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The cost-effectiveness of telestroke in the treatment of acute ischemic stroke

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ABSTRACT

Objective: To conduct a cost-effectiveness analysis of telestroke—a 2-way, audiovisual technology that links stroke specialists to remote emergency department physicians and their stroke patients—compared to usual care (i.e., remote emergency departments without telestroke consultation or stroke experts).

Methods: A decision-analytic model was developed for both 90-day and lifetime horizons. Model inputs were taken from published literature where available and supplemented with western states' telestroke experiences. Costs were gathered using a societal perspective and converted to 2008 US dollars. Quality-adjusted life-years (QALYs) gained were combined with costs to generate incremental cost-effectiveness ratios (ICERs). In the lifetime horizon model, both costs and QALYs were discounted at 3% annually. Both one-way sensitivity analyses and Monte Carlo simulations were performed.

Results: In the base case analysis, compared to usual care, telestroke results in an ICER of $108,363/QALY in the 90-day horizon and $2,449/QALY in the lifetime horizon. For the 90-day and lifetime horizons, 37.5% and 99.7% of 10,000 Monte Carlo simulations yielded ICERs <$50,000/QALY, a ratio commonly considered acceptable in the United States.

Conclusion: When a lifetime perspective is taken, telestroke appears cost-effective compared to usual care, since telestroke costs are upfront but benefits of improved stroke care are lifelong. If barriers to use such as low reimbursement rates and high equipment costs are reduced, telestroke has the potential to diminish the striking geographic disparities of acute stroke care in the United States. *Neurology*® 2011;77:1–1

GLOSSARY

CEAC = cost-effectiveness acceptability curve; **ICER** = incremental cost-effectiveness ratio; **mRS** = modified Rankin Scale; **QALY** = quality-adjusted life-year; **STARR** = Stroke Telemedicine for Arizona Rural Residents; **tPA** = tissue plasminogen activator.

Risk factors for stroke are more prevalent, and specialized stroke treatment options less available, in rural and remote areas than urban areas of the United States.[1,2] IV tissue plasminogen activator (tPA) is an effective treatment for ischemic stroke but must be given in the first 3–4.5 hours after symptom onset.[3,4] Only 2%–4% of ischemic stroke patients receive this treatment, with the lowest percentage in rural areas.[5] Part of the low treatment rate is due to the late presentation of symptomatic patients beyond the treatment window.[6] In rural areas, the problem is compounded by a general lack of stroke specialists with experience using tPA.[7]

Telestroke has emerged as an efficacious method of delivering stroke specialist care to remote hospitals without such expertise on-site, but there are many up-front costs involved with the initial installation of telestroke and training practitioners in its usage. The vast majority of surveyed stroke specialists and emergency physicians think that telestroke can be effective at reducing geographical differences in stroke management and is superior to telephone consultation, but they also cite implementation barriers of training time, cost of installation, and

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Supplemental data at www.neurology.org

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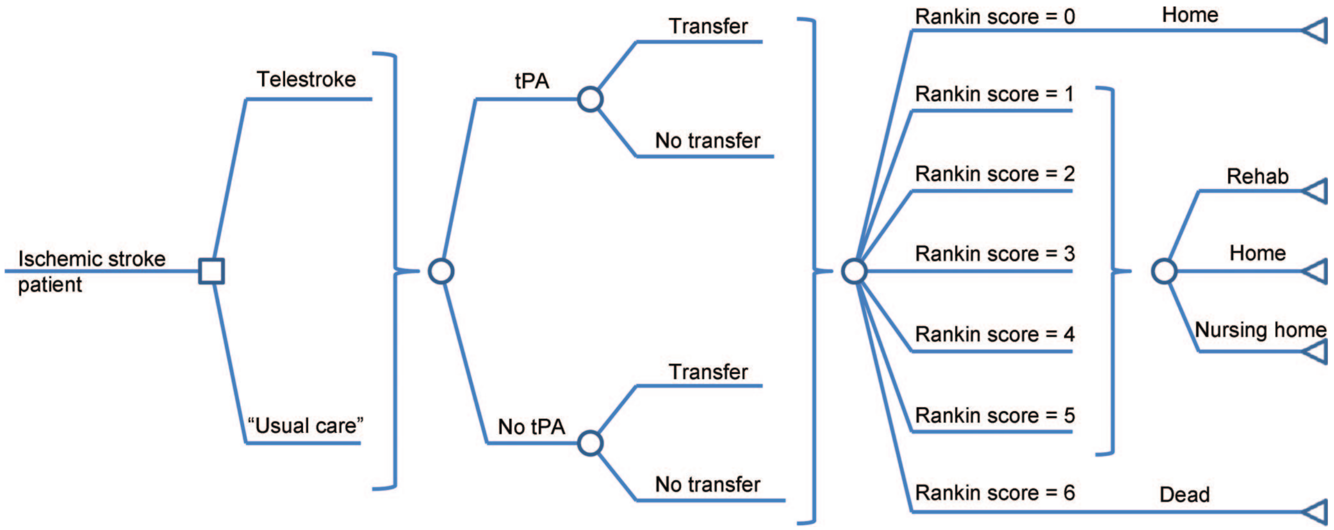
Figure 1 **Cost-effectiveness model**



tPA = tissue plasminogen activator.

reimbursement ambiguity.[8] To our knowledge, the trade-off between the long-term outcomes and short-term costs has not been examined in a US hub-spoke model.[9] Our objective in this study was to conduct a cost-effectiveness analysis of telestroke compared to usual care in order to inform stakeholders regarding acute stroke assessment decision-making and resource utilization.

METHODS

Overview. We constructed a decision analytic model of a hub-spoke telestroke system in order to examine the cost-effectiveness of telestroke compared to usual care. "Hub" refers to the tertiary hospital staffed with stroke specialists, and "spokes" are the community hospitals connected to the hub by telestroke network. In the model, "usual care" refers to a situation in which telestroke capabilities are not available. In other words, spoke hospital physicians must make decisions concerning the care of a patient presenting with stroke without consultation from a stroke expert at a hub hospital. The model was evaluated for both short-term (the first 90 days after incident stroke) and long-term (the patient's remaining lifetime) timeframes.

Model structure. The model, depicted in figure 1, was programmed in TreeAge Pro 2009 (TreeAge Software, Williamstown, MA). We assumed a telestroke system with 8 spokes (range 6–12),[10] each of which had 12 telestroke consults per year (range 6–30), and 1 hub with 4 neurologists (range 3–5) rotating telestroke calls from either the office/hospital (1 shared hospital-based telestroke unit) or the home (each with a home telestroke unit). A base case assumption of 8 spoke hospitals represented an established and mature telestroke network; however, we also explored an assumption of a start-up telestroke network (i.e., 1–3 spokes). Outcomes from the model included costs (total cost being the sum of hospital, tPA, transfer, and caregiver costs) and quality-adjusted life years (QALYs).

Patients entered the model by presenting with acute ischemic stroke at a spoke hospital. Costs and outcomes were compared between facilities either equipped with telestroke capabilities or not. In each type of facility, each patient was given a probability of receiving tPA and being transferred to a hub facility with stroke experts. Upon admission, patients were assigned an initial modified Rankin Scale (mRS) score (table e-1 on the *Neurology*® Web site at www.neurology.org), based on the expected distribution of initial stroke severity.[11] Patients with an mRS score of 0 were assumed to be discharged to home, while those with scores between 1 and 5 could be discharged to home, a rehabilitation facility, or a nursing home. In patients who were discharged to rehabilitation, the score was assumed to improve by 1 point at 90 days[12]; the initial mRS score was assumed to not change in patients who were discharged either to home or to a skilled nursing facility. This 90-day mRS score was carried over to the remaining lifetime for each patient.

Only initial strokes were modeled. Costs were estimated for both the 90-day and lifetime timeframes from a societal perspective. Annual costs depended on mRS score and were converted to 2008 US dollars. Costs and QALYs were discounted at an annual rate of 3%.

Input parameters. The model was populated with input parameters taken from peer-reviewed literature. Where the literature was lacking, parameters were estimated from University of Utah and the Stroke Telemedicine for Arizona Rural Residents (STARR) telestroke networks. These parameters are defined in table 1 and explained here by category.

Event probabilities. We estimated the probabilities of receiving tPA and of being transferred to a hub hospital both for patients who were in telestroke spoke hospitals and for those who were not. The probability that a patient would receive tPA in a telestroke or usual care hospital was taken from published literature,[13–15] and the transfer probabilities were obtained from the STARR network. We also obtained from published literature the probabilities of mRS scores based on whether a patient received tPA or not.[16,17]

First 90 days costs. Costs in the first 90 days were of 2 different types: telestroke infrastructure and patient care costs.

Table 1 **Probability and cost inputs to decision analytic model**

General probability inputs	Telestroke (range)	Usual care (range)
Receiving tPA[13-15]	0.27 (0.22-0.32)	0.03 (0-0.07)
Being transferred if received tPA[15]	0.52 (0.28-0.68)	0.90 (0.80-1)
Being transferred if did not receive tPA	0.28 (0.22-0.35)	0.78 (0.66-0.90)

Probability inputs that vary by mRS

	Probability of mRS (range)[16,17]		Outcomes (range)[26,27]		Discharge probabilities (range)[25]		
mRS	If tPA	If no tPA	Utility values	Years of remaining life	To home	To rehab facility	To SNF
0	0.18 (0.13-0.23)	0.11 (0.06-0.16)	0.85 (0.80-1)	15 (13-17)	1 (1-1)	0 (0-0)	0 (0-0)
1	0.24 (0.19-0.29)	0.16 (0.11-0.21)	0.80 (0.75-0.90)	11.7 (8.4-14.9)	0.81 (0.76-0.86)	0.19 (0.14-0.24)	0 (0-0)
2	0.07 (0.02-0.12)	0.12 (0.07-0.17)	0.70 (0.53-0.75)	8.4 (7.6-9.3)	0.81 (0.76-0.86)	0.19 (0.14-0.24)	0 (0-0)
3	0.13 (0.08-0.18)	0.14 (0.09-0.19)	0.51 (0.45-0.65)	6 (5.2-6.8)	0.81 (0.76-0.86)	0.19 (0.14-0.24)	0 (0-0)
4	0.13 (0.08-0.18)	0.20 (0.15-0.25)	0.30 (0.25-0.55)	3.7 (2.9-4.6)	0.34 (0.29-0.39)	0.48 (0.43-0.53)	0.17 (0.12-0.22)
5	0.06 (0.01-0.11)	0.07 (0.02-0.12)	0.15 (0-0.32)	2.5 (1.4-3.5)	0.17 (0.12-0.22)	0.33 (0.28-0.38)	0.5 (0.45-0.55)
6	0.18 (0.13-0.23)	0.21 (0.16-0.26)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)

General cost inputs

Variable	Costs (range)	Variable	Costs (range)
tPA[38]	$3,430 ($1,715-$6,861)	Training-2 spoke nurses (4 hours)[39b]	$240 ($160-$320)
Transfer[19,20]	$2,446 ($1,223-$4,892)	Training-1 spoke physician (4 hours)[39b]	$360 ($320-$400)
Hospital[21]	$1,764 ($881-$3,527)	Training-1 hub nurse (4 hours)[39b]	$120 ($80-$160)
Annual telestroke hub equipment costs[9a,b]	$16,204 ($12,836-$19,572)	Training-1 hub physician (4 hours)[39b]	$360 ($320-$400)
Annual telestroke spoke equipment costs[9a,b]	$5,309 ($2,654-$10,618)	Annual telestroke spoke fees and maintenance costs[9b]	$4,255 ($2,128-$8,511)
Annual medical costs[24]	$6,659 ($3,329-$13,318)	Annual telestroke hub maintenance costs[9b]	$2,221 ($1,666-$5,056)
No. of telestroke spokes[10]	8 (1-12)	No. of patients per spoke	12 (6-30)

Cost inputs that vary by mRS

mRS	Rehabilitation costs (range)[22]	SNF costs (range)[22]	Daily caregiver costs (range)[23]	Cost multipliers (range)[28]
0	$0 ($0-$0)	$0 ($0-$0)	$0 ($0-$0)	1 (1-1)
1	$9,390 ($4,695-$18,780)	$6,707 ($3,353-$13,414)	$13 ($7-$26)	1 (1-1)
2	$10,732 ($5,365-$21,463)	$6,707 ($3,353-$13,414)	$13 ($7-$26)	1.27 (1.04-1.70)
3	$14,085 ($7,042-$28,170)	$8,049 ($4,024-$16,097)	$28 ($14-$56)	1.94 (1.30-2.50)
4	$16,768 ($8,384-$33,536)	$9,390 ($4,695-$18,780)	$28 ($14-$56)	3.98 (1.70-7.00)
5	$20,122 ($10,060-$40,243)	$10,732 ($5,365-$21,463)	$28 ($14-$56)	6.01 (2.05-10.00)
6	$0 ($0-$0)	$0 ($0-$0)	$0 ($0-$0)	0 (0-0)

Abbreviations: mRS = modified Rankin Scale; SNF = skilled nursing facility; tPA = tissue plasminogen activator.

[a] Assuming 3-year straight line depreciation.

[b] Per facility costs.

Telestroke infrastructure costs for both spoke and hub facilities included equipment, staffing, and training and were taken from the Utah Telehealth Network and STARR experiences.[9] These equipment costs are presented in table 1, per facility. These facility-level costs were incorporated into the model at the patient level using the assumed number of spoke hospitals and number of patients per spoke hospital. We assumed that telestroke equipment lasts for 3 years and that during those 3 years, it undergoes a straight-line depreciation. We assumed that 2 nurses and 1 physician from each spoke hospital would need to be trained by 1 nurse and 1 physician from the hub hospital. Patient care costs were obtained from published literature and included tPA[18] and transfer[19,20] costs (which were independent of stroke severity), as well as hospital,[21] rehabilitation,[22] skilled nursing facility,[22] and daily caregiver[23] costs (which varied by mRS score).

Transferring patients from one facility to another can be done by ground or by air. In assigning a cost for this transfer, we assumed the mean of the ambulance and helicopter transfer costs. As some telestroke networks may utilize predominantly ground or air transportation between the hub and spokes, we also ran the model assuming only ground transportation and, separately, only air transportation. Hospital costs consisted of all those incurred, including emergency department and inpatient physician and nursing fees, room and board, medications (ex-

Table 2 Base case results

A: For established telestroke network (8 spoke hospitals)

Strategy	Cost	Incremental cost	Effectiveness (QALYs)	Incremental effectiveness	ICER
90-Day horizon					
Usual care	$13,872	—	0.119	—	—
Telestroke	$14,274	$402	0.123	0.004	$108,363/QALY
Lifetime horizon					
Usual care	$130,343	—	8.85	—	—
Telestroke	$133,527	$3,184	10.15	1.30	$2,449/QALY

B: For start-up telestroke network (1–3 spoke hospitals)

	ICER	
No. of spoke hospitals	90-Day horizon	Lifetime horizon
1	$480,258/QALY	$3,509/QALY
2	$267,747/QALY	$2,903/QALY
3	$196,910/QALY	$2,701/QALY

ICER = incremental cost-effectiveness ratio; QALY = quality-adjusted life-year.

cluding tPA, which was modeled separately), and diagnostic tests. Caregiver time was assumed to only apply to patients with an mRS score between 1 and 5 and to those discharged to either a rehabilitation facility or home. Patients discharged to home had 90 days of caregiver time; for those discharged to a rehabilitation facility, the caregiver time was calculated as the difference between 90 days after the average length of stay in the rehabilitation facility. This average length of stay in a rehabilitation facility varied by mRS score.

Long-term costs. Long-term costs included those associated with activities that occurred after the initial 90-day period. These costs included annual medical cost[24] and daily caregiver costs,[23] both obtained from the literature. These annual medical costs were composed of additional hospitalizations, outpatient physician visits, medical equipment, and other costs that would be covered by a third-party payer. Long-term costs were the same regardless of telestroke use, but cost multipliers were used to vary these long-term costs by mRS after the incident stroke.

Discharge probabilities. The probabilities of being discharged to home, a rehabilitation facility, or a skilled nursing facility were obtained from the literature[25] and were stratified based on mRS score.

Outcomes. The effectiveness outcome of interest in this study was QALYs, which are constructed by multiplying the years of remaining life with the utility weight associated with a certain mRS score. We assumed 0.25 years of remaining life for the 90-day horizon model. Utility weights are measured on a scale, where 1.0 represents a state of perfect health and 0.0 represents death. The utility weight associated with mRS scores used here was obtained from a previous study[26] and has been used in several other cost-effectiveness analyses of stroke.[27,28] We measured overall cost-effectiveness using the incremental cost-effectiveness ratio (ICER), which is calculated by dividing the difference in average costs per patient between telestroke and usual care by the difference in average QALYs per patient between telestroke and usual care.

Sensitivity analysis. The inputs that have been described above are point estimates taken from the literature that often come from very specific patient populations. We performed a one-way sensitivity analysis for each input over a plausible range of values in order to determine whether varying the magnitudes of these inputs affected the results of the model. These were plotted in a tornado diagram showing the inputs with substantial impacts on the ICER. We also performed a probabilistic sensitivity analysis using a second-order Monte Carlo simulation, in which all parameters varied at once rather than 1 or 2 at a time, based on random draws from a distribution. Assumptions of distributions and the range for each input parameter are shown in table 1. Variable distributions around the point estimates were taken from the literature when available. When not available in the literature, the boundaries of the potential distribution were estimated by doubling and halving the point estimates.

RESULTS

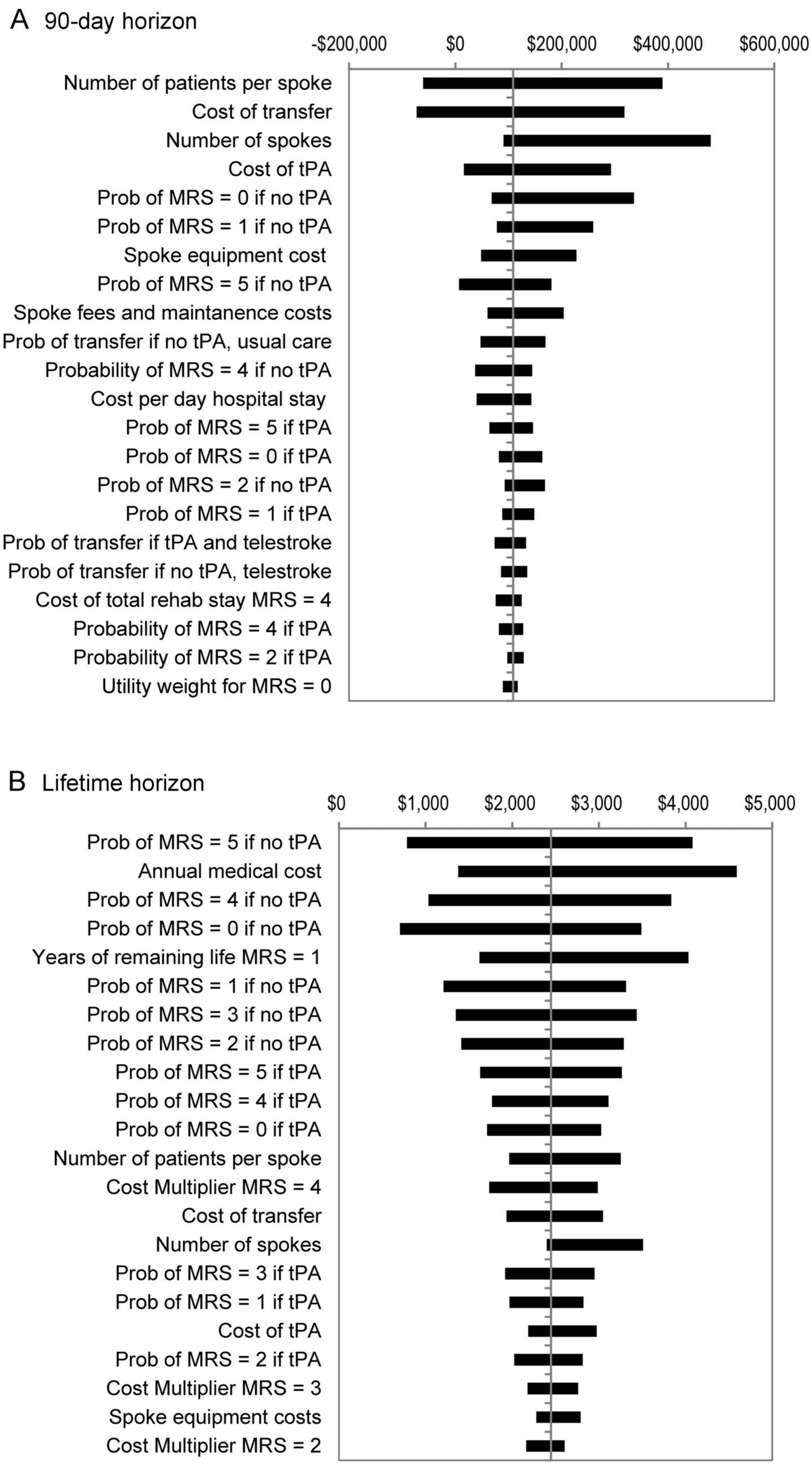
Base case. Results from the model using both time horizons are presented in table 2A. In both 90-day and lifetime horizons, costs are higher on average for telestroke patients. This is due primarily to the costs of the system itself. Telestroke patients, however, have more QALYs on average. The ICER for telestroke compared to usual care is $108,363/QALY for the 90-day horizon and $2,449/QALY for the lifetime horizon.

Table 2B depicts the ICERs for each horizon for a newly established telestroke network. These results show that the cost-effectiveness of telestroke is quite sensitive to the number of spoke hospitals when using the 90-day horizon (ICERs ranging from $480,258/QALY for 1 spoke hospital to $196,910/QALY for 3 spoke hospitals) compared to the lifetime horizon (ICERs ranging from $3,509/QALY for 1 spoke hospital to $2,701/QALY for 3 spoke hospitals).

Sensitivity analysis. Results from one-way sensitivity analyses for the 90-day and lifetime horizon models are presented in tornado diagrams in figure 2, A and B, respectively. The horizontal bars in these diagrams represent the ICER range associated with the high and low values for that particular input parameter. Figure 2A shows that the base case results for the 90-day horizon models were sensitive to variation in several input parameters. The inputs that changed the ICER dramatically for this model were number of patients per spoke and the cost of transfer. Using the values at the low end of the allowable range for these inputs led to situations in which telestroke was dominant compared to usual care (i.e., both less costly and more effective). In the lifetime horizon model, the inputs that had the most impact on the ICER were the probability of mRS score of 5 and annual medical cost.

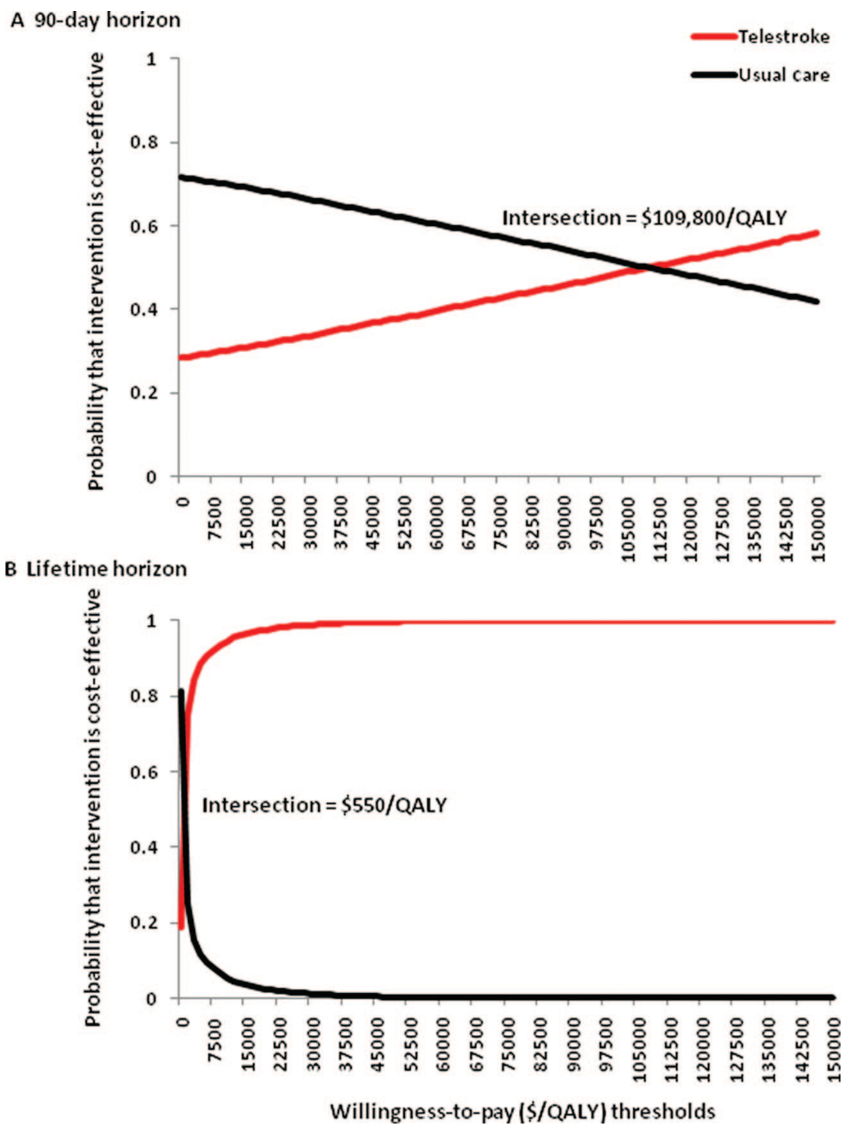
To explore the relationship further between the cost of transfer and the cost-effectiveness of telestroke compared to usual care, we ran each model separately for each type of transfer. For the lifetime horizon model, the ICERs were $3,047/QALY for ambu-

Figure 2 **Tornado diagrams depicting results of one-way sensitivity analyses of (A) the 90-day horizon and (B) the lifetime horizon**



Figures show incremental cost-effectiveness ratios (ICERs) associated with upper and lower ends of range of values for each input. Midlines for each figure are base-case ICERs: (A) $108,363/quality-adjusted life-year (QALY) and (B) $2,449/QALY. mRS = modified Rankin Scale; tPA = tissue plasminogen activator.

Figure 3 **Cost-effectiveness acceptability curve of telestroke compared to usual care for (A) the 90-day horizon and (B) the lifetime horizon**



Figures depict the probability that telestroke and usual care are cost-effective over a range of willingness-to-pay thresholds in 10,000 second-order Monte Carlo simulations. The percentage of simulations in which a treatment was cost-effective based on a certain willingness-to-pay threshold is represented on the vertical axis, while the horizontal axis represents levels of this willingness-to-pay threshold. QALY = quality-adjusted life-year.

lance transfer and $1,933/QALY for helicopter transfer, while for the 90-day horizon model the ICER was $318,234/QALY for ambulance transfer. Telestroke was dominant in the case of a helicopter transfer.

The threshold of $50,000/QALY is commonly cited as the cutoff for cost-effectiveness.[29] Other authors have advocated categorizing ICERs less than $20,000/QALY as inexpensive and those over $100,000/QALY as expensive.[30] In the 90-day horizon model, the ICER for telestroke compared to usual care was just above this $100,000/QALY threshold. But telestroke was cost-effective under any of these definitions when using a lifetime horizon.

Figure 3, A and B, depicts the results from the probabilistic sensitivity analysis for the 90-day and lifetime horizon models, respectively. The results are shown as cost-effectiveness acceptability curves (CEACs) from 10,000 simulations.[31] These CEACs show the probability that telestroke is cost-effective compared with usual care over a range of monetary values that a decision-maker might be willing to pay for a particular unit change in QALYs. The percentage of simulations in which a treatment was cost-effective based on a certain willingness-to-pay threshold is represented on the vertical axis while the horizontal axis represents levels of this willingness-to-pay threshold. For the 90-day and lifetime horizons, respectively, 37.5% and 99.7% of 10,000 simulations yielded ICERs less than $50,000/QALY.

DISCUSSION Despite the perceived usefulness of telestroke in providing timely consultation for remote patients with acute stroke, little evaluation has been done assessing the economic impact of this technology.[9,32] In this study, we have shown that telestroke is more cost-effective in the lifetime horizon, with an ICER of $2,449/QALY, than in the 90-day horizon (ICER of $108,363/QALY). This divergence of results by time horizon is most likely due to the large up-front fixed costs of telestroke equipment compared to the lifelong benefit of improved quality of life from increased tPA use.

The American Heart Association and American Stroke Association advocate for tPA use in appropriate patients as the most beneficial treatment for acute ischemic stroke.[3] The shortage of stroke specialists and other physicians with experience administering this drug in rural areas is a substantial barrier preventing more widespread tPA use.[33] Telestroke has the potential to lower this barrier by providing long-distance consultation to such areas, in effect increasing the expertise, and therefore quality, of stroke care at rural hospitals.

In an era of spiraling health care costs, our findings will give critical information to medical policy makers to help them determine if up-front investment in technology, infrastructure, and human resources is worthwhile for the patients served by their health system. The cost-effectiveness of telestroke suggests that insurance plans should include urgent telestroke consultation as a covered benefit, particularly since lack of uniform reimbursement is a current barrier to adoption of the technology. In the future, we hope to expand this work to evaluate how the volume of telestroke systems, number of patients treated, and methods and distance of transportation affect the incremental cost-effectiveness ratios. We briefly explored the sensitivity of our results to the size of the telestroke network (i.e., number of spoke hospitals) and mode of transfer. Both of these inputs are directly related to the distance between spoke and hub hospitals. Thus, given the sensitivity of these results to assumptions related to mode of transfer, future work to identify the distance thresholds that affect the cost-effectiveness of telestroke will allow policy makers to determine whether their health system's particular characteristics support telestroke as a cost-effective solution to evaluating and treating their patients with acute stroke.

The only other published cost-effectiveness analysis of telestroke examined the establishment of a telestroke system in Denmark. This study has limited relevance to the United States, as it assumed an in-hospital neurologist and a 1:1 spoke:hub model, rather than the more efficient and commonly used system of home-based units with multiple spokes per hub. Despite these limitations, their findings were similar to ours: they found that telestroke becomes more cost-effective as the time horizon increases, with an ICER of telestroke compared to "conservative treatment" of $50,100/QALY using a 1-year horizon, and the dominance of telestroke using time horizons of 2 years and 30 years.

While this article presents novel and important results, there are several limitations. First of all, our model assumed that the patient entering the hospital had an ischemic stroke. In this way, we only estimate the costs and QALYs associated with telestroke and usual care with respect to ischemic stroke patients. Telestroke, however, may also provide benefits to patients who have had a hemorrhagic stroke or who appear to have had a stroke, but in fact have had a stroke mimic. In a usual care setting, these stroke mimic patients are often transferred to a tertiary care center due to uncertainty of diagnosis, but telestroke consultation could allow stroke specialists to assist rural providers in diagnosis, treatment, and transfer decision, potentially lowering costs by avoiding unnecessary transfers. Indeed, a review of international telestroke networks found that 8%–33% of telestroke consultations are ultimately diagnosed as stroke mimics.[34] Second, several inputs were not available in the published literature: the probability of a stroke patient being transferred to a tertiary care facility (in both the telestroke and usual care cases) and the costs of telestroke hub and spoke equipment. For these inputs, we were forced to make assumptions or utilize estimates from manufacturing and clinical experts working with telestroke. Third, telestroke is just one of many methods for increasing tPA usage for acute stroke patients, with other methods including targeted physician education[35] and telephone-only consultations.[36] In randomized trials of telephone-only vs telestroke consultations, the telephone-only consultations show poor sensitivity for ruling in tPA-eligible patients.[37] Future studies should compare cost-effectiveness of telestroke with these alternative methods in real-world settings.

Telestroke is a cost-effective method of delivering acute stroke care to communities without access to on-site stroke specialists, with an incremental cost-effectiveness ratio of $2,449 per QALY over a patient's lifetime. If barriers to use such as low reimbursement rates and high equipment costs are reduced, telestroke has the potential to diminish the striking geographic disparities of acute stroke care in the United States.

AUTHOR CONTRIBUTIONS

R.E.N.: drafting/revising, study concept, analysis, acquisition of data, statistical analysis, study supervision/coordination, principal investigator. G.M.S.: drafting/revising, study concept, analysis. E.S.: study concept, analysis, acquisition of data, study supervision/coordination. B.M.D.: drafting/revising, study concept, acquisition of data. J.J.M.: drafting/revising, study concept, analysis, statistical analysis, study supervision/coordination, principal investigator.

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DISCLOSURE

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