcomes solely attributable to the program or intervention under review by comparing the difference in outcomes of rigorously defined treatment and control groups. The use of RCTs in telemedicine remains scant. Reardon¹⁸ affirms that the deficiency of RCT studies is considered a common drawback of the telemedicine literature. Although RCTs are being implemented with increasing frequency in this area, their execution continues to face many challenges; in particular: (1) the small samples that are usually encountered in telemedicine programs threaten both the internal and external validity of the results; (2) the timing and maturity of the programs and the diversity in outcomes can make the evaluation too complex; and (3) the difficulty of randomizing can impede the rigorous selection of experimental treatment and control groups. An additional challenge of RCTs, not exclusive to telemedicine per se, is the ethical issue of withholding a beneficial or superior intervention from those randomly placed in the control group.

- Lack of long-term evaluation studies: The existing literature is also devoid of any long-term economic evaluation studies. Whitten and colleagues⁶ conducted a review of 612 telemedicine articles and found that none of the economic studies presented in these articles examined long-term data. The authors conclude that without long-term analysis, it is not possible to assess either the presence or sustainability of cost-savings attributable to telemedicine.
- Absence of quality data and appropriate measures: The shortage of appropriate data for the economic evaluation of telemedicine is an important challenge. Ruckdäschel and colleagues²³ find that only 20% of all published telemedicine studies contain quantitative data or make reference to the costs of telemedicine. Among these studies, the economic evaluation data vary widely in quality and scope. Kennedy²⁴ shares this view, stating that the lack of appropriate data is one of the main challenges in the economic evaluation of telemedicine.
- Small sample sizes: Sample sizes in most telemedicine studies are relatively small, thus posing numerous statistical challenges and limiting the scope of the possible analyses.

As telemedicine programs develop, the need for rigorous economic evaluation is ever more crucial for a rigorous assessment and sustained expansion of these initiatives. Given the advantages of BCA over other methods of economic evaluation, the next section focuses on BCA and research guidelines for its application in telemedicine.

Results

RESEARCH GUIDELINES FOR BCAS OF TELEMEDICINE

This section aims at providing general research guidelines on how to carry out BCA in telemedicine. For any type of economic evaluation, it is crucial to define the perspective(s) from which the analysis will be undertaken (whether, for example, that of the patient, the provider, the taxpayer, the employer, or private insurers) so as to set boundaries to the analysis. It is important to note that outcomes included as economic benefits from the perspective of a particular group of stakeholders could actually become economic costs or irrelevant when viewed from another perspective. A societal perspective in a BCA includes all stakeholders (being careful not to count transfers, as they represent shifts in resources from one group to the other rather than net changes in societal value) and provides a more comprehensive and comparable analysis of the intervention. For our purposes, we have disaggregated the measures from the client/patient, provider, and other stakeholder's perspectives.

The guidelines for conducting a BCA in telemedicine are covered in the following sections. First, we focus on the estimation of eco-

conomic costs by identifying the most common economic costs of telemedicine programs and proposing additional ones. Second, we examine how to estimate economic benefits by (1) reviewing the most commonly measured outcomes in the evaluation of telemedicine and (2) suggesting ways to convert the outcomes into economic benefits using monetary conversion factors. Obtaining and/or estimating monetary conversion factors is one of the main challenges of BCA and one of the most important reasons why other methods of economic evaluation are often chosen by researchers.

The following sections cite a wide selection of studies, as examples of outcomes and ways to measure and monetize them. The particular methodology and rigor of each study are not addressed, since this is not the main focus of the current article.

ECONOMIC COST ESTIMATION

As previously mentioned, the economic costs of telemedicine have been more thoroughly researched than the economic benefits. Nevertheless, the majority of the existing studies focus exclusively on accounting costs and neglect opportunity costs. Those studies that do address opportunity costs generally address costs related to the client's/patient's travel and consultation time when participating in a telemedicine program. Costs to stakeholders other than the client/patient and the provider are often not accounted for.

This subsection describes some of the economic costs that could result from telemedicine programs from the perspectives of the various stakeholders and provides empirical examples when available (*Table 2* summarizes the key categories).

Client/patient perspective. From the client/patient perspective, participating in a telemedicine program has an opportunity cost in terms of time, either from less time available for work (and possibly loss of earnings), absences from school, or reduced amount of leisure time. In addition, the client/patient can face direct costs such as those incurred through transportation to the telemedicine program facility or out-of-pocket expenses (e.g., consultation). The latter can be particularly important in cases where some or all telemedicine services are not reimbursed by health insurance or where the target population is uninsured, as may be the case in rural or remote areas of developing countries. In the United States, telemedicine services are not always covered by insurance or are only partially covered, or reimbursement is provided only for specific types of programs or geographical areas. Laws and policies for telemedicine coverage are also different for Medicare, Medicaid, and private insurers.²⁵⁻²⁷ Therefore, providers and other stakeholders should carefully review

current reimbursement policies in their location before delivering services that may be restricted or excluded by insurance programs.

Provider perspective. The providers sometimes bear the heaviest economic burden in the implementation of telemedicine programs, since fixed costs such as equipment can often be very high. In some cases, the savings gained from telemedicine initiatives can be tempered by the additional equipment and personnel required to operate a fully functional telemedicine program.

Although we designate costs as fixed and variable, this will certainly differ from program to program. Fixed costs for a program include capital costs of the equipment and technology necessary to run it. A teledermatology program, for instance, installed a video-conferencing unit and video cameras for communication and image transmission to the expert.²⁸ These capital costs are usually annualized and adjusted for the equipment's expected lifetime (see, for example, Bishai et al.²⁹). In many cases the installed equipment is used for other initiatives as well, so only a fraction of the total cost of the equipment needs to be applied to the program's total capital cost estimation (as in Bergmo³⁰). The opportunity cost of the facility or space being used for the program needs to be included as a fixed economic cost even if the accounting cost is zero. Martinez and colleagues³¹ evaluate a telemedicine system in Alto Amazonas, Peru, and include the solar panels for energy supply, the communication equipment (VHF transceiver, radio modem, box, and accessories) and transmitter (a tower with accessories, one VHF antenna, civil works, lightning conductor, coaxial cable, and accessories), and the workstation (laptop, printer, and personal computer).

Variable costs include maintenance (Persaud et al.¹¹ estimate maintenance at 5% of equipment cost), technicians, equipment training, repairs, and telecommunication. Costs also include wages to personnel (general practitioners, specialists, and others) as well as administrative support and supplies. In terms of the setup and support *in situ* of the program, some cases might warrant the inclusion of additional costs such as data collection, travel expenses, local training, and initiatives to promote the program and increase client participation. Martinez and colleagues³¹ include as variable costs the telephone bills, maintenance and repair expenses (including technician's travel expenses), consumables, informatics training for new staff, and wages.

Other stakeholders. An economic evaluation from a societal perspective should consider economic costs to all stakeholders (e.g., employers, taxpayers, private insurers) other than the client/patient and the program. Yet these costs are rarely included in the

Table 2. Common Cost Categories of Telemedicine Programs

CLIENT/PATIENT	PROVIDER	OTHER STAKEHOLDERS
	<i>Fixed costs</i>	
Time costs (employment, classroom time, or leisure) Medical costs (out-of-pocket)	Equipment/technology (capital investment) Depreciation Facilities (office space)	Costs to the taxpayer from expanded coverage and payment of telemedicine services in Medicare and Medicaid Costs to private insurers from expanded coverage and payment of telemedicine services and costs to their clients if, as a result, insurance premiums increase Loss of productivity (work absences) for the employer from workers' participation in a program
	<i>Variable costs</i>	
	Maintenance and repairs Telecommunication costs (connections, etc.) Administrative support and supplies Training Wages to technicians Wages to staff Other expenses	
	<i>Other costs: program setup</i>	
	Travel (transportation, accommodation, per diem; travel time) Training Other expenses (promoting the program, etc.)	

economic evaluation of telemedicine. Although the decision of which stakeholders to include should be program specific, we provide some examples here.

The increase in coverage and payment of telemedicine services could represent a cost to several different stakeholders. For one, the taxpayer bears the cost of expanded coverage in the case of public health insurance programs. Similarly, as private insurers broaden their coverage of telemedicine programs, they incur additional costs that could ultimately be transferred to clients through increases in insurance premiums. However, the extent to which costs to these

stakeholders will effectively rise will depend on how much of these costs are compensated by the gains that telemedicine can offer in terms of, for example, reduced travel and health services utilization.

Finally, employer burden can include productivity costs from worker's absenteeism due to participation in a telemedicine initiative. It is important to note that, although these productivity costs may exist, the following section covers the much larger productivity gains often derived from telemedicine programs because absenteeism usually diminishes from less travel and consultation time of clients/patients.

ECONOMIC BENEFITS ESTIMATION

For the estimation of economic benefits, we (1) review the most commonly measured outcomes in the evaluation of telemedicine programs by discussing examples from the literature, followed by (2) an analysis on how to obtain or derive monetary conversion factors to convert those same outcomes to dollar values.

Select and measure outcomes. To estimate the economic benefits, the first step is to select the relevant outcomes of the program (Table 3). Telemedicine programs, diverse as they are, have distinct applications and objectives depending on the specialty, target population, location, etc. The identification and analysis of outcomes in an economic evaluation therefore need to be in line with each program’s

goals. For instance, the outcomes evaluated in a telemedicine program aimed at increasing access to healthcare or reducing health services utilization will not be the same as those in programs where knowledge transfer (i.e., educational purpose) or medical effectiveness are the main objective. A recent article by Vergara-Rojas and Gagnon³² identifies commonly used indicators relevant to the field of telehomecare; this type of review can be very useful for selecting and standardizing the outcomes included in a BCA in a particular application of telemedicine.

Client/patient perspective. Telemedicine programs are frequently evaluated for their medical effectiveness (e.g., health improvement). Many existing studies focus on single health outcomes such as

Table 3. Common Outcomes of Telemedicine Programs

CLIENT/PATIENT	PROVIDER	OTHER STAKEHOLDERS
<i>Medical effectiveness</i>	<i>Healthcare services and others</i>	<i>Other outcomes</i>
Reduced morbidity Avoided mortality	Reduced length of hospital stay Avoided hospitalizations Avoided hospital readmissions Avoided emergency room visits	Increased productivity of workers (less travel, less illness) Avoided cases of communicable diseases More efficient access to healthcare for special groups (prisoners, etc.)
<i>Employment</i>	Avoided laboratory tests	
Increased earnings	Avoided patient transportation to healthcare facilities Avoided physician office/clinic visits	
<i>Healthcare services and others</i>	Avoided referrals	
Increased access to healthcare Increased health knowledge/ability for self-care Faster/accurate diagnosis and treatment Reduced waiting and/or consultation time Increased medication adherence	Reduced length of consultations Increased medication adherence Increased knowledge transfer among practitioners Increased accuracy and faster diagnosis and treatment Increased patient satisfaction	
<i>Decreased travel</i>	<i>Decreased travel and/or home visits for staff</i>	
Increased employment/leisure/classroom time Avoided travel expenditures: transportation, accommodation, and other expenses Decreased risk of job loss: less time away from work for travel	Increased employment time (productivity) Avoided travel expenditures: transportation, accommodation and per diem	

hemoglobin A1c levels for home blood sugar monitoring interventions (see Hersh et al.² for a list of studies), blood pressure,^{33–35} mortality, and activities of daily living,³⁶ while others concentrate on a group of associated outcomes.

To evaluate medical effectiveness in a more generic and comparable way, some studies calculate QALYs gained, which adjust the duration of the health outcome by a utility score for health status that ranges from 0 (death) to 1 (perfect health). This utility score is obtained from a structured set of questions to patients in which they rank different states of health. In other words, by combining quantity-of-life measures (as the duration of the benefit in years or the expected remaining years of life) and health quality values (from the patient's perception of perfect health), we can convert health outcomes into a quality-of-life score and ultimately into dollar values. A detailed description of the concept, calculation, and assignment of QALYs can be found in Drummond and colleagues.⁵

Barnett and colleagues¹⁶ evaluate a program for veterans with diabetes and measure health across eight dimensions to construct a single health state utility score between 0 and 1 to calculate QALYs and the pre-post program difference in this outcome. Jackson and colleagues¹³ also use QALYs to evaluate the effectiveness of an ophthalmology for retinopathy of prematurity (ROP) initiative (ROP is an ophthalmological condition affecting low-birth-weight infants). Similarly, studies in other areas such as drug-abuse interventions^{37,38} estimate change in QALYs by assigning utility weights to the health problems associated with drug abuse and adding the discounted relative utility declines in each period throughout the duration of the condition.

Besides medical effectiveness, a decrease in travel costs for the patient (and for the caretaker if the patient is a child or a disabled or elderly person) is a widely studied outcome in telemedicine since one of the common objectives is to reach persons in remote areas. Telemedicine has the ability to reduce or avoid costs by utilizing communications technology, which eliminates the need for transportation. In fact, the telemedicine programs with the greatest likelihood of success are those directed at rural areas and special populations (e.g., prison inmates) where transportation costs are a significant concern. Bishai and colleagues²⁹ study the impact of telemedicine on transportation costs by measuring the distance between the referral facility and the community. In addition, most authors calculate and include the avoided accommodation and other daily expenses.^{39–42}

A patient seeking diagnosis and/or treatment for a particular condition may have to forgo wages, leisure time, or classroom time to travel to a referral facility. Most studies indicate that telemedicine decreases the travel time to appointment sites.⁴³ Similarly, waiting

and/or consultation time can be reduced via telemedicine consultations.^{43,44}

Additional outcomes of telemedicine initiatives are health knowledge transfer from the practitioner to the patient, ability to self-care, and medication adherence.^{35,45,46} Advocates of telemedicine also stress its potential to reduce the time required to diagnose efficiently and accurately,^{47,48} and increase access to healthcare. However, some of these outcomes do not have a value in themselves for the client/patient but as means for health improvement. For instance, Friedman and colleagues³⁵ find a greater reduction in diastolic blood pressure among patients whose medication adherence improved from participation in a telemedicine program. Therefore, and as explained below, clearly recognizing this indirect effect and incorporating it in a BCA is a difficult task.

Provider perspective. It is common in the economic evaluation of telemedicine to study the effect of these programs in avoiding excessive and/or unnecessary use of health services. Most studies agree that telemedicine reduces the use of health services such as physician office visits,⁴⁹ emergency department visits,^{49–51} number of hospitalizations,^{51,52} hospital readmissions,^{50,53} home visits,⁵² length of hospital stay,⁵³ use of ambulance services,⁴⁷ number of referrals,³¹ duration of consultations, number of laboratory tests, and avoided transfers/evacuations.^{54,55}

Medication compliance and faster/accurate diagnosis and treatment, which were mentioned above as means for health improvement, can also have benefits through the reduction of healthcare utilization. For instance, reduced transfers or referrals, fewer physician office visits, reduced hospitalization rates, or fewer emergency room visits can be relevant outcomes indirectly derived from medication adherence or timely diagnosis and treatment. Sokol and colleagues⁵⁶ studied the impact of medication adherence on healthcare utilization and costs and found that hospitalization rates were significantly lower for patients who complied with their medication regimen. Similarly, telemedicine programs can reduce healthcare utilization through early detection of a condition, timely treatment, and the avoided need for further tests. Mulholland and colleagues⁴⁷ studied the diagnosis of neonatal congenital heart defects using telemedicine and found that an urgent and potentially dangerous transfer was avoided in 74% of the cases.

A telemedicine program can also avoid travel-related costs for the program's staff. These include money spent on transportation, accommodation, and per diem. A reduction in travel time or home visits has the additional benefit of increasing staff productivity. Travel time is calculated by estimating the average time that it takes the staff

(e.g., via air, private vehicle, bus) to travel from the referral facility to the community (see, for example, Martínez et al.³¹).

Knowledge transfer among practitioners is less straightforward to measure and often not accounted for in economic evaluations of telemedicine. Frequent interaction between local health professionals and the specialist promotes knowledge creation and avoids unnecessary future costs such as patient transfers (and possibly travel costs and specialist fees from the client/patient perspective) in cases where the local practitioner can diagnose or treat the patient directly. Bergmo³⁰ estimates the number of avoided referrals that can be attributed to the transfer of knowledge between the specialist and the general practitioner allowing for the patient to be treated locally. Wootton and colleagues²⁸ measure the benefit of knowledge transfer as the days of training that general practitioners believe they would have required to obtain the same knowledge. The authors also account for savings from avoided referrals due to knowledge transfer including patient and practitioner's time and patient's travel costs.

A provider is usually concerned with client/patient satisfaction for the program's sustainability. Satisfaction and program acceptance surveys are often administered to participants to assess whether they feel that the program has been successful.^{35,41,42,45,57} These surveys often assign certain points to each answer based on a satisfaction scale.

Finally, informal discussions with telemedicine providers suggests that some are concerned about reimbursement opportunities currently and in the future, but the extent of this concern is not well understood at this time.

Other stakeholders. In this article, we categorize those outcomes not included in the client/patient and provider perspectives as other stakeholders outcomes. As an example, a telemedicine program can potentially result in increased productivity through the reduction of work absences (from hospitalizations, consultations, emergency room visits, etc.). This outcome is usually measured as the number of hours/days of lost work time or absences avoided. Stensland and colleagues⁷ study an orthopedic and dermatological care telemedicine program and note a significant reduction in work absences from face-to-face to telemedicine consults. In this case, the benefit of the telemedicine program can be attributed to the employer as avoided loss of productivity from medical leave of the patient or family member.

Another research area that warrants a distinct analysis—and one in which telemedicine has the potential to generate significant savings for taxpayers—is the economics of using telemedicine to treat prisoners. The safety concerns and costs of transporting prisoners to

external specialty care centers are very high and include overtime for the guards accompanying the prisoner, the cost of secure and reliable transportation, and the cost of the visit itself. The Colorado Department of Corrections reported savings of \$450 per telemedicine intervention per inmate, or roughly \$100,000 a year, which includes the avoided cost of transportation and security.⁵⁸

A telemedicine program can also contribute to the prevention and treatment of communicable diseases such as human immunodeficiency virus/acquired immune deficiency syndrome and malaria through remote consultations, education, and monitoring. Finally, as telemedicine programs expand, it would be interesting to study the impact that the potential increased efficiency in the use of health services, together with the costs of setting up a program, has on insurance premiums and other insurance-related expenses.

OBTAIN AND/OR DERIVE MONETARY CONVERSION FACTORS

To estimate the economic benefits of telemedicine programs, clinical and social outcomes must be translated into monetary values using reliable conversion factors. Monetary conversion factors should be as precise as possible in terms of the location and context of the program and, when available, more than one factor should be used for each outcome to allow for sensitivity analyses. This section discusses potential approaches to converting telemedicine outcomes into monetary values. *Table 4* provides a summary.

Client/patient perspective. Attaching a monetary value to health improvement measures requires an estimate of the value of a QALY as well as the value a statistical life. Viscusi and Aldy⁵⁹ provide a comprehensive review of the large number of studies that estimated the value of a statistical life. The authors find that the median value of a statistical life for a prime-age worker in the United States is approximately \$7 million (in year 2000 dollars). The value of a statistical life can be converted into the value of a statistical life-year by dividing it by the average expected remaining years of life. Multiplying the change in QALYs from the program by the value of a statistical life-year yields dollar measures of health improvement associated with avoided morbidity and mortality.

The loss of earnings in hours or days, either from traveling to a referral facility, from work absences due to illness or from job loss due to absences, can be converted into dollar values using context-specific wage estimates collected either from a survey of participants²⁸ or from geographical-specific or national averages, depending on data availability. Stensland and colleagues⁷ use information from the Bureau of Labor Statistics to derive the average

Table 4. Representative Monetary Conversion Factors for Telemedicine Outcomes

A. CLIENT/PATIENT PERSPECTIVE		
OUTCOME MEASURE	UNIT	MONETARY CONVERSION FACTOR
<i>Medical effectiveness</i>		
Reduced morbidity	Change in quality-adjusted life-years (QALYs)	Value of a statistical life-year from the value of a statistical life ^a
Avoided mortality	Change in QALYs	Value of a statistical life-year from the value of a statistical life ^a
<i>Employment</i>		
Increased earnings	Missed hours/days of employment avoided	Average or minimum context-specific wage rate (hourly or daily)
<i>Healthcare services and others</i>		
Increased access to healthcare	Indirect effect: Change in QALYs ^b	Value of a statistical life-year from the value of a statistical life ^a
Increased health knowledge/ability for self-care	Indirect effect: Change in QALYs ^b	Value of a statistical life-year from the value of a statistical life ^a
Faster/accurate diagnosis and treatment	Indirect effect: Change in QALYs ^b	Value of a statistical life-year from the value of a statistical life ^a
Reduced waiting and/or consultation time	Missed hours/days of employment, classroom or leisure time	Average or minimum context-specific wage rate (hourly or daily)
Increased medication adherence	Indirect effect: Change in QALYs ^b	Value of a statistical life-year from the value of a statistical life ^a
<i>Decreased travel</i>		
Increased employment/leisure/classroom time ^d	Missed days or hours of classroom time or work absences avoided; increased available leisure time	Average or minimum context-specific wage rate (hourly or daily)
Money spent on travel: transportation	Distance	Mileage allowance rate or airfare cost to nearest referral facility
Money spent on travel: accommodation	Average cost for overnight hotel stay in referral location	1.00 ^e
Money spent on travel: other expenses	Money spent on local transportation and meals	1.00 ^e

^aViscusi and Aldy⁵⁹ found a median value of a statistical life of \$7 million in 2000 dollars.

^bAs explained in the text, these outcomes and their indirect effect can be very difficult to value with currently available information.

^cThe costs of the caretaker must be added in the case where the patient is a child, disabled or elderly person, for example.

^dValue of leisure time can be calculated using the average or minimum context-specific wage rate as the opportunity cost of leisure.

^eValue already expressed in monetary units.

continued →

Table 4. Representative Monetary Conversion Factors for Telemedicine Outcomes *continued*

B. THE PROVIDER PERSPECTIVE		
OUTCOME MEASURE	UNIT	MONETARY CONVERSION FACTOR
<i>Healthcare services and others</i>		
Reduced length of hospital stay	Days	Context-specific charges per inpatient day in a hospital
Avoided hospital readmissions	Count ^a	Context-specific charges per inpatient day in a hospital multiplied by the average duration of hospital readmissions
Avoided hospitalizations	Count	Context-specific charges per inpatient day in a hospital multiplied by the average duration of hospitalizations
Avoided emergency room visits	Count	Average context-specific charges per emergency room visit ^b
Avoided laboratory tests	Count	Average context-specific charges per laboratory test
Avoided patient's transportation to healthcare facilities	Count	Average context-specific charges for patient transport (ambulance or other)
Avoided physician's office visit	Count	Average context-specific physician's fee ^c
Avoided referrals	Count	Average context-specific specialist fee
Reduced length of consultations	Minutes or hours	Average context-specific physician or specialist's fee (hourly)
<i>Other outcomes</i>		
Increased medication adherence	Indirect effect: avoided use of healthcare utilization: number of emergency department visits, hospitalizations, referrals, etc. ^d	Average context-specific charges for specific healthcare services
Increased knowledge transfer among practitioners	Avoided referrals from knowledge transfer or hours/days of training required to obtain same knowledge plus work time lost (in hours or days) for training	Average context-specific specialist fee (patient avoided costs should be included as well or cost per day of training plus work loss at average context-specific physician's hourly or daily fee)
Increased accuracy and faster diagnosis and treatment	Indirect effect: avoided use of healthcare utilization: number of emergency department visits, hospitalizations, referrals, etc. ^d	Average context-specific charges for specific healthcare services
Increased patient satisfaction	..	1.00 ^e (willingness-to-pay for telemedicine program)
<i>Decreased travel and/or home visits for staff</i>		
Increased employment time (productivity)	Days or hours	Average context-specific wage rate for nurses, physicians and other specialists (hourly or daily)
Money spent on travel: transportation	Distance in kilometers or miles	Car mileage allowance rate or airfare cost
Money spent on travel: accommodation	Average cost for overnight stay	1.00 ^e
Money spent on travel: per diem	Assigned per diem or total daily additional expenses	1.00 ^e

continued →

Table 4. Representative Monetary Conversion Factors for Telemedicine Outcomes *continued*

^aCount refers to frequency/number of times.

^bFor example, French et al.⁶⁰ use the physician fee for the first hour of critical care, evaluation, and management of the unstable critically ill or unstable critically injured patient, requiring constant attendance of a physician. The estimate is obtained from the American Medical Association.

^cFor example, French et al.⁶⁰ use the geographic-specific fee for an office consultation with a new or established patient, which requires a detailed history, a detailed examination, and medical decision making of low complexity. The estimate is obtained from the American Medical Association.

^dAs explained in the text, these outcomes and their indirect effect can be very difficult to value with currently available information.

^eValue already expressed in monetary units.

C. OTHER STAKEHOLDERS PERSPECTIVE		
OUTCOME MEASURE	UNIT	MONETARY CONVERSION FACTOR
Increased productivity of workers (less travel, less illness)	Avoided missed days/hours of employment time	Average or minimum context-specific wage rate (hourly or daily)
More efficient access to health for special groups (prisoners, etc.): transportation costs, staff costs (security guards, etc.)	Distance to referral facility and days/hours of work for staff	Mileage allowance rate for transportation and average daily or hourly wage rate for staff
Avoided cases of communicable diseases	Cases	Average medical costs (health resources utilization and staff) per case, average avoided loss of wages and productivity from illness per case

cost of employee compensation per hour worked in the time period of interest (also see Stensland et al.,⁷ Finkelstein et al.,³⁶ Harper⁴¹). The same approach can be used for leisure time using the rate of pay as the opportunity cost of leisure.

Travel costs avoided are usually calculated using easily accessible information on mileage charges,^{7,28,29,39,41} air fares,^{8,39,40} overnight accommodation, and estimates of daily additional expenses (taxi, meals, etc.) at the location of the referral facility. An hourly context-specific compensation estimate can be used to account for the opportunity cost of time resulting from reduced waiting and consultation times.

Additional outcomes mentioned above are patient's health knowledge, ability for self-care, medication compliance, faster/accurate diagnosis and/or treatment, and access to healthcare. Identifying the indirect effect of these outcomes on health improvement is not easy, making them very difficult to value with currently available information. With more effort and better data, future research could potentially value them for their impact on QALYs.

In cases where market values or reliable alternative monetary conversion factors cannot be determined, the willingness-to-pay (WTP) technique, which estimates the maximum amount an individual is willing to pay for a program or health outcome based on various hypothetical scenarios, can be useful for BCA. The WTP

approach is advantageous because the outcome is already valued in monetary terms, allowing for its direct incorporation into the BCA. Intermediate outcomes such as faster diagnosis and treatment, and access to healthcare might be easier to value using the WTP method as an alternative to the monetary conversion factors proposed above.

Qureshi and colleagues⁶¹ study WTP for telemedicine as compared to in-person clinic visits for dermatology patients with a history of psoriasis or melanoma. Results showed a preference for telemedicine, as participants were willing to pay out-of-pocket fees for this service to reduce waiting times for consultation. Similarly, Bradford and colleagues⁶² estimate WTP for a telemedicine program of patients with chronic heart failure and find that patients are willing to pay for access to telemedicine to avoid the inconveniences of traveling to a doctor's office. Finally, although economic evaluation in telemedicine has generally not focused on valuing patient satisfaction, it might be informative to do so by measuring stated preferences through a WTP approach rather than through survey questions and utility scores.

Despite the clear advantages outlined above, WTP has its limitations. Although WTP can provide an estimate of how much the patient/client values the program or even a specific outcome, it is difficult to separate out the monetary value of specific outcomes such as health improvement, faster diagnosis, health knowledge transfer,

and reduced travel. This limits the applicability of the knowledge yielded by the evaluation of the program.

Shackley and Ryan⁶³ emphasize the inherent differences in WTP between patients with high and low income levels and how these differences could influence the results of the BCA. On the other hand, they argue that the use of relative measures of WTP, as opposed to absolute WTP measures, can overcome this limitation in some cases. For a detailed analysis of the WTP technique, see Drummond and colleagues.⁵

Provider perspective. The cost of healthcare services such as length of hospital stay, number of hospitalizations and readmissions, emergency department visits, laboratory tests, and patient transportation to healthcare facilities can be estimated with context-specific financial information from medical institutions. In the case of the United States, some of these costs can be obtained from the American Hospital Association (AHA) or the American Medical Association. For instance, the AHA estimates that the average hospital-adjusted cost per inpatient day in the United States was \$1,612 in 2006, ranging from \$774 in South Dakota to \$2,455 in Alaska. For outcomes such as physician office visits, avoided number of referrals, and length of consultations, the hourly rate of pay of staff can be used as a monetary conversion factor for the staff's time.

As in the case of some patient/client outcomes, medication adherence and faster/accurate diagnosis and/or treatment can have value for the provider as means for reduced healthcare utilization. Again, valuing the indirect effect of these outcomes for their incorporation in a BCA can be a challenging task.

Avoided travel costs from reduced staff travel can be calculated with accessible estimates for money spent on transportation (airfare or mileage charges), accommodation, and per diem.⁶⁴ As with client/patient travel, a context-specific hourly or daily wage rate for nurses, physicians, and other specialists can be used to account for loss of work time associated with the time spent traveling.

In the case of knowledge transfer, if this outcome is measured by its capacity to reduce referrals,³⁰ avoided referral costs, including specialist and private fees avoided, can be used to convert this outcome into dollar values. Alternatively, Wootton and colleagues,²⁸ who measure knowledge transfer as (1) the days of training required for local practitioners to obtain the same knowledge obtained through contact with the specialist and (2) the days of work lost from attending training, use (1) the average per-day cost of a general practitioner training course and (2) a context-specific hourly rate of pay for the general practitioner to convert knowledge transfer outcomes into dollar values.

Finally, for the case of client/patient satisfaction, the WTP approach discussed above could be better suited to calculating the monetary value of preferences for the program.

Other stakeholders. The value of productivity increases linked to a telemedicine program can be estimated using context-specific wage estimates per hour or day for the worker(s) in question. In the case of treating prisoners, the avoided costs of transferring inmates, including the hourly wage of the security personnel required for this purpose, can be included to estimate the full benefits of telemedicine. Finally, the benefits of telemedicine in avoiding the spread of communicable diseases can be estimated from the avoided cost of the resources used in the treatment of new cases and from the avoided health effects on the population.

Discussion RECOMMENDATIONS

The research gaps identified throughout this analysis provide opportunities for future research on the economic implications of telemedicine. This section offers recommendations to improve the economic evaluation of telemedicine and to encourage researchers to undertake new BCAs. Listed below are several specific suggestions.

- Identify and include both accounting and economic (opportunity) costs of a program from the perspectives of the various stakeholders.
- Identify program outcomes that can be converted into monetary values (see, for example, Rush and Scott⁶⁵). This should take into account the perspectives of the various stakeholders, the programs' objectives, and the maturity of the program.
- Collect current and reliable program data on resource utilization and outcomes.
- Design and evaluate more RCTs, whenever possible. Results based on rigorous RCTs provide a "gold standard" on the impact of telemedicine. If RCTs are not feasible due to small sample sizes, a complex set of outcomes, difficulties in identifying treatment and control groups, or ethical concerns, alternative methodologies should account for the potential bias of non-randomization.⁶⁶
- Obtain and/or derive reliable program-, context-, and specialty-specific monetary conversion factors to estimate the economic benefits of program implementation and operation. Such an effort will contribute to a standardized methodology for BCA in telemedicine evaluation.
- Collect and analyze long-term cost and outcome data to study the sustainability and economic value of telemedicine initiatives.

In addition to the research gaps identified above, there are important challenges that need to be overcome in the design and implementation of economic evaluation in telemedicine. Primarily, the small samples and data limitations often encountered in telemedicine programs limit the scope of statistical analyses and, consequently, the evidence that can be derived from them. An increase in funding for large-scale programs can provide the data needed to undertake rigorous economic evaluations with results that can be generalized and presented to decision makers.

Finally, involving economists early in the design and evaluation of telemedicine programs can help to ensure that the necessary data are collected properly for a comprehensive BCA. To that end, the authors recommend that the American Telemedicine Association (ATA) reach out to health economics professional organizations (e.g., American Society of Health Economists, International Health Economics Association, Academy Health) to explore mechanisms for interaction between the telemedicine and health economics communities. Formal collaborative venues might include joint meetings, embedded health economics panels within ATA meetings (and vice versa), or short courses at the ATA Annual Meeting. In partnership with professional economics associations, building on the framework proposed in this article, the ATA may be able to develop recommended guidelines for defining costs, outcomes, and monetary conversion factors that would lead to improved economic assessment of telehealth's benefits with data from a broad spectrum of programs.

Conclusions

The vast majority of the economic evaluations of telemedicine focus on cost estimate alone, with a few CEAs. Consequently, the full range of economic benefits of telemedicine programs is rarely considered and quantified. The full societal benefits of these initiatives are therefore unknown, making it difficult for decision makers to compare different programs and to make an informed decision as to which are worth implementing from a societal perspective.

This review article has focused on BCA, and particularly on identifying general outcomes of telemedicine programs that can be converted into dollar values. Given the heterogeneity of telemedicine programs in objectives, processes, outcomes, and other areas, some key outcomes may not have been mentioned. Nevertheless, the review and recommendations herein have value for all types of programs to ensure that the necessary information on costs and outcomes is available for economic evaluation, including future research on BCA in telemedicine.

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