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ROI Assessment on Using Information Technology in the Course of Admission Decisions in Myocardial Infarction Diagnosis

Ofir Ben-Assuli
Ono Academic College, Tel-Aviv University, ofir@ono.ac.il

Moshe Leshno
Tel-Aviv University, Israel, leshnom@post.tau.ac.il

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Ofir Ben-Assuli
Ono Academic College, Tel-Aviv University
ofir@ono.ac.il

Moshe Leshno
Tel-Aviv University
leshnom@post.tau.ac.il

ABSTRACT

The healthcare sector has been investing heavily in health information technologies (HIT), with the aim of improving decision-making through improved medical processes, reduced costs and integration of medical data. However, the overall contribution of HIT to the medical field is not obvious, especially, in high-stress environments such as the emergency department (ED). The objective of this research is to explore whether investing in HIT in an ED is rewarding in evaluating acute myocardial infarction diagnosis in EDs.

We evaluated the overall profitability of certain integrative medical IS in a cost-effectiveness analysis using an experimental study in the course of diagnosing an acute myocardial infarction. The results in the paper show that our specific medical cases received a clear cost-effective reading since the results (ΔCosts/ΔQuality) were lower than the range of all common threshold values. Furthermore, the use of HIT in the ED also improved the quality of the medical care.

Keywords

Cost-Effectiveness, Information Economy, Medical Decision-Making.

INTRODUCTION

The healthcare sector has been investing heavily in information technologies in recent years, with the aim of improving medical decision-making through improved medical processes, reduced costs and integration of data on patients. Indeed, information retrieved by information systems can improve the quality of the decisions made and reduce the risks and uncertainties that stem from the lack of information (Ahituv, Neumann, and Riley, 1994). However, the new integrative medical IS are extremely costly, and their impact on high-stress environments such as emergency departments (EDs), which often have to deal with an enormous number of patients under heavy time constraints, is not obvious. The overcrowding in EDs often results in inferior clinical outcomes and reported medical errors on many aspects of emergency care, including: diagnostic errors, malfunctioning administrative procedures and wrong documentation (Fordyce, Blank, Pekow, Smithline, Ritter, Gehlbach, Benjamin and Henneman, 2003). Many of these malfunctions might have been prevented by using medical IS. Testing the contribution of medical IS is therefore a difficult and complex matter, as is estimating their return on investment (ROI). The purpose of this study was to examine the capacity of medical IS to contribute to the evaluation of acute myocardial infarction (AMI) diagnosis under the constraints of EDs. This purpose was accomplished by conducting a cost-effectiveness analysis of medical IS as the selected tool for ROI estimations.

BACKGROUND

The effects of medical information systems at the point of care have been studied in previous studies from different aspects. There are studies dealing with the impact of online medical systems on the stressful ED environment. For instance, in the psychiatric research, the Center for Technology in Government (1995) has published a project report on supporting psychiatric assessments in EDs and showed the contribution of computer-assisted decision software to admission decisions. Additionally, Gaynor, Seltzer, Moulton and Freedman (2005) showed the contribution of a decision support system in crises and in emergency services. Yet, despite the increasing use of these systems by clinicians, there has been little research documenting the economical effectiveness of their use.

The impact of using health information technology (HIT) on medical decision-making has been studied in many past researches (Westbrook, Gosling and Coiera, 2005). Additionally, general implications and outcomes of HIT have been studied in order to determining diagnostic and therapeutic strategies (Shortliffe 1987) and measuring the effectiveness of triaging patients in the ED by using medical IS (Michalowski, Kersten, Wilk and Slowinski, 2007). Goldschmidt (2005) claims that though until recently the field of HIT has been mostly the realm of enthusiasts, and the future trends include a vision that HIT can transform the healthcare system – thereby simultaneously improving quality and productivity. He concluded that the increase in national health expenditures and the desire to improve the quality of healthcare are driving the widespread adoption of HIT but we should further research their outcomes.

There are few works that studied the financial implications and the outcomes of HIT, however, these topics are getting more academic attention only during the last years. For instance, theoretical frameworks to assess the potential value of medical information have been established only in the recent years (Basu and Meltzer, 2007). Walker, Pan, Johnston, Adler-Milstein, Bates, and Middleton (2005) showed that interoperability between independent laboratories, radiology centers and pharmacies would enable reduction of redundant tests, delays and additional costs.

An important issue to mention in our research is the general implications of a particular HIT, the electronic medical record (EMR). They are usually accessed via a computer, often over a network, and may incorporate many different locations and sources. Among the many forms of data often included in EMRs are patient medical history, chronic drugs, allergy lists and laboratory test results. Specifically, we focus on the contribution of HIT as EMR systems as the investigated source of the medical history in the EDs, rather than on other sources of medical information without an IS (as hard copy patient record, physical examinations or speaking with the patient) which have been appeared in previous research (Hampton et al. 1975).

Ovretveit, Scott, Rundall, Shortell and Brommels (2007) stated that there is little research and a lack of theory about the implementation of EMR systems and the measurement of their financial rewording.

RESEARCH OBJECTIVE

The objective of this research is to explore whether investing in HIT in an ED improves clinical decision-making in evaluating AMI diagnosis and whether it is financially rewarding. Hence, the main research hypotheses are:

- The use of integrative medical IS improves decision-making in an ED in the course of evaluating an AMI diagnosis.
- The use of integrative medical IS is financially rewarding in the course of evaluating an AMI diagnosis.

Based on the two most frequent chest pain ED cases, a cost-effectiveness analysis was made of certain integrative medical IS that serve seven main hospitals in Israel. In it we balanced the quality gained from information regarding past medical history against the costs of providing the information

METHODOLOGY

The assessment of the cost-effectiveness of our medical IS was carried out after two main stages:

- Performing an experimental study using an analytical model – We performed controlled experiments that simulate the complicated reality of an ED environment, representing the main decision process (whether to admit or discharge the patient).
- Developing a theoretical analytical model that represents the admission decision in EDs – We developed our model using medical decision trees as presented by Pauker and Kassirer (1987) (presented below in our study) and as used by Golan, Wolf, Pauker, Wong and Hadley (2005) and Dotan, Pinchuk, Lichtenberg and Leshno (2009), for evaluating the expected value of the medical IS using a Markov model. The evaluation of this normative value of information was based on the medical literature and on the decisions made by physicians who participated in our experimental study.
- Integrating the results of the experimental study and the analytical model and conducting a cost-effectiveness analysis.

The Experimental Study

In the experimental study, we compared the performance of physicians who had access to complete clinical information on patients to that of physicians who lacked such access. The main stages were:

- Selecting the medical scenarios – The cases have been chosen from the most common clinical scenarios in the national center for health statistics (NCHS), the United States' principal health statistics agency. The selected scenarios also appeared on the books of the educational commission for foreign medical graduates (ECFMG) in order to be recognized as having optimal credibility (The ECFMG assesses the readiness of international medical graduates to enter residency or fellowship programs in the USA). According to the NCHS, we chose the most common specific principal reason given by adult patients for visiting the ED, the chest pain.

- Constructing the medical scenarios - The cases were selected and developed by a panel of six senior physicians in cooperation with an international medical simulation center (MSR institution[1]) and were finalized with a pilot study. The technical data have been added to the ECFMG instructions from previous relevant researches on chest pain and on acute myocardial infarction (AMI) differential diagnosis (DD) (Lee and Goldman, 2000, Pope, Aufderheide, Ruthazer, Woolard, Feldman, Beshansky, Griffith and Selker, 2000).
- The research took place in the form of a website-based application[2]. The subjects were real practical physicians with no need for training on the simulated IS (due to a simplest design of the system). The tested physician randomly received three cases with one of the following access patterns: with a full access to the medical IS or lack of any access to the medical IS. The physician decided on the medical strategy including: viewing the medical history and the physical examination, designing the diagnostic workup plan and deciding on the main DD and whether to admit or discharge the patient.

The Theoretical Analytical Model

We begin this section with a presentation of our decision tree (most of the explanations of the calculations in the tree are not shown here in order to avoid data overload). We then provide explanations on our selected payoff approach, the general expected utility (EU) using the quality adjusted life years (QALY) measurement. Finally, we conduct the cost-effectiveness analysis.

Discussion on the use of expected utility and the threshold decision

We wish to initiate a discussion on the payoff of each alternative, by using the EU method. Figure 1 shows the main decision node of our model. We used one threshold probability (having the AMI disease), which represents an indifference point between admission and discharge decisions (in accordance with Pauker et al. 1987).

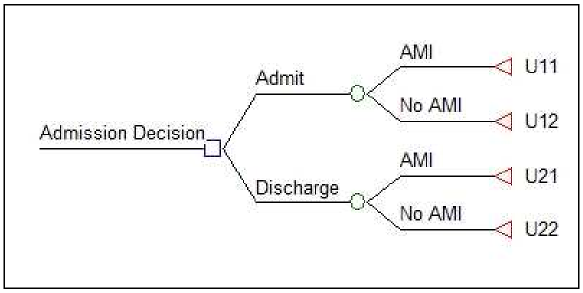

Figure 1. Admission decisions and general utilities

We added a few more variable definitions as follows:

P - The probability of having the AMI DD. This threshold probability could be calculated by comparing the EU of admission to the EU of discharge: $E_A(U) = E_D(U)$

$E_A(U)$ - The EU of an admission decision; $E_D(U)$ - The EU of a discharge decision.

According to figure 1, The EU of admission and discharge would be calculated as follows:

$E_A(U) = P \cdot U_{11} + (1-P) \cdot U_{12}$; $E_D(U) = P \cdot U_{21} + (1-P) \cdot U_{22}$

Payoff by the QALY approach using a Markov model

The QALY is a measure used worldwide in the medical research field, based on the principle that a year of poor health is of lower utility than a year of life with a good health quality. We implemented the decision tree with the QALY measurement to estimate the differences between individuals admitted and discharged from the ED, in order to simulate the long-term progression of diseases via examination of the events associated with an ongoing risk (Sonnenberg and Beck, 1993, Sesso Chen, L'Italien, Lapuerta, Lee and Glynn, 2003). We implemented a Markov model to estimate the differences between

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[1] See at: http://www.msr.org.il

[2] See the experimental cases at: http://gsba-rs.tau.ac.il/MedicalED/ (The assigned number in each case is not necessary the same assigned number of each case in our analysis due to the random order of the cases).

individuals admitted and discharged from the ED. The basic assumption of these models is that each individual belongs, at any given time, to one of a finite number of health states, which allows for transitions from one health state to another during a predefined interval of time (Sesso et al. 2003). We used the model based on the possible transitions between the predefined health states outlined by Sesso et al. (2003) for the progression of cardiovascular disease (CVD) as follows: "No CVD", no history of CVD; "CVD", history of a CVD-related event. The transition from "No CVD" state to "CVD" state occurs via an event of a nonfatal stroke (STRK), nonfatal AMI (MI), or via revascularization (RV).

Figure 2 shows the structure of the tree for the QALY analysis using a Markov model.

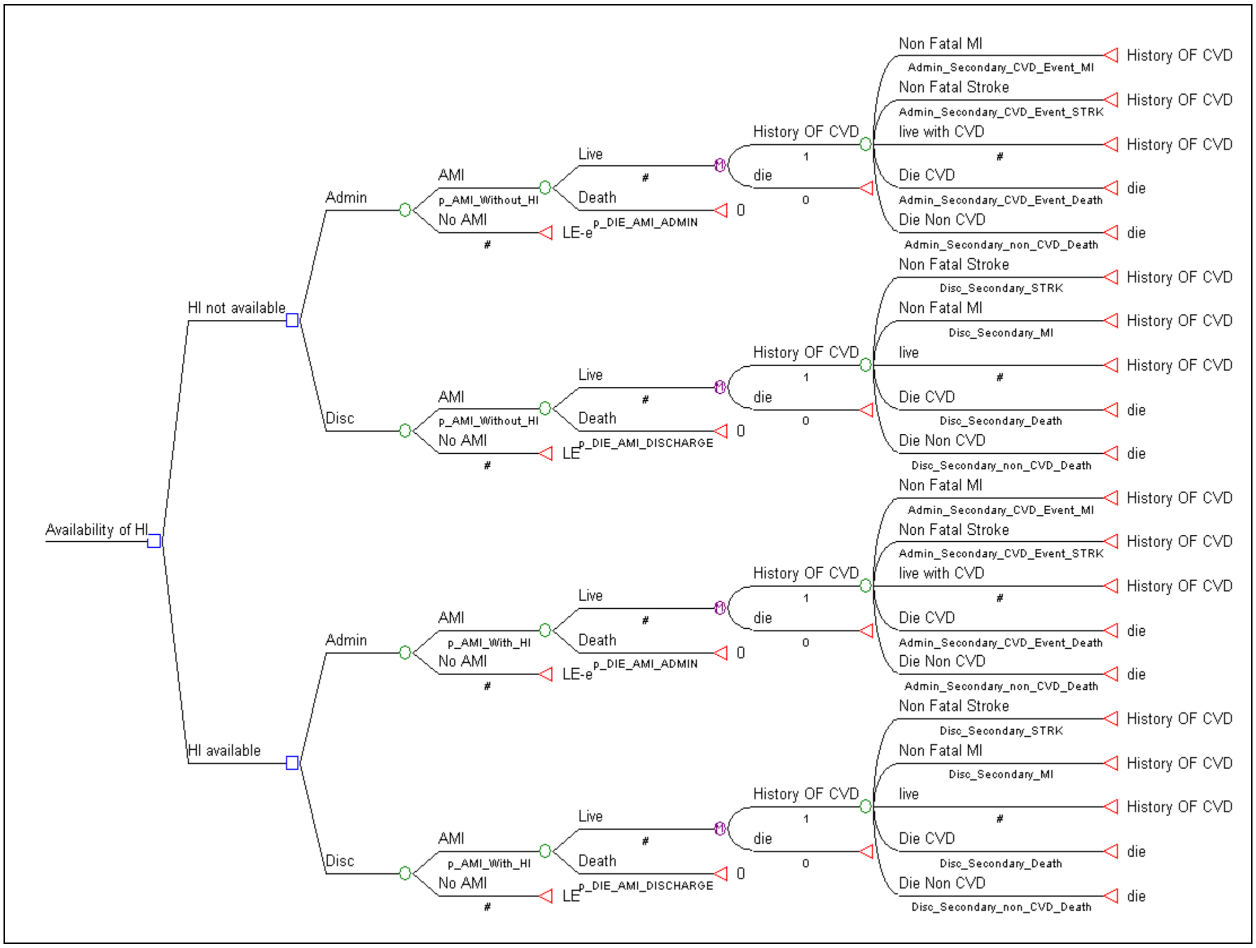

Figure 2. The decision tree using QALY approach and Markov model

Assessments of the probabilities and the outcomes

We further clarify the related assessments of the probabilities and the outcomes.

The AMI probabilities:

P_AMI_With_HI: The probability in the case where the DD is AMI (D+) **when history was available** and after a negative result was obtained from **both** of the examinations used in our experiment (electrocardiogram (ECG) as T1 and cardiac enzymes (CE) as T2). Hence, the results of the post-prior probability $P\left(D^{+}\middle|T_1^{-}T_2^{-}\right)$ (calculated by the following equations and the appropriate values from the experimental study) **when history was available** are:

In case 1: **9.6%**. The range for sensitivity analysis: [5%-15%]

In case 2: **2.1%**. The range for sensitivity analysis: [0.5%-5%]

Letting:

$P\left(T_1^{+}\middle|D^{+}\right)=senT_1$ - The sensitivity of the T1 examination (ECG).

$P(T_1^- | D^-) = speT_1$ - The specificity of the T1 examination (ECG).

These are the post prior probabilities equations (derivations and mathematical steps are not shown here):

$$P(D^+ | T_1^+ T_2^+) = \frac{senT_1 \cdot senT_2 \cdot P(D^+)}{senT_1 \cdot senT_2 \cdot P(D^+) + [1 - speT_1] \cdot [1 - speT_2] \cdot [1 - P(D^+)]}$$

$$P(D^+ | T_1^+ T_2^-) = \frac{senT_1 \cdot (1 - senT_2) \cdot P(D^+)}{senT_1 \cdot [1 - senT_2] \cdot P(D^+) + [1 - speT_1] \cdot speT_2 \cdot [1 - P(D^+)]}$$

$$P(D^+ | T_1^- T_2^+) = \frac{(1 - senT_1) \cdot senT_2 \cdot P(D^+)}{[1 - senT_1] \cdot senT_2 \cdot P(D^+) + speT_1 \cdot [1 - speT_2] \cdot [1 - P(D^+)]}$$

$$P(D^+ | T_1^- T_2^-) = \frac{(1 - senT_1) \cdot (1 - senT_2) \cdot P(D^+)}{[1 - senT_1] \cdot [1 - senT_2] \cdot P(D^+) + speT_1 \cdot speT_2 \cdot [1 - P(D^+)]}$$

P_AMI_Without_HI: The probability in the case where the DD is an AMI (D+) **when history was not available** (after a negative result was obtained from both of the examinations (ECG as T1 and the CE as T2) in experiment case 1, and, when a positive result was obtained from the ECG examination and a negative result was obtained from the CE examination in experiment case 2). Hence:

In case 1: the post-prior probability $P(D^+ | T_1^- T_2^-)$ derived from the calculations of equations shown above, when history was **not** available is: **0.5%**. The range for sensitivity analysis: [0.1%-5%].

In case 2, the post-prior probability $P(D^+ | T_1^+ T_2^-)$ derived from the calculations of equations shown above, when history was **not** available is: **38.7%**. The range for sensitivity analysis: [30%-46%].

P_Die_AMI: The probability of a death of a patient within 30 days in the case where the DD is AMI (D+). In our study this probability has two options that are derived from the admission decision: P_Die_AMI_Admin and P_Die_AMI_Discharge:

P_Die_AMI_Admin - The probability of a death of a patient within 30 days in the case where the DD is AMI (D+) **when a decision to admit was made**.

We chose to adopt a mortality ratio within 30 days from Pope et al. (2000)'s large data set which was appropriate and in the range of mortality rates of other studies as well. We set the P_Die_AMI_Admin to **5.7%**. The range for sensitivity analysis: [3.5%-7.9%].

P_Die_AMI_Discharge -The probability of a death of a patient within 30 days in the case where the DD is AMI (D+) **when a discharge decision was made**.

We used the previous research that explored the relationships between the two derived probabilities of P_Die_AMI (Pope et al. 2000). Consequently, we set the P_Die_AMI_Discharge to **10.83%**. The range for sensitivity analysis: [8%-14%].

The Markov model probabilities and outcomes

The probabilities used in our model (in Table 3 below) were extracted from many clinical studies listed in the Meta analysis made by Dotan et al. (2009). The outcomes (in QALYs) were taken from the accepted preference scores catalogue "The Cost-effectiveness Analysis Registry" (CEA[3]). The cost-effectiveness analysis was performed in our study by balancing the QALY units gained as the beneficial effect of admission decision according to the disease conditions against the expected costs (Golan et al. 2005) and by using a Markov model (Leshno, Halpern and Arber, 2003).

The evaluation of the costs associated with admission decisions

In general, acute care costs include hospitalization and any other related services such as ambulance, physician services, rehabilitation costs, ordering and performing medical tests. In all of our cases we did not include the administrative referral costs. In order to properly evaluate the additional costs in US Dollars per year, we used secondary data from several recent studies (Fitch, Pyenson, and Iwasaki, 2007, Heeg, Peters, Botteman and Van Hout, 2007) and we used second assessments of experts and price-lists from the Israel Ministry of Health on this data. These costs per first year including derived operations for each admission decision are presented in Table 3 below with a wide range of sensitivity analyses.

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[3] See at: https://research.tufts-nemc.org/cear/Default.aspx

FINDINGS

The Experimental Study

The experiments were performed on 102 real physicians during 2010 year. 53 physicians were provided with an access to the medical IS and 49 physicians were not provided with an access to the medical IS in the experiments (the difference in the number of physicians is due to the random access patterns of the medical IS. In general we had three simulated cases:

- In case 1, without any additional information from the medical IS, the normative medical decision of the physician should be to discharge this patient and the main DD is not one of the diagnoses related to AMI. On the contrary, with additional information from the medical IS, the normative medical decision of the physician should be to admit this patient and the main DD is one of the diagnoses related to AMI.
- In case 2, without any additional information from the medical IS, the normative medical decision of a physician should be to admit this patient and the main DD is one of the diagnoses related to AMI. On the contrary, with the additional information from the medical IS, the normative medical decision of the physician should be to discharge this patient and the main DD is not one of the diagnoses related to AMI.
- In case 3, which serves as a control case, in both cases (with or without access to the medical IS) the normative medical decision of the physician should be to admit this patient and the main DD is one of the diagnoses related to AMI. This case was verified to serve as a control case in our results and is not shown here in order to avoid data overload.

The term "medical history" below concerns to the additional information gained from the medical IS only for physicians who received an access to it. For other physicians, they were exposed only to the major complaint and to the demographic data which were equally provided to all the participants. We compared the number of admission decisions made by the physicians, of patients with medical history which was not viewed, and patients with medical history which was viewed.

Percentage of Admissions when Medical History Was Not Viewed	Percentage of Admissions when Medical History Was Viewed	Increase in Admissions	p-value
36.7% (18 physicians)	88.7% (47 physicians)	142.7%	<0.001

Table 1. Case 1: Comparing proportions admission rates

Percentage of Admissions when Medical History Was Not Viewed	Percentage of Admissions when Medical History Was Viewed	Decrease in Admissions	p-value
87.8% (43 physicians)	56.6% (30 physicians)	35.54%	<0.001

Table 2. Case 2: Comparing proportions admission rates

Summary of the main findings:

Viewing medical history contributes to admission decisions. Not only does it clearly reduce the number of unnecessary admissions (case 1), but it also increases the necessary admissions (case 2).

The Cost-Effectiveness

In this section, we firstly show the variable values including the range for sensitivity analyses and secondly, we compare the results (in a manner of QALYs) between the two admission decisions (admit and discharge). Here are the variable values including the range of sensitivity analyses:

Variable	Definition	Value	Range for sensitivity analysis
P_AMI_With_HI	The probability of having an AMI when HI was available	Case 1: 9.6% Case 2: 2.1%	Case 1:[5%-15%] Case 2:[0.5%-5%]
P_AMI_Without_HI	The probability of having an AMI when HI wasn't available	Case 1: 0.5% Case 2: 38.7%	Case1:[0.1%-5%] Case 2:[30%-46%]
P_Die_AMI_Admin	The probability that the patient dies within 30 days after having an AMI when a decision to admit was	5.7%	[3.5%-7.9%]

	made		
P_Die_AMI_Discharge	The probability that the patient dies within 30 days after having an AMI when a decision to discharge was made	10.83%	[8%-14%]
Markov Model: Primary CVD (Base rates and ranges)			
Non-CVD death		7.18	1.11–13.25
CVD death		2.4	0.26–4.55
Myocardial infarction (MI)		1.45	0.18–2.72
Nonfatal stroke		1.15	0.87–1.43
Revascularization		0.78	0.37–1.19
Markov Model: Secondary CVD (Base rates and ranges)			
Non-CVD death		10.98	6.06–15.9
CVD death		15.32	11.38–19.26
Myocardial infarction (MI)		11.77	9.08–14.46
Nonfatal stroke		8.67	7.85–9.5
Markov Model: Utility (in QALYs per year)			
The patient Admitted or discharged and died		0	-
Discharge decision after Non-AMI DD		1	-
Admission decision after Non-AMI DD (redundant)		0.999	0.998-1
The patient Admitted or discharged after Non-AMI DD and lived (in QALYs per year in Markov Model)			
History of MI		0.7	0.5–0.7
History of Stroke		0.4	0.2–0.7
History of both Stroke and MI		0.29	0.14–0.43
The additional costs in US Dollar per year used (including derived operations)			
Costs when an 'admit' decision was made after AMI DD		15,000$	5,000$–20,000$
Costs when an 'admit' decision was made after non-AMI DD (redundant)		500$	300$-1,000$
Costs when a 'discharge' decision was made after AMI DD		8,250$	2,750$–11,000$
Costs when a 'discharge' decision was made after non-AMI DD		0$	-

Table 3. Variable Values and Sensitivity Analysis

We used the "TreeAge Pro" program in order to analyze the decision tree (Figure 2).

Admission Decision	QALYs Per patient (Life-Expectancy)	Costs Per patient ($)	ΔQALY Per patient	Δ C Per patient	ΔC/ΔQALY
Admit	22.2611 years	1892$	0.0603	1112.43$	1112.43$/0.0603 =18448.26$
Discharge	22.2008 years	792$			

Table 4. Case 1: Cost-Effectiveness Analysis

Findings from case 1:

- The additional QALY units per admitted patient (justified) from viewing medical history are measured as the difference between the decision to admit and the decision to discharge, resulting in: 22.2611 – 22.2008 = 0.0603 QALYs. These findings also correspond, with the findings of the experimental study. The results of our sensitivity analysis further validate our findings due to many changes in our variables including Monte Carlo simulation on 100,000 trials (average ΔQALY=0.064). Meaning that the use of medical IS during the period of treatment in the ED improves the QALYs per patient.

- The additional costs per admitted patient resulting from viewing medical history were measured as the difference between the decision to admit and the decision to discharge resulting in: 1,904.43$ – 792$ = 1,112.43$. The more costly option is to admit the patient as expected.

Admission Decision	QALYs Per patient (Life-Expectancy)	Costs Per patient ($)	ΔQALY Per patient	Δ C Per patient	ΔC/ΔQALY
Admit	32.615 years	173.25$	0.005	-631.25	Cost-Saving
Discharge	32.610 years	804.5$			

Table 5. Case 2: Cost-Effectiveness Analysis

Findings from case 2:

- The additional QALY units per discharged patient (justified) resulting from viewing medical history are measured as the difference between the decision to admit and the decision to discharge resulting in: 32.615 – 32.610 = 0.005 QALYs. These findings also correspond, with the experimental findings. The results of the sensitivity analysis further validate our findings including Monte Carlo simulation on 100,000 trials, which yielded similar results (average ΔQALY=0.007). Meaning that the use of medical IS during the period of treatment in the ED improves the QALYs per patient.

- The additional costs per discharged patient resulting from viewing medical history were measured as the difference between the decision to admit the patient and the decision to discharge the patient resulting in: 185.68$ – 804.5$ = -631.25$ (saving 631.25$). The least costly option is to discharge the patient, meaning that the discharge decision in this case using the medical IS is the most optimal.

DISCUSSION

The main question is: what the affordable cost threshold value is made for adoption of medical IS. In general, in strategic policy decision-making in the healthcare sector there are accepted rules in health economics policies. According to Medicare[4] organization, any investment in medical accessory, medicine or treatment which led to improvement has a cost-effectiveness threshold of 50,000$ for gaining one QALY unit per patient (below 50,000$ it is very cost-effective). The standard practice of Medicare is not a comprehensive practice but rather a minimal threshold for benchmark values. Many studies and organizations have set higher threshold values for which medical intervention is financially justifiable (such as: Devlin and Parkin, 2004). According to the world health organization[5], an intervention is considered to be (all monetary values are in 2009 values in Israel):

- Cost-Saving: if treatment costs averted exceed intervention costs.
- Very Cost-Effective: if the costs per QALY saved $\leq$ per capita GNP (around $27,000).
- Not Cost-Effective: If the costs per QALY saved > 3 x per capita GNP (around $81,000).

Our results varied in both of the medical cases. In case 1, the additional costs per patient per one QALY unit as a result of using integrative medical IS is 18,448.26$ (**very cost-effective**), and in case 2, the **saved** costs per patient per one QALY unit as a result of using integrative medical IS is 618.82$ (**cost-saving**). Consequently, in our study, both of our special medical cases of chest pain received a clear cost-effective reading, since the results were lower than the range of the threshold values. Hence, in our specific cases, the investment in our integrative medical IS seems to be financially worthwhile.

CONCLUSIONS

Our findings lead to these major conclusions:

- The use of integrative medical IS during the period of treatment in the ED improves the clinical decision-making and the QALYs per patient for each chosen medical decisions in AMI.
- Investing in an integrative medical IS is financially worthwhile, provided that medical history was supplied to the physicians in the EDs during the triage of the patients in our specific cases of chest pain formulated in our experiments.

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[4] See at: http://www.medicare.gov/

[5] See at: http://www.who.int/en/.

CONTRIBUTION AND LIMITATIONS

The main purpose of our research was to contribute to scientific knowledge by providing additional insight into the various research fields. We enumerate two main contributions:

- Viewing of medical history contributes to admission decisions. This contribution was discovered both in the theoretical normative model and also in the course of an experimental study.
- Proving cost-effectiveness for the use of medical IS by using a Markov model in evaluating AMI diagnosis in an ED.

It is important to note the limitation that our findings related only to our specific experimental cases, which represent accepted and very frequent scenarios in the medical literature. However, these theoretical cases are quite limited in the generalization option. Hence, although we believe our results are valid, further research is advisable on this subject.

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