A Comparative Analysis of Medical Technologies using the Diffusion of Innovations Theory

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The global medical technology market was valued at $512.29 billion in 2022 and is projected to grow 5.9% every year (*Medical devices market share, growth, trends: Forecast [2030]* 2023). New technologies can provide better outcomes for patients or make it easier for physicians. There is no doubt that medical advancements have improved life expectancy and quality of treatment over decades, such as increasing life expectancy by seven years from 1950 to 1990 (*U.S. life expectancy 1950-2023*). In addition, with an aging global population and the rise of chronic illnesses, the number of medical surgeries and diagnostic tests is also increasing every year, fueling the demand for greater medical technologies. With a constant influx of new technologies, hospitals and physicians must decide which technologies to incorporate into their care, if any.

However, the widespread adoption of these medical technologies is not at the same pace as the influx of medical devices. It is frequently stated that it takes an average of 17 years for research evidence to reach clinical practice (Morris et al., 2011). In addition to the time and expense it takes to get FDA approval, many obstacles prevent devices from being used as a standard of care within hospitals, such as set-up costs, market changes, and user preferences.

The goal of this STS research paper is to explore how the adoption process may differ between different types of medical technologies. Specifically, I would like to compare and contrast the adoption of electronic medical records (EMRs), robotic-assisted surgeries (RAS), and oral emergency contraceptives (ECs).

Background and Context

The field of medical technology is vast and encompasses a wide range of innovations that benefit patient care, treatment outcomes, and/or healthcare delivery. To compare the processes of different medical technologies, I have chosen three distinct technology sectors: electronic medical records (EMRs), robotic-assisted surgeries (RAS), and oral emergency contraceptives (ECs). These sectors were chosen because they gained momentum two decades ago and have been increasing in adoption practices since then. In addition, there is significant current relevance with all three, as well as present unique challenges and opportunities in their adoption processes.

Electronic Medical Records

Information and communication technologies have exploded since the 1990s and much research has been performed for its integration across all fields. However, the health sector has less of a successful integration compared to other fields, and complex factors must be thoroughly researched to enable the potential of this technology. Electronic medical records (EMR) manage the details of patient care, billing as well as general demographics and information (Cucciniello et al., 2015). Several sociological and technical factors have influenced the implementation of EMRs. In one study conducted at a large teaching hospital, physicians listed the main obstacle they encountered while using EMR was the great amount of time required for data entry by physicians, far more than expected (Greiver et al., 2011). With many physicians complaining of improper training, they viewed the EMR system as complex and inflexible. However, by 2021, nearly 96% of non-federal hospitals have a certified EMR system. Understanding how this innovation was able to diffuse is essential for other digitally based healthcare.

Robotic-Assisted Surgeries

A different sector of healthcare that will be explored is the recent advancement of robotic-assisted surgeries (RAS). This technology has expanded exponentially since its first introduction in 2001, and it is commonly used in urology, gynecology, and general surgery. RAS allows surgeons to operate with greater precision than traditional methods and has been cited to be more effective, however, recent discussions have arisen about the cost tradeoffs. Although RAS helps physicians and can be more accurate, some research has suggested that surgery risks and outcomes stay relatively similar (Dhanani et al., 2021). Yet, these robotic-assisted surgeries are continuing to expand despite the uncertainty of their usefulness. It will be necessary to understand why this technology is different from other advanced technologies of recent decades in terms of its adoption rates to have a better understanding of medical technology acceptance.

Oral Contraceptives

The last sector of healthcare that will be explored in this study is the pharmaceutical industry. As a huge contributor to the annual global medical health expenses, the pharmaceutical industry is crucial for efficient and reliable care. Physicians play an essential role as prescribers, and previous research has indicated that physician-targeted marketing, social agreement among physicians, and patient influence can greatly influence the diffusion of medical drugs (Liu & Gupta, 2012). However, these drugs vary significantly in terms of societal need, expectations, side effects, access, and results. In this paper, one type of medical pill will be explored: emergency contraceptives (ECs). For more than 40 years, physicians and researchers have been aware of contraceptive methods. However, it wasn't until the last 15 years that ECs became more widely known and marketed as an option for all women (Sundstrom et al., 2020). Exploring how

physician influence and patient influence can affect the adoption of these drugs will greatly help us understand how pharmaceutical drugs differ from other medical innovations.

By focusing on these three distinct technology sectors, this paper aims to understand the general adoption factors for medical technologies and context-driven specifications.

Theoretical Framework

From the 1960's, research has been performed examining the numerous factors that influence the adoption of medical technology. Many of these studies use various frameworks, with one of the most widely known being the Innovation Diffusion Theory (IDT), taken from Everett Rogers' pioneering work in 1962. According to IDT, before an individual decides to adopt a technology, they pass through two phases: knowledge and persuasion. An individual gains knowledge when they are exposed to technology and understand its mechanisms. Next, they enter the persuasion stage when they form a view based on the innovations' perceived attributes. Then, based on these perceived attributes, an individual will decide to either adopt or reject the innovation (Rogers, 1995).

In this paper, I would like to use the Diffusion of Innovations theory to analyze how these medical innovations have spread through society. There are five attributes of an innovation that influence its perception and therefore adoption. These attributes are relative advantage, compatibility, complexity, observability, and trialability.

Relative Advantage refers to how superior an innovation appears compared to the existing alternatives. This includes many factors such as economic benefits, convenience, satisfaction, or prestige. It is one of the most important factors in the final adoption of an innovation and can significantly predict how quickly an innovation gets adopted.

Compatibility refers to how well an innovation fits with existing values and needs of users. Some people judge innovations based on the "culture" of technology and whether it represents them before they choose to adopt it.

Complexity refers to how difficult an innovation is to understand or use. Users are more likely to adopt innovations that are simple, straightforward, and have a less steep learning curve.

Observability refers to how visible an innovation or its results are to potential users. If an innovation is not popular or the results are not well-known, users are less likely to adopt it.

Trialability refers to how easily a user can try out the innovation before fully committing to it. If there is a large set-up cost or requirements to train new staff, it may take longer for widespread adoption.

These attributes from Roger's IDT will be used to compare how electronic medical records, robotic-assisted surgery, and oral contraceptive technologies are adopted differently.

Methods

A comparative analysis is performed by examining existing publications describing the adoption of each of the three medical technology types. Peer-reviewed articles were searched for from the databases of Google Scholar and University of Virginia Library Catalogs. Some of the search terms included: 'pharmaceutical drugs', 'robotic-assisted', 'electronic medical record', along with 'physician adoption,' 'challenge,' 'implementation', or 'diffusion of innovation.' Primary source studies are included as well as literature review sources, and quantitative analysis of factors of adoption within these sources were taken highly into consideration.

After the collection of sources, the diffusion of innovations framework was applied to each of the three technologies. By focusing on one technology at a time, all of the sources were

examined to see how often each attribute of the IDT was mentioned. A scale of 1-5 was given for each attribute, with 1 being that a particular attribute is the greatest hindering factor for that technology to be implemented fully. A score of 5 is given to attributes that are positively mentioned in literature or not seen as a problem at all. One exception to this rating is that the attribute "complexity" of the traditional IDT was modified to be "simplicity" so that a higher score reflects the same extreme as the other attributes. This would mean that a perfect score of 25/25 reflects an innovation that has a high relative advantage over existing alternates, is compatible with current hospitals, is simple to use, has a memorable presence in the market, and can easily be tested by physicians. While it is rare for any innovation to acquire all of these characteristics, the scores from each attribute are weighted equally to make comparative analyses between technologies easier.

Results

Electronic Medical Records

Electronic medical records have a high relative advantage over the previously existing systems of manual paper records which have been in decline since the 1980's. 80% of hospitals in the US had a basic form of EMRs by 2017, replacing the previously existing systems of manual paper records that have been in decline since the 1980s ((Adler-Milstein et al., 2017), (Berner et al., 2005)). One study found that clinical staff were optimistic about EMRs because they provide a central location and immediate access to patient data, which reduces time scouring through different data files such as patient administration papers (Cucciniello et al., 2015). This would indicate that EMRs have a high relative advantage over manual records by saving time and promoting more detailed patient records. However, it was difficult to implement

EMRs because of the long training time needed. Staff who are more technologically competent had an easier time learning to use the EMR systems, but this complicated the process of receiving real-time data because few staff started using the system before others, forcing everyone to check both online systems and physical papers simultaneously for accurate patient information (Terry et al., 2008). This steep learning curve meant that EMRs had low simplicity and low compatibility with existing physician skill sets. In addition to the difficult learning curve, EMRs have a neutral observability because this technology was one of the fastest-growing medical systems in the 2000s and well encouraged by those who have successfully adopted it. However, the extent of this technology's benefits was not properly understood by many physicians because of the long training time. This would mean that many physicians underused this system and experienced suboptimal results for up to years at a time. Therefore, EMRs can have a low trialability if they are not able to experience maximum benefits without strenuous time and effort.

Robotic-assisted Surgeries

In the early stages of the adoption of RAS, physicians were attracted to RAS because of its perceived usefulness with increased precision, better visualization, and easier access (BenMessaoud et al., 2011). Because of public advertisement and media coverage, patients trusted RAS and were more attracted to hospitals offering these services. However, technical superiority and cost benefits were unclear of this technology and evidence suggests that patient outcomes are not significantly better with RAS than the traditional methods, with physicians continuing to report personal satisfaction but not better patient outcomes (Dhanani et al., 2021). Therefore, although there is a perceived advantage for hospitals to use RAS if they wish to be

seen as innovative and technically advanced, the high setup and training costs along with average patient outcomes show there is a marginal relative advantage to RAS.

The compatibility of RAS in general is highly dependent on the hospital system. For medium-large hospitals and medical schools, there is often a culture and promotion of innovation, and for these centers, RAS can be highly compatible with their values (Cundy et al., 2014). For smaller or safety net hospitals, innovation may not be as high of a priority, and therefore RAS is not highly compatible with their current staff.

RAS is a highly complex procedure and requires long and difficult training for many types of staff. Surgeons are used to feeling organs during surgeries, and surgeons have stated they need at least 25 surgeries to learn to "feel" with their eyes (BenMessaoud et al., 2011). In addition, nurses and technicians must also receive additional training, which is difficult during their busy days.

After the early minority of adopters reported success with RAS, many physicians increased efforts to educate their peers. These skilled physicians would move hospitals, taking their skills with them, and allow for proctored audiences on their surgeries. Although there was literature and online videos on how to use these tools, the ability to observe RAS live and discuss technical failures or risks became a primary factor for the second and third-wave physician adopters ((Compagni et al., 2015). This results in high observability for this technology and possible trialability.

Oral Contraceptives

Emergency contraceptives have a high relative advantage over other methods for contraception with an effective rate of 75-89% (Cunnane et al., 2006). The alternates of

hormonal methods are not recommended as emergency measures, and surgical methods are expensive and risky, which prevents access to many rural or lower-income women (Robinson et al., 1996). Although ECs still have a high cost, they also provide privacy and convenience, making them one of the best choices on the market.

ECs do not score highly on compatibility. One study in 2013 in Quebec found that one-third of the nurses interviewed did not prescribe contraceptives, despite completing the necessary training (Guilbert et al., 2013). This is because some providers decide based on their own beliefs and values which users are "appropriate," and therefore should be prescribed to. In addition, other physicians believe the patient must bring up the topic of contraceptives during a visit and not themselves, which is contrary to what many patients feel (Robinson et al., 1996). While in the past decade, ECs have been more commonly used, the lack of discussions between physicians and patients is continuing to be a barrier for prescription-based ECs.

The lack of discussions is further worsened by the lack of knowledge among potential users and physicians. Emergency contraceptives are so little used or understood by users and physicians, making it more difficult for physicians to discuss comfortably all of the contraception options (Hickey, 2009). This indicates a poor observability for ECs. Lastly, similar to all oral drugs, ECs have a high simplicity and trialability because there is often a one-time purchase and minimal set-up costs.

***Table 1**: Summary of Attribute Scores*

Innovation Type	Relative Advantage	Compatibility	Simplicity	Observability	Trialability	Total Score
Electronic Health Records	5	2	1	3	2	13/25

Robotic-Assisted Surgical tools	3	3	1	5	2	14/25
Oral Contraceptives	5	2	4	2	3	16/25

Discussion

The results of this comparative analysis show that the sums of all attribute scores among the technologies are relatively similar (Table 1). This makes sense if we consider that all of these technologies have gained momentum in the early 2000s and are being widely used right now. Electronic medical records are the only technology to be fully implemented in the current day, and that is because the US implemented legislation to mandate the adoption of electronic medical records by all public and private healthcare providers in 2014. While we are not sure how the adoption rates of EMRs will be today without this legislation, we can best reason that the implementation challenges will be the same as before.

Oral contraceptives had the highest sum for total positive attributes, yet this does not reflect the current day in terms of being widely used. While contraceptives are accessible to most residents in the US, this study fails to consider unwanted pregnancies in different cultures and countries. The political influences and current legislature on emergency contraceptives have a heavy influence on current usage. This is exemplified within certain states that are politically to the right within the US, and in which they have increased barriers to these contraceptives. Therefore, while ECs have a high relative advantage score, the low compatibility score should be taken into greater consideration for the final adoption rates.

The number of RAS has been rising every year in the US and worldwide, with the highest number of RAS occurring in the US. This technology is unique compared to the others in that

despite a lower relative advantage concerning technical superiority, the high score of observability promotes the adoption of RAS.

These findings show that technologies often have a variety of advantages and disadvantages, with rarely any technologies having a high score among all attributes. Literature suggests that relative advantage and compatibility should be the greatest predictors of current adoption rates (Sanson-Fisher, 2004). While this study cannot support or deny these claims, it can be seen that an average relative advantage and compatibility score is present at a minimum on all of these technologies. It may be difficult for a technology to succeed with a low relative advantage and compatibility score, even with the competitive presence of other attributes. However, the vice versa may not be true, where a high relative advantage and compatibility scores with low simplicity, observability, and trialability may not indicate a difficult adoption rate.

Limitations exist in this study because there is not an equal amount of literature or peer-reviewed articles on these technologies. In total, there were four studies used to investigate the adoption practices of EMRs for this report, four studies for RAS, and five studies for ECs. The diffusion of innovations framework has been used to study electronic medical records before and made it easier to convert to a numeric score for this review. However, there are no studies that use this framework for individual medical drugs. Because the literature for RAS and ECs had to be reviewed and simplified to a different degree than others, there may be bias and missing important information when converting to this framework. Other attributes may be more relevant to these technologies than the attributes included in this framework. In addition, while many of these studies in this report are US-based, there are quite a few from other countries. Changing the

physician or user demographics may have had important effects on the scores of these technologies and confounded the results.

To further improve this report, a primary evidence collection would be helpful rather than conducting a literature review. This would include creating a questionnaire about physicians' perceptions that can precisely measure the scores of all five attributes. This survey can then be handed directly to physicians who interact with any of the three technologies. Using the same survey for all three technologies would reduce bias and allow for statistical hypotheses to be tested.

Conclusion

Three different medical technologies were compared in this study: electronic medical records (EMRs), robotic-assisted surgeries (RAS), and oral emergency contraceptives (ECs). By using the Innovation Diffusion Theory (IDT), this report analyzed the important factors relevant to the adoption of these three technologies. The five key attributes that were used to compare were: relative advantage, compatibility, simplicity, observability, and trialability.

The findings from this study report nuanced differences between the technologies. EMRs, despite their high relative advantage, have faced challenges in simplicity and trialability. RAS, while having high observability, does not have high compatibility, simplicity, or trialability. ECs have great relative advantage scores but suffer from low compatibility and observability. Most technologies will have advantages and disadvantages during their implementation. Understanding how these key innovations have been perceived and implemented over the past two decades will be invaluable for a more efficient and transparent healthcare system in the future.

References

Adler-Milstein, J., Holmgren, A. J., Kralovec, P., Worzala, C., Searcy, T., & Patel, V. (2017). Electronic health record adoption in US hospitals: The emergence of a digital "advanced use" divide. *Journal of the American Medical Informatics Association : JAMIA*, *24*(6), 1142–1148. https://doi.org/10.1093/jamia/ocx080

BenMessaoud, C., Kharrazi, H., & MacDorman, K. F. (2011). Facilitators and Barriers to Adopting Robotic-Assisted Surgery: Contextualizing the Unified Theory of Acceptance and Use of Technology. *PLOS ONE*, *6*(1), e16395. https://doi.org/10.1371/journal.pone.0016395

Berner, E. S., Detmer, D. E., & Simborg, D. (2005). Will the Wave Finally Break? A Brief View of the Adoption of Electronic Medical Records in the United States. *Journal of the American Medical Informatics Association*, *12*(1), 3–7. https://doi.org/10.1197/jamia.M1664

Compagni, A., Mele, V., & Ravasi, D. V. (2015). How Early Implementations Influence Later Adoptions of Innovation: Social Positioning and Skill Reproduction in the Diffusion of Robotic Surgery: Academy of Management Journal. *Academy of Management Journal*, *58*(1), 242–278. https://doi.org/10.5465/amj.2011.1184

Cucciniello, M., Lapsley, I., Nasi, G., & Pagliari, C. (2015). Understanding key factors affecting electronic medical record implementation: A sociotechnical approach. *BMC Health Services Research*, *15*(1), 268. https://doi.org/10.1186/s12913-015-0928-7

Cundy, T. P., Marcus, H. J., Hughes-Hallett, A., Najmaldin, A. S., Yang, G.-Z., & Darzi, A. (2014). International attitudes of early adopters to current and future robotic technologies in pediatric surgery. *Journal of Pediatric Surgery*, *49*(10), 1522–1526. https://doi.org/10.1016/j.jpedsurg.2014.05.017

Cunnane, M. S., Dickson, G., & Cook, R. L. (2006). Women's Experiences with Emergency Contraception in an Internal Medicine Practice. *Journal of Women's Health*, *15*(9), 1080–1089. https://doi.org/10.1089/jwh.2006.15.1080

Dhanani, N. H., Olavarria, O. A., Millas, S., Askenasy, E. P., Ko, T. C., Liang, M. K., & Holihan, J. L. (2021). Is robotic surgery feasible at a safety net hospital? *Surgical Endoscopy*, *35*(8), 4452–4458. https://doi.org/10.1007/s00464-020-07948-z

Greiver, M., Barnsley, J., Glazier, R. H., Moineddin, R., & Harvey, B. J. (2011). Implementation of electronic medical records: Theory-informed qualitative study. *Canadian Family Physician Medecin De Famille Canadien*, *57*(10), e390-397.

Guilbert, E. R., Rousseau, M., Guilbert, A. C., Robitaille, J., Gagnon, H., & Morin, D. (2013). Process Evaluation of a Task-Shifting Strategy in Hormonal Contraception: Does Training Translate into Practice? *Journal of Obstetrics and Gynaecology Canada*, *35*(12), 1090–1100. https://doi.org/10.1016/S1701-2163(15)30759-3

Hickey, M. T. (2009). Female College Students' Knowledge, Perceptions, and Use of Emergency Contraception. *Journal of Obstetric, Gynecologic, & Neonatal Nursing*, *38*(4), 399–405. https://doi.org/10.1111/j.1552-6909.2009.01035.x

Liu, Q., & Gupta, S. (2012). A Micro-level Diffusion Model for New Drug Adoption. *Journal of Product Innovation Management*, *29*(3), 372–384. https://doi.org/10.1111/j.1540-5885.2012.00912.x

Robinson, E. T., Metcalf-Whittaker, M., & Rivera, R. (1996). Introducing Emergency Contraceptive Services: Communications Strategies and the Role of Women's Health Advocates. *International Family Planning Perspectives*, *22*(2), 71–80. https://doi.org/10.2307/2950736

Rogers, E. M. (1995). Diffusion of Innovations: Modifications of a Model for Telecommunications. In M.-W. Stoetzer & A. Mahler (Eds.), *Die Diffusion von Innovationen in der Telekommunikation* (pp. 25–38). Springer. https://doi.org/10.1007/978-3-642-79868-9_2

Sundstrom, B., Smith, E., Vyge, K., Miletich, A., Benigni, G., Delay, C., Mann, E. S., & DeMaria, A. L. (2020). Moving Oral Contraceptives over the Counter: Theory-based Formative Research to Design Communication Strategy. *Journal of Health Communication*, *25*(4), 313–322. https://doi.org/10.1080/10810730.2020.1752334

Terry, A. L., Thorpe, C. F., Giles, G., Brown, J. B., Harris, S. B., Reid, G. J., Thind, A., & Stewart, M. (2008). Implementing electronic health records. *Canadian Family Physician*, *54*(5), 730–736.