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## Impact of a University-Based Outpatient Telemedicine Program on Time Savings, Travel Costs, and Environmental Pollutants

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### ABSTRACT

**Objective:** The objective of this study was to estimate travel-related and environmental savings resulting from the use of telemedicine for outpatient specialty consultations with a university telemedicine program. **Methods:** The study was designed to retrospectively analyze the telemedicine consultation database at the University of California Davis Health System (UCDHS) between July 1996 and December 2013. Travel distances and travel times were calculated between the patient home, the telemedicine clinic, and the UCDHS in-person clinic. Travel cost savings and environmental impact were calculated by determining differences in mileage reimbursement rate and emissions between those incurred in attending telemedicine appointments and those that would have been incurred if a visit to the hub site had been necessary. **Results:** There were 19,246 consultations identified among 11,281 unique patients. Telemedicine visits resulted in a total travel distance savings of 5,345,602 miles, a

total travel time savings of 4,708,891 minutes or 8.96 years, and a total direct travel cost savings of \$2,882,056. The mean per-consultation round-trip distance savings were 278 miles, average travel time savings were 245 minutes, and average cost savings were \$156. Telemedicine consultations resulted in a total emissions savings of 1969 metric tons of CO<sub>2</sub>, 50 metric tons of CO, 3.7 metric tons of NO<sub>x</sub>, and 5.5 metric tons of volatile organic compounds. **Conclusions:** This study demonstrates the positive impact of a health system's outpatient telemedicine program on patient travel time, patient travel costs, and environmental pollutants.

**Keywords:** cost analysis, health economics, telemedicine.

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### Introduction

Telemedicine is frequently regarded as a model of care that is patient-centric and environmentally friendly [1–3]. This model of care can be especially useful for outpatient services when travel distance, time, and cost can be a barrier. From the community and patient perspective, telemedicine allows quality health care to be delivered to patients in communities where in-person subspecialty services are not available, providing support and training for complex medical conditions to local providers, increasing accessibility for families to specialists, and minimizing time away from work and home [1,4–7]. Greater travel distances for services can result in a reduced number of physician visits, increased rates of attrition, and inadequate management of chronic conditions [8]. Telemedicine has been reported as more convenient than traveling to meet a specialist and has resulted in equal or higher patient satisfaction and comparable patient outcomes compared with in-person appointments [9–12], making this a viable and beneficial option of care.

Although research has documented the benefits of telemedicine from the patient's perspective, most studies have evaluated a relatively small sample over a short period of time, and have frequently relied on subjective survey data [4,5,13]. Similarly,

there is limited evidence documenting the environmental impact of reduced travel associated with telemedicine due to relatively small sample sizes and data collected over a short time frame [1,3,14]. To date, there has not been a comprehensive evaluation of the benefits of telemedicine with regard to aggregated travel mileage, travel time, travel cost, and greenhouse gas emission over the life of a telemedicine program. The present study evaluated these outcomes resulting from the University of California, Davis (UC Davis) telemedicine program. Specifically, this study sought to estimate reductions in distances traveled for telemedicine appointments and to calculate the potential reduction in pollution and greenhouse gases associated with the estimated reductions in distances traveled.

### Methods

#### Overview of University of California Davis Health System's Telemedicine Program

Data were evaluated from the University of California Davis Health System's (UCDHS's) telemedicine program, which began

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in 1998 and has conducted more than 48,000 outpatient and inpatient interactive, video-based consultations [15,16]. The program is based out of the UCDHS, located in Sacramento, California, and primarily provides subspecialty consultations in more than 30 clinical specialties and to more than 120 locations across California. The primary focus of the program, consistent with the mission of the University of California, is to provide services that are otherwise unavailable to rural and underserved regions of California.

This retrospective study was designed to compare telemedicine services with hypothetical in-person consultations—under the assumption that patients would have traveled to different clinic sites if telemedicine was not used—with a focus on the patient travel time, patient travel costs, and environmental reduction in pollution and greenhouse gas emissions related to travel. The UCDHS telemedicine database includes demographic and clinical data on all telemedicine encounters, a unique patient identification number, the date of telemedicine consultations, the telemedicine client site visited, and the type of subspecialty telemedicine service provided. The unique patient identification number is linkable to individual telemedicine consultations.

### Selection of Patients

Patients who were California residents and who received an outpatient telemedicine consultation with the UCDHS between July 1996 and December 2013 were included. Patient records were excluded if there was no home address listed or if a particular unique identification number or medical record number associated with the patient consultation was associated with more than one patient with different names and birth dates. Patients in the database who received a telemedicine consultation while serving time in a California Department of Corrections and Rehabilitation facility were also excluded because analyzing this population would not provide insight into savings from a patient's perspective. Telemedicine outpatient services were provided to 157 client sites located in 56 of California's 58 counties (97%).

### Outcome Measures

The four outcome measures for this study were as follows:

1. *Potential travel savings*, defined as the round-trip distance savings arising from the use of telemedicine, calculated as the difference between the distance traveled from the patient's home address to the telemedicine client site and the distance the patient would have traveled for an in-person consultation at the UCDHS.
2. *Potential time savings*, defined as the round-trip time savings arising from the use of telemedicine, calculated as the difference between the time required to travel from the patient's home address to the telemedicine client site and the time that would have been required to travel for an in-person consultation at the UCDHS.
3. *Potential cost savings*, defined as the round-trip cost savings arising from the use of telemedicine, calculated as the difference between the travel costs associated with traveling from the patient's home address to the telemedicine client site and the travel cost associated with traveling for an in-person consultation at the UCDHS.
4. *Potential reduction in pollution and greenhouse gas emissions*, defined as the amount of vehicle emission pollutants that were not emitted as a result of reductions in travel distance, calculated by multiplying per-mile emissions by the travel distance savings.

### Distance Calculation

Distances were calculated by doubling the difference between the one-way distance from the patient's home to the UCDHS and the one-way distance from the patient's home to the telemedicine client site. For addresses listed as a P.O. Box, the ZIP code centroid associated with the P.O. Box address was used as the patient's address. MapPoint 2013 (Microsoft Corporation, Redmond, Wash) was used to geocode patient and telemedicine client site addresses. MP Mileage 2.5 (Winwaed Software Technology LLC, Irving, Texas) was used to calculate the travel distances between patient address and client site as well as the travel distances between patient addresses and the UCDHS. The "quickest route" option was selected instead of "shortest route" or "straight line" for these calculations. To calculate the distance savings, the round-trip mileage to travel to the telemedicine client site was subtracted from the round-trip distance that would be traveled to receive an in-person consultation.

### Travel Time and Travel Cost

The following travel speeds were used to calculate travel time: interstates (motorways) were set at 65 miles per hour (mph); limited access roads were set at 55 mph; other (major) roads were set at 50 mph; arterial (minor) roads were set at 35 mph; and streets were set at 25 mph. These speeds were set in accordance with California standard practices [17]. To calculate the cost of travel, an inflation-adjusted Internal Revenue Service annual standard mileage reimbursement rate was used [18]. Inflation calculations were made using the Bureau of Labor Statistics consumer price index (CPI) Inflation Calculator, setting the buying power equivalence to 2014. This federally established rate is set to reflect the cost of vehicular travel including insurance, fuel, and vehicle maintenance for the miles driven.

### Environmental Impact of Telemedicine

The 2008 Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks report, produced by the U.S. Environmental Protection Agency Office of Transportation and Air Quality, was used to obtain average pollutant values for passenger vehicles [19]. To estimate the environmental impact of the travel distance savings, the emissions per mile driven were multiplied by the total distance savings (Table 1).

### Sensitivity Analysis

For primary analyses, all telemedicine consultation encounters were assumed to have replaced in-person consultations, and that without access to telemedicine, these encounters would have otherwise occurred in-person at the UCDHS. However, it is likely that not all telemedicine encounters actually replaced in-person encounters either because the referring primary care provider would not have made an in-person referral or some patients may have forgone in-person consultations given the inconvenience of travel. Sensitivity analyses were therefore conducted by varying this assumption to determine the impact on results. Specifically, calculations were repeated assuming in-person encounter rates of 90%, 75%, and 50%.

### Statistical Analysis and Human Subjects

Python 2.7 (Python Software Foundation, Wilmington, Del) was used to edit, merge, and link data sets. Microsoft Access 2013 SQL queries were also used for data analysis. Statistical analyses were performed using Microsoft Excel 2013.

**Table 1 – Pollution and greenhouse gas emission standards [18].**

Pollutant	Abbreviation	Emission per mile driven (g)
Volatile organic compounds	VOC	1.034
Carbon monoxide	CO	9.4
Nitrogen oxides	NO <sub>x</sub>	0.693
Particulate matter under 10 microns	PM10	0.0044
Particulate matter under 2.5 microns	PM2.5	0.0041
Carbon dioxide	CO <sub>2</sub>	368.4

### Ethics Approval

The study was approved by the Human Subjects Review Committee at the University of California Davis (institutional review board ID 585558-1).

### Results

In total, the telemedicine database contained data for 38,051 individual outpatient telemedicine consultations. Among these, 16,242 consultations were completed for patients residing in a California Department of Corrections and Rehabilitation facility, which were excluded. Of the remaining, 1599 consultations had a medical record number with no matching address in the UCDHS Medical Records Department database, 677 consultations were not attended (“no-shows”), 68 consultations had a home address outside the state of California, 208 consultations had a home address listed as the UCDHS, 10 consultations had a home address listed as the telemedicine client site, and 1 consultation was not geocoded because of an incorrect address and ZIP code. These 2,563 (11.8%) consultations were excluded, leaving 19,246 consultations, representing 11,281 patients, for analysis. The ZIP code centroid was used to calculate distances for 6787 (19.1%) consultations.

The average one-way distance traveled to a client telemedicine site was  $17 \pm 34$  miles, the average travel time to a client site was  $23 \pm 32$  minutes, and the average travel cost to the client site was  $\$8.85 \pm \$18$ . If the consultations had been conducted in-person and the patients traveled to the UCDHS, the average one-way distance to UCDHS would have been  $156 \pm 109$  miles, the average time to travel to the UCDHS would have been  $145 \pm 94$  minutes, and the average travel cost to the UCDHS would have been  $\$84 \pm \$62$ .

The use of telemedicine for a single consultation resulted in an average round-trip travel distance savings of  $278 \pm 228$  miles ( $P < 0.01$ ), an average travel time savings of  $245 \pm 195$  minutes ( $P < 0.01$ ), and an average cost of travel savings of  $\$150 \pm \$128$  ( $P < 0.01$ ) (Table 2). The median travel distance savings were 284 miles, the median travel time savings were 235 minutes, and the median travel cost savings were \$140. In aggregate, among all consultations during the study period, the use of telemedicine resulted in a total travel distance savings of 5,345,602 miles, a total travel time savings of 8.96 years (or 4,708,891 minutes), and a total travel cost savings of \$2,882,086. The use of telemedicine resulted in a travel-related emissions reduction of 1969 metric tons of carbon dioxide (CO<sub>2</sub>), 50 metric tons of carbon monoxide (CO), 3.7 metric tons of nitrogen oxides (NO<sub>x</sub>), and 5.5 metric tons of volatile organic compounds.

The results of the sensitivity analyses are presented in Table 2. Even if only 50% of telemedicine consultations saved

the patient from traveling to the in-person subspecialty clinic for the consultation, there was still substantial travel, time, and cost savings. Under this assumption, there was an average round-trip travel savings of 139 miles, an average round-trip time savings of 123 minutes, and an average travel cost savings of \$78 per telemedicine consultation conducted.

### Discussion

In this study, the travel savings were calculated as a result of the use of telemedicine in terms of distance savings, time savings, cost savings, and reduction in pollution and greenhouse gas emissions. First, from a patient perspective, telemedicine services resulted in significantly shorter travel distances ( $P < 0.01$ ) to outpatient medical appointments, lower travel cost, and shorter travel time compared with in-person consultations. When considering all outpatient telemedicine encounters, the use of telehealth technologies resulted in a total distance savings of 5,345,602 miles, a total time savings of 8.96 years (or 4,708,891 minutes), and a total cost savings of \$2,882,086 over the 17½ years of the program. Second, telemedicine consultations resulted in a reduction in pollution and greenhouse gas emissions as a result of reduced travel distances. This reduction in CO<sub>2</sub> emissions alone is equivalent to the 1-year emissions for electricity production of 271 average four-member households [20].

This study is one of the few studies that has, on a large scale, objectively examined travel distance, time, and cost savings resulting from the use of telemedicine. These results are consistent with previous studies that have examined the impact of telemedicine on travel from a patient’s perspective [4,5]. A 2002 Arkansas study, which examined 410 patient encounters, found that 92% of sampled patients saved \$32 in fuel costs and 84% of sampled patients saved \$100 in wages [4]. These researchers also found that with the use of telemedicine, 74% of sampled patients saved between \$75 and \$150 in family expenses and were less likely to miss work, resulting in an additional opportunity cost for a medical appointment [4]. A more recent study examined the University of Kansas Medical Center child psychiatry telemedicine program [5]. This study, which included 132 patients and 257 telemedicine consultations, found that telemedicine consultative services resulted in an average mileage cost savings of \$86.13 [5]. In a third study, the University of Kentucky developmental-behavioral pediatrics telemedicine program used geographic information systems to determine a median distance and time savings of 63.8 miles and 66.8 minutes, respectively, for each visit as a result of the use of telemedicine [21].

An earlier evaluation of the UCDHS telemedicine program over a 5-year period by Yellowlees et al. [1] found that the average telemedicine consultation saved approximately 200 miles in one-way travel distance per patient and 4.7 million miles of travel distance. This study, however, calculated cost savings as average fuel costs with an added flat rate of \$200 in vehicle costs. In the current study, the 2014 federally established mileage reimbursement rate was used to more accurately reflect travel cost savings in a 2014 dollar value.

There are several limitations to this study. First, because this study relied on retrospective data, the type of analyses possible were limited. If planned prospectively, more detailed information could have been collected including time taken off work for the appointment resulting in loss of wages, waiting time, appointment duration, and additional costs such as parking. In addition, the study did not include health care provider expenses, which could impact total cost savings offered by telemedicine, such as the cost of telemedicine units (both new units and replacement of outdated or broken units), staff hourly wages (physicians, licensed nurses, IT support staff), Internet usage, and telecommunications connectivity. Previous studies have found that

**Table 2 – Sensitivity analyses across in-person replacement thresholds.**

Savings and Reductions	Replacement thresholds			
	100%	90%	75%	50%
Miles saved				
Average round-trip to the UCDHS	278	250	209	139
Aggregated total	5,345,602	4,811,041	4,009,202	2,672,801
Minutes saved				
Average round-trip to the UCDHS	245	221	184	123
Aggregated total	4,708,891	4,238,002	3,531,668	2,354,446
Dollars saved				
Average round-trip to the UCDHS	150	135	113	75
Aggregated total	2,882,086	2,593,877	2,161,565	1,441,043
Emissions reduction				
Carbon dioxide	1969	1772	1477	985
Carbon monoxide	50	45	38	25
Nitrogen oxides	3.7	3.3	2.8	1.9
Volatile organic compounds	5.5	5.0	4.1	2.8

UCDHS, University of California Davis Health System.

despite these costs to implement and maintain a telemedicine program, from the health care system perspective, telemedicine programs still remain cost-effective [22–24], although this may vary by specialty [25]. If additional data were made available, a more accurate picture of the environmental impact of telemedicine could be obtained.

Second, study calculations were based on the assumption that all consultations resulted in a travel benefit because travel to the UCDHS was avoided. However, patients may have traveled to a different community or tertiary center with similar subspecialty services available or may not have sought treatment if medical centers were located far away. Details regarding potential appointment destination in the absence of telemedicine, however, were not available and using the UCDHS as the single point of reference may have resulted in an overestimate or underestimate of travel savings. It should also be noted that subspecialty appointments conducted using telemedicine represent a very small fraction of the total outpatient subspecialty consultations provided in person at the UCDHS. In addition, travel savings were estimated on the basis that patients traveled to their appointment using their own private transport (when they may have relied on alternative forms of transport such as rail, bus, or plane) and that patients traveled in cars that emitted average Environmental Protection Agency emission values, when in reality, they may have been using sports utility vehicles, trucks, outdated automobiles with higher than average emissions, or newer hybrid vehicles with lower than average emissions. Identifying the patient's mode of transportation would have provided a more accurate assessment of the emissions savings.

The use of electronic records data also presented challenges with regard to data errors, which might have arisen during initial transcription or during the transition to electronic medical records from paper-based records. Perhaps as a result of address errors, some patients were found to have traveled further to their telemedicine appointment relative to their distance to the UCDHS, resulting in a negative distance savings. Similar issues were identified in a telemedicine program evaluation by Soares et al. [21], who attributed negative distance savings to patient preferences. In addition, the monetary amounts for the reduction in environmental load were not included. Future studies should detail the monetary conversion of emission reduction because this would give a more accurate representation of cost reductions offered by telemedicine.

## Conclusions

In conclusion, this study provides evidence of the potential time efficiency, cost efficiency, and positive environmental impact of telemedicine for outpatient consultations, lending support for a long-term environmentally sustainable option to reduce the burden on families when receiving quality health care. Future research is encouraged to consider additional time and financial data, including more accurate alternative care models, out-of-pocket costs, and hourly wages lost from work, as well as cost-benefit analyses of patient outcomes such as wellness and satisfaction for outpatient consultations when telemedicine is used compared with face-to-face appointments. The results from this study confirm that telemedicine can reduce the environmental impact of pollution and greenhouse gas emissions by reducing automobile travel. By increasing the use and distribution of health care services provided using telemedicine, patients and the environment will benefit.

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