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Factors Influencing Surgeon Adoption of Technology in the Medical Device Industry

Sean Reynolds

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Factors Influencing Surgeon Adoption of Technology in the Medical Device Industry

by

Sean Reynolds

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree

Of

Doctorate in Business

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ACCEPTANCE

This dissertation was prepared under the direction of the *SEAN REYNOLDS* Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Business Administration in the J. Mack Robinson College of Business of Georgia State University.

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DEDICATION

This work is dedicated to my biological mother, Frances Reynolds, with whom this doctoral journey was established as a young child growing up in Detroit, MI. Her vision and words were bestowed and imprinted into my psyche long before I knew I would genuinely endeavor in this intellectual achievement. Thank you, Mom!

With love and appreciation, I also dedicate this work to my adoptive mother, Carolyn E. Johnson and sisters, Karen, and Nicole. Thank you so much for your support and encouragement during this process. Your words and cheers help to keep me motivated and focused. This is an accomplishment that we can relish in together because I would not have accomplished it without you all!

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LIST OF ABBREVIATIONS

3DP – 3D Printed
AT – Attitude Towards Technology
BI – Behavioral Intention to Use
DV – Dependent Variable
HF – Hospital Factors
I – Image
IT – Information Technology
IU – Intention to Use
IV – Independent Variable
JR – Job Relevance
L – Loyalty
MRI – Magnetic Resonance Imaging
OQ – Output Quality
PEEK - Polyetheretherketone
PEOU – Perceived Ease of Use
PU – Perceived Usefulness
QR – Quick Response
RD – Results Demonstrability
SN – Subjective Norm
TAM – Technology Acceptance Model
TAM-C – Technology Acceptance Model Clinical
TPB – Theory of Planned behavior
TRA – Theory of Reasoned Action
TRI – Technology Readiness Index
UTAUT – Unified Theory of Acceptance and Use of Technology
V - Voluntariness

ABSTRACT

Factors Influencing Surgeon Adoption of Technology in the Medical Device Industry

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Sean Reynolds

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The medical device industry can be quite competitive, and companies that succeed tend to provide innovative solutions that are adopted by surgeons for clinical use in surgery. However, successful clinical adoption of technology is often problematic for some companies, and this research aims to determine which behavioral factors influence surgeon adoption of technology in the medical device industry. This empirical investigation uses the Technology Acceptance Model 2 (TAM2) to test the relationships between technology acceptance and variables that impact surgeon behavior. This research examines spine surgeons' adoption of 3D-printed implants used in surgery, and the results suggest that subjective norms, job relevance, and output quality represent predictors of a positive intention to use technology, which denotes a positive influence on technology adoption. Environmental and economic hospital factors have a moderating effect on the relationship between intention to use and 3D-printed implant adoption. These results contribute to research by extending the framework of the TAM2 to clinical adoption while testing for additional factors that have not historically been measured. The results also provide practitioners with insights to create marketing campaigns to address the behavior variables that influence surgeon adoption of technology.

INDEX WORDS: Theory of Reasoned Action, Theory of Planned Behavior, Technology Acceptance Model, TAM, TAM2, Surgeon, Adoption, Subjective Norm, Hospital Factors, Medical Devices, 3D Printing, Surgery, Perceived Usefulness, Perceived Ease of Use, Intention to Use, Behavioral Intent

I CHAPTER 1. INTRODUCTION

I.1 Introduction to the Problem

Organizations consistently seek new ways to remain competitive amongst peers, and a competitive edge is often attained through the launch of new, innovative products (Tellis, Prabhu & Chandy, 2009; Clark & Guy, 1998). These new products are touted as being better than the norm and often may entail significant pricing to offset the research and development invested in designing the products. New, innovative products are unfortunately not necessarily adopted by their target consumer, which is evident across many industries but especially in healthcare, and more specifically, the medical device industry. The adoption of medical technology is not necessarily linear from the innovation process to adoption as there are factors that will impact the adoption process (Gelijns & Rosenberg, 1994). Surgeon users are often the target audience of this industry's innovations and influence the success of these devices. The products are usually designed using surgeon input to address surgeon needs and promote adoption of these devices. Some technologies enjoy successful adoption from clinicians due to improved clinical outcomes, reduced operating times, greater efficiencies, or cost savings to the procedure (not necessarily the cost of the technology). The successful adoption of these products is necessary for the continued growth of some organizations, as companies spend significant research, development, and marketing funds to bring these products to market. However, strategic and tactical marketing plans can be arbitrary and conceptually flawed (Varadarajan, 2010). The marketing plan may be based on intuition. Targeting and success are measured based on the comparison of historical sales revenue of similar older products. Depending on the product, this "intuition" may be quantified and estimated based on variables such as surgeon age, the volume of surgical procedures, or industry influence. These sales and marketing plans generally follow the process for diffusion models (Rogers, 2003) in which surgeon targets equate to “innovators,” and are projected to influence the “majority”. This approach does not always translate into increased sales (Mahajan & Muller, 1998). The product adoption can, unfortunately, be hit or miss. Although these models describe sales and marketing timing techniques, they do not provide insight into the decision process (Roback et al., 2007) by surgeons. Thus, sales and marketing techniques create a need for more defined ways to successfully target surgeons and determine what drives their adoption behaviors.

Due to the constant addition of new technologies in the medical industry and specifically the spine industry, there needs to be a better understanding of why surgeons adopt certain technologies as opposed to others. Companies that launch these new products need to understand better the underpinnings regarding what influences surgeon adoption rates (Hatz et al., 2017). Thus, allowing marketing strategies to be better designed and implemented will help position these products for surgeons who are more willing to adopt new technologies.

Research has shown that there is a need for more sophisticated marketing managers who can more broadly influence new product success, performance, and profitability (Cake, 2010). However, these marketers also need more advanced insight into their customer base and into what drives their customers towards technology adoption. Customers may not wholly realize their exact needs and how the technology may assist them, so it is incumbent on marketing professionals to uncover new ways to identify these unarticulated motivations (Cake, 2010). This research seeks to explore these motivations and hopefully provide insight into surgeon factors that influence their adoption of technology.

This research investigates the factors that influence spine surgeon adoption of innovative technologies utilized in the spine sector of the medical device industry. This sector is the focus because this surgical environment is currently ripe with access to new technologies that could impact spine surgeries globally. Surgeons often trial and adopt new technologies that affect how they operate. Many of these technologies are promoted by medical device companies to enable surgeons to operate quicker, more efficiently, more safely, and with improved clinical outcomes. There is occasionally clinical evidence to support these claims, but often there is none. As a result, surgeon adoption can be challenging as many surgeons may not adopt new technologies since they do not want to change current practices. Recent innovations such as three-dimensional printing (3DP), also known as additive manufacturing, has created new opportunities for spinal implant companies and provided surgeons with surgical implants and tools that could significantly impact successful patient recovery post-operatively. The possibilities for companies developing these innovations are numerous, such as the reduced cost of goods, improved research and development design timelines and new device creation that is difficult or impossible using traditional manufacturing processes (Tack et al., 2016). For surgeons and patients, these new 3D-printed implants and tools have the potential to improve clinical performance and outcomes, such as improved fusion rates in patients, which will aid in their surgical recovery (Kim et al., 2017). Many organizations within the medical device industry often target younger surgeons or surgeons with high surgical volumes, which assumes that these populations more readily adopt new technology. Approaches such as targeting high-volume users are chosen for business reasons; however, adopting surgeons' reasons for selecting the technology is not always clear. This approach may ignore other variables that ultimately affect surgeon adoption, and they may adopt technology but discontinue use a few months later. This research intends to provide a more insightful and validated method of successfully marketing these new technologies and subsequent others to surgeons. The focus of this research is on examining 3D-printing technology adoption among surgeons, including facilitators and barriers to technology adoption.

I.2 Barriers to New Technology Adoption

New technology has always faced the challenge of potentially not being adopted, and usually, new technologies are associated with start-up organizations. If surgeon users do not adopt these new technologies, it can threaten a company's survival. Large companies are not unscathed by non-adoption since they must account for the lost revenue. However, it should be noted that new, innovative devices typically originate from small companies.

What ultimately impacts new technology adoption? The literature has identified six barriers: cost, legality (regulatory), time, fear, usefulness, and complexity (Garrett et al., 2016; Gelijns et al., 1991, Chapter 6; Citron, 2011). Of these barriers, those most associated with the direct user include time, fear, usefulness, and complexity. The others are more organizationally based since hospitals are more concerned with cost and legality (regulatory approvals) (Egeland et al., 2017).

Regarding the influences on the customer concerning time, if the technology takes too long to master, this will impact the adoption. Surgeons can be an impatient customer, and thus the technology must be straightforward. This is closely related to complexity since sophisticated technology runs the risk of slow adoption rates. Another aspect that minimizes adoption concerns is fear. In this litigious society, surgeons do not want to adopt technology that will harm their patients and ultimately impact their clinical practice. Thus, the technology must be vetted and proven (Lieberman & Wenger, 2004). Finally, usefulness represents the most critical aspect as the technology should provide clinical benefits to the surgical procedure and ultimately positively impact the patient's clinical outcome (Hogaboam & Daim, 2018).

The barriers to new technology adoption can be overcome, but only if the concerns of the customers and organizations are addressed. Once these entities are satisfied, the technology's "desirability, acceptability, feasibility can lead to adoptability" (Ulucanlar et al., 2013).

I.3 3D Printing Technology

The 3D-printed medical device market is projected to grow from $973M in 2018 to $3.69B by 2026, with a compounded annual growth rate of 18.2% (Kunsel & Sumant, 2019). The drivers of this growth include the applications and benefits that many in the medical arena find to be game-changing. The historical benefit of 3D printing was rapid prototyping, but it has become a powerful manufacturing technology that allows for speed, customization, and minimization of waste (Ben-Ner & Siemsen, 2017). This technology has allowed companies to manufacture devices that were traditionally impossible or cost-prohibitive to manufacture via the historical method of subtractive manufacturing (Kunsel & Sumant, 2019). Subtractive manufacturing involves milling or cutting material away from a solid block of material via a computer numerical control (CNC) machine. In additive manufacturing, products are constructed by depositing material in layers in a computer-aided design (CAD) shape

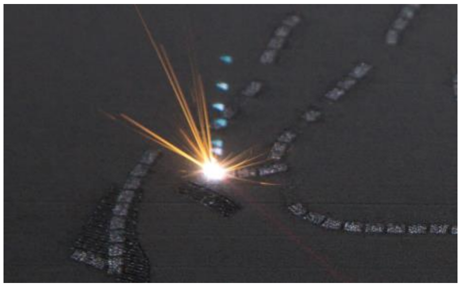

Figure 1 3D Printing Laser Process

Source: 3D Systems

and using lasers to bond the material (Figure 1). This process is completed layer by layer until the final product is complete. In recent years, the machinery used for additive manufacturing has become much more affordable, thus accelerating the adoption of this technology for the manufacturing process (Figure 2).

Figure 2 3D Printer, DMP Factory 350

Source: 3D Systems

Although this manufacturing process benefits the medical costs of goods (Ventola, 2014), it also provides benefits clinically, such as in surgical planning. 3D printing allows clinicians to plan more difficult procedures by utilizing 3D-printed models of the anatomy or of existing surgical hardware previously implanted (Figure 3). These models allow the clinician to plan the surgery to mitigate and account for potential difficulties during the procedure (Lah & Patralekh, 2018). This planning utilizes advanced 3D spatial and computerized planning software (Figure 4), which allows the clinician to account for anatomical differences and product specifications. The software results are then programmed into the 3D printer to print the resultant model, which is used pre-operatively and intra-operatively for surgical planning.

Figure 3 3D Printed Surgical Spine Model

Source: 3D Systems

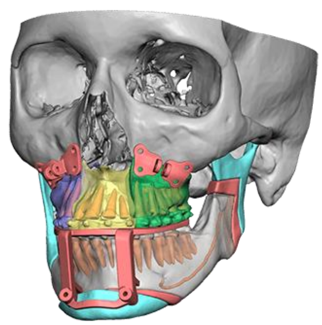

Figure 4 3D Systems VSP Planning Software

Source: 3D Systems

Additional beneficial clinical uses of 3DP include the creation of cutting guides, customized, patient-specific implants and standardized implants, which assist the surgeon in providing clinical options to patients to help improve procedural work-flow, and patient fit and clinical outcomes (Mobbs et al., 2017; Wang et al., 2016; Wilcox et al., 2017). 3DP has benefitted multiple specialties and continually proves to have beneficial future capabilities concerning the 3D printing of tools, different biomaterials such as ceramics or Polyetheretherketone (PEEK) (Honigmann, 2018), bioprinting of bone and cartilage (Brown, 2017; Lal & Pratralekh, 2018; Yan et al., 2018), and the biological printing of organs (Yan et al., 2018). Although there are plentiful clinical uses of 3DP (Ventola, 2014), this research investigates the surgeon adoption of 3DP in spinal implants.

I.4 3D Printed Implants: Spine Application

Various materials are used to make implants in spine surgeries, including screws, interbody spacers, vertebral body replacement, and rods. The most commonly utilized materials to make interbody implants are titanium and PEEK, which are both used to restore disc height between vertebral bodies while alleviating nerve impingement and reducing spinal instability (Iorio, Reid & Kim, 2016). Fusion is desired since it creates further rigidity in the spine to assist the patient in recovery.

There are inherent advantages and disadvantages to both materials (Seaman et al., 2017). Titanium has positive biocompatibility that allows osteoinduction and osseointegration of adjacent bony structures (Raines et al., 2010). As described by Albrektsson and Johansson (2001), osteoinduction is the process by which bone grows on a surface and osseointegration is the stable fixation of an implant via direct bone-to-implant contact. The negative aspect of titanium is that it is often challenging to determine fusion using radiographic imaging. The mass of solid titanium often causes magnetic resonance imaging (MRI) scatter, which complicates the recognition of nearby bony anatomy (Ernstberger, Buchhorn & Heidrich, 2009).

PEEK has positive radiographic imaging due to its translucence, and thus a surgeon can identify the potential fusion since they can see through the implant. PEEK may promote fusion when coupled with appropriate bone grafting material; however, fusion onto the PEEK material may not be possible due to the hydrophobic nature of PEEK (Phan et al., 2016). Fusion onto the material helps promote osseointegration; however, PEEK is also expensive to manufacture due to the raw materials. There have been attempts to design large windows into titanium interbodies or vertebral body replacement cages. Still, cages can use a limited number of openings before compromising the implant's structural integrity. Companies are marketing titanium-coated PEEK devices to help promote bony ingrowth onto the implant. However, due to minimal spacing between the vertebral bodies, PEEK coated with titanium often shed upon implantation, effectively losing their fusion enhancements (Torstrick et al., 2018).

3DP (additive manufacturing) affords many advantages compared to prior options. For example, a titanium implant can be created with porosity throughout the entire implant rather than solely the center of the implant (Figure 5).

Figure 5 Stryker Spine 3D Printed Implants

Source: Stryker Spine

The implant walls can be porous, which helps promote bony fusion in and through the implant. Titanium also has a strong affinity to bone, and thus 3D-printed surfaces are often rough and promote the necessary bony surface adhesion properties required for fusion (McGilvray et al., 2018). Also, 3D-printed implants with porosity have more favorable radiographic imaging qualities that allow a surgeon to assess the fusion across the implant (Furlow, 2017). The 3DP process now allows for more complicated and customized designs (Figure 6) to be created cost-effectively compared to traditional machining or extrusion techniques. From a manufacturing perspective, it is more cost-effective to develop implants via additive manufacturing (Garg & Mehta, 2018). From a clinical perspective, fusion rates could be improved compared to traditional solid titanium or PEEK implants (Kim et al., 2017). There are unfortunately few long-term clinical studies that validate these claims (Wilcox et al., 2017), and such studies over time will further examine the potential impact of 3DP implants on spinal surgery.

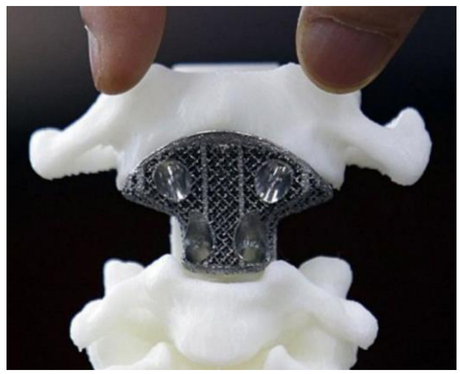

Figure 6 Customized Cervical Implant

Source: https://www.foxnews.com/health/first-ever-3d-printed-vertebra-implanted-in-12-year-old-cancer-patients-spine

This research attempts to show what intrinsically motivates spine surgeon adoption of 3DP technology and to determine whether there are correlations between social norms, clinical variables, and surgeon or hospital factors with the adoption of this technology. This research can provide sales and marketing departments of medical device organizations with a template of why adoption occurs as opposed to intuitive conjecture.

The research findings could influence how medical device organizations market new technology, and the results should provide new insights into how and whom to commercialize these technologies in the spine sector of the medical device industry. The same correlations could also be applied to all surgeons within the medical device industry to influence marketing activities.

Another practical use of this research regards further refining customer segment targeting when launching new technology, as marketing firms can utilize this research to target surgeon profiles that are shown by the research to be more open to technology adoption.

II CHAPTER 2: LITERATURE REVIEW

A plethora of research has investigated the adoption of technologies, creating numerous theories and frameworks such as the diffusion of innovations theory (Rogers, 2003). This theory examines how communication is shared among individuals and organizations that lead to adopting technology over time. This has resulted in a widely utilized framework called the adoption curve (Figure 7), which classifies adopters into numerous categories such as innovators, early adopters, early majority, late majority, and laggards. The adoption curve is highly utilized in the medical device industry to categorize surgeon customers during customer segmentation exercises and serves as a quick method of segmenting surgeon adopters and helps identify marketing tactics to influence subsequent sales. This segmentation unfortunately never identifies the foundational behavior regarding why a surgeon adopts technology or not. There are consequently numerous other theories, such as the social network theory (Mitchell, 1969) or absorptive capacity theory (Cohen & Levinthal, 1990), which analyze adoption influences from a social network or corporate standpoint (Wisdom et al., 2014). Previous research has highlighted the strong impact of one’s social network on their subsequent adoption of innovation (Chor et al., 2015). For this research, the focus is on individuals’ behavioral influences that ultimately drive their behavioral intentions. Two historical theories that studied these phenomena are the theory of reasoned action (Fishbein & Ajzen, 1975) and the theory of planned behavior (Ajzen, 1985).

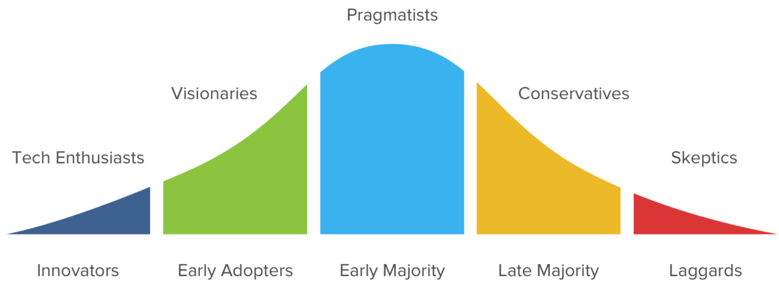

Figure 7 Roger's Adoption Curve

Source: www.crazyegg.com

II.1 Theory of Reasoned Action

This research investigates surgeon behavior concerning technology adoption, and its underlying theoretical influence by the theory of reasoned action (TRA) developed by Fishbein and Ajzen (Fishbein & Ajzen, 1975; 1980). The TRA seeks to explain how behavior is determined by the behavioral intent to emit the behavior. As depicted in Figure 8, the behavioral intention is influenced by attitudinal factors (one's attitude toward a behavior) and subjective norms (one's perceptions of what they think a group thinks they should do). This theory has been used to predict moral behavior. It assumes that one will behave sensibly, given that available knowledge inputs have been considered and influence their actions. The more favorable one's attitude and the influence of subjective norms, the higher the perceived control, and thus the more significant the intention to enact the behavior. This theory did not account for skills or resources that could impact the preferred behavior.

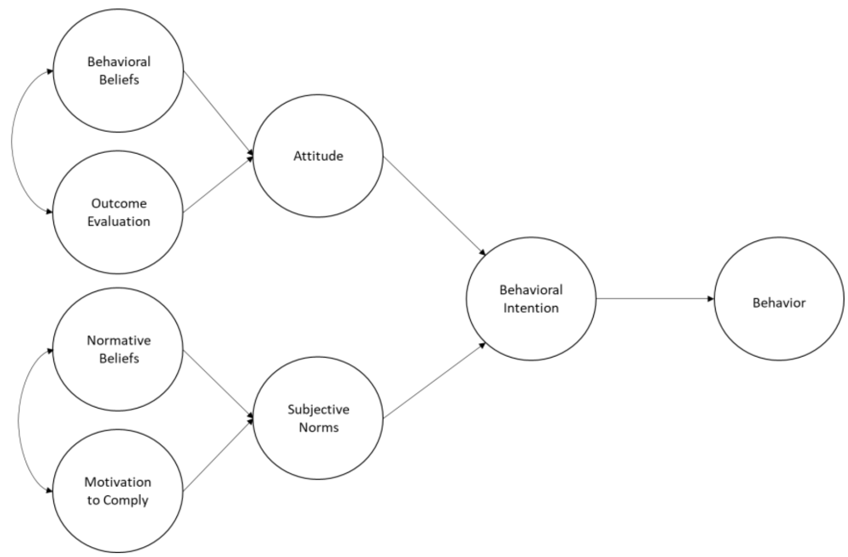

Figure 8 Theory of Reasoned Action Model

Source: Fishbein & Ajzen (1975)

II.2 Theory of Planned Behavior

In 1985, Ajzen sought to explain the TRA further and created the theory of planned behavior (TPB), which is a theoretical model to predict and explain human social behavior and serves as a framework for behavioral change interactions (Figure 9). He wanted to establish a methodology to measure the influence of behaviors and norms on intention and, ultimately, the resultant behavior. He noted that perceived behavioral control was not accounted for in the TRA, and thus the TPB would improve upon the TRA by measuring this construct. Perceived behavioral control describes one's behavior as being influenced by their self-confidence (Bandura, Adams, Hardy & Howells, 1980). Although the TPB attempts to measure normative influences, it does not account for environmental or economic influences, which could ultimately impact one's behavioral intentions (Abbas et al., 2018). This gap is also reflected in the technology acceptance model (TAM), which is rooted in the foundation of the TPB.

The TPB serves as the foundational theory for this study since the intent is to measure behaviors and norms to establish a correlation with surgeon adoption of technology. As a result, it was determined that the TAM, which is a model framework based on the TPB, would be needed to analyze surgeon adoption behaviors.

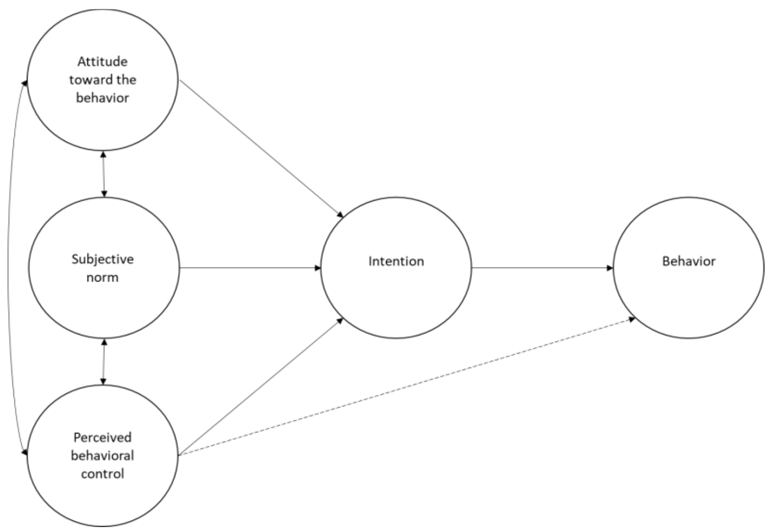

Figure 9 Theory of Planned Behavior Model

Source: Ajzen (1991)

II.3 Technology Acceptance Model

The TAM (Davis, 1989) was developed to guide research on technology adoption as a result of human behavioral elements (Davis, 1989). The TAM (Figure 10) was initially designed to explore the acceptability of an information system as well as how user behavior affects the adoption of information technology (IT) systems. It was created to be more specific than TRA which was more general in its analysis of behaviors (Davis, Bagozzi and Warshaw, 1989) The model was designed to fulfill three objectives. The first objective was to determine the significant variables that mediate between system characteristics and the actual use of computer-based systems by end-users in organizations. The second objective was to determine how these variables causally relate to one another, to system characteristics and user behavior. The third and final objective was to determine how user motivation can be measured before organizational implementation to evaluate the likelihood of user acceptance of the new system. The TAM measures these behaviors by using constructs that reflect one's perceived usefulness (PU) and perceived ease of use (PEOU) of the technology. These two constructs then influence users' attitude towards technology (AT), which ultimately influences the user's behavioral intention (BI) to use the technology. It should be noted that subsequent research has also referred to BI as intention to use (IU). From BI, there should be some level of adoption of the technology.

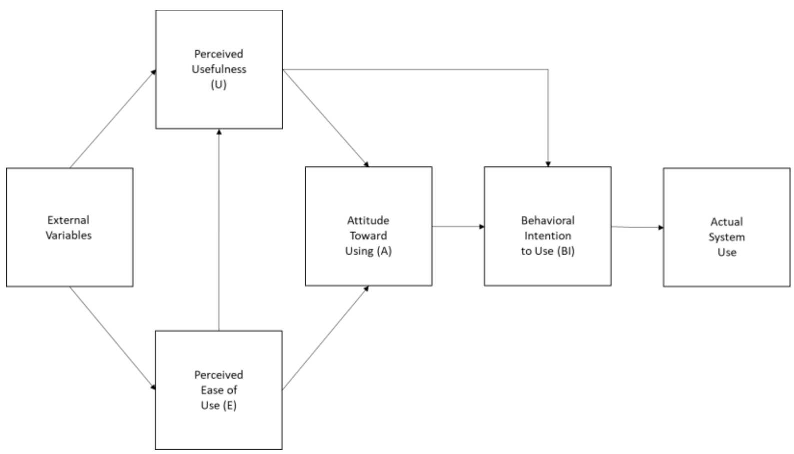

Figure 10 TAM Framework Model

Source: Davis, Bagozzi & Warshaw (1989)

The TAM has proven to be a validated framework for studying technology adoption across different areas, from consumer adoption to education to hospital management systems (Ratten, 2015; Nagy, 2018; Escobar-Rodriguez, 2012). In subsequent years since its inception, there have been many updates to the TAM. These updates are the final version of TAM by Venkatesh and

Davis (1996); the TAM2 by Venkatesh and Davis (2000); the unified theory of acceptance and use of technology (UTAUT) by Venkatesh, et al. (2003); and the TAM3 by Venkatesh and Bala (2008). Lai (2017) discussed these models and their respective contributions to studying technology adoption, specifically to IT. Minimal research has explored the various TAM frameworks when considering surgeon adoption of technology for clinical practices. In the few studies focused on healthcare, the TAM was limited to studies of electronic health records system adoption (Terrizzi, et al. 2012) and automated medication management systems in hospitals (Escobar-Rodríguez, Monge-Lozano & Romero-Alonso, 2012; Alemida, Farias & Carvalho, 2017). The lack of TAM framework application to clinical adoption marks a gap in the body of knowledge in this area. The majority of the TAM's healthcare applications have been towards healthcare IT and healthcare mobile technology adoption (Barker et al., 2003; Chang et al., 2003; Chau & Hu, 2001; Chen et al., 2007; Duyck et al., 2008; Holden & Karsh, 2010; Hu et al., 1999; Liang et al., 2003; Liu & Ma, 2005; Pare et al., 2006; Rawstorne et al., 2000; Schaper & Pervan, 2007; Tung et al., 2008; Wu et al., 2007; Yi et al., 2006). In addition, as noted with the TPB, the TAM does not account for additional environmental or economic factors.

II.4 Technology Acceptance Model 2

The TAM2 (Venkatesh & Davis, 2000) framework (Figure 11) is utilized in this study to help determine which factors influence surgeon adoption of technology for clinical usage. The Venkatesh model established new constructs encompassing social influence (subjective norms, voluntariness, and image) and cognitive instrumental processes (job relevance, output quality, result demonstrability, and perceived ease of use) as determinants of perceived usefulness and usage intentions. Based on the other TAM frameworks, this framework is closely aligned with the processes observed in surgeon decision-making when evaluating technology for clinical use based on the cognitive instrumental and social influence processes. For this study, the TAM2is applied to surgeon adoption; however, this model requires modification to reflect the gap of healthcare-related factors that may influence the model. This gap is discussed in detail in the theoretical framework section.

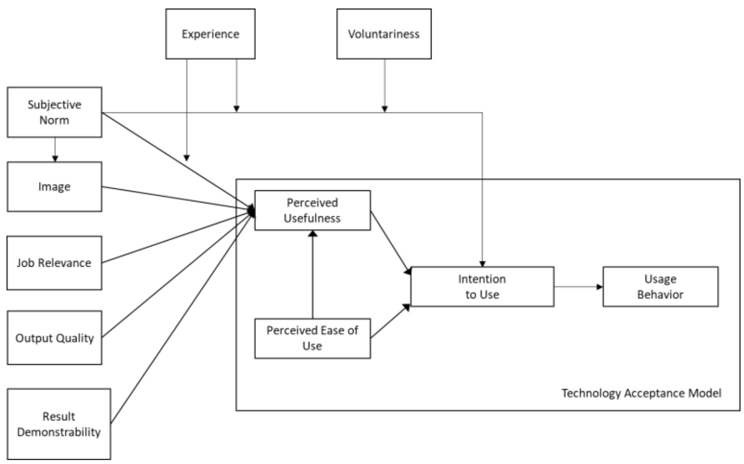

Figure 11 TAM2 Framework Model

Source: Venkatesh & Davis (2000)

II.5 Theoretical Importance

This research investigates factors that influence surgeon adoption of technology in the spine industry. These factors are measured using the TAM2, which was modified to examine potential moderation from additional external variables, which are critical to the surgeon decision process concerning technology adoption. Two authors had different approaches to applying the TAM2. The first study examined the use of TAM2 and its applicability to pediatricians and their adoption of internet-based health applications (Chismar & Wiley-Patton, 2003). The second author published an article that postulated the potential use of TAM to enhance infusion pump use in healthcare (Strudwick, 2015). This application was the closest of any of the TAM models concerning clinical adoption intentions. This study further builds upon applying the TAM2 in the healthcare setting regarding the clinical adoption of technology used in surgery. Thereby adding to the body of knowledge since the majority of healthcare research employing the TAM has been focused on healthcare-related IT rather than on different modes of technology such as surgical products (e.g., 3D-printed implants). The results of this research could also assist in drafting marketing strategies that organizations can use better to influence surgeon adoption of their newly designed technology products.

This research includes both theoretical and practitioner importance. The framework developed by Venkatesh and Davis (2000) forms the foundation of this research in examining the external factors that influence surgeon adoption of technology, specifically spinal surgeons' adoption of 3D-printed implants. It is theoretically relevant to test the TAM2 frameworks of Venkatesh and Davis (2000) within the surgical domain to determine further whether the TAM2 can be applied to clinical settings rather than solely the historical IT setting. This research will also advance the understanding of how external factors can impact surgeons' behavioral intentions concerning technology adoption. This empirical study will help to contribute to the body of TAM knowledge by answering the research question: ***What factors influence the surgical adoption of emerging technology in the medical device industry?***

III CHAPTER 3: RESEARCH DESIGN

III.1 Introduction

This research is based on quantitative research methods that involve surveying neurosurgery and orthopedic spine surgeons via a survey instrument created in Qualtrics. The data collected by the survey instrument were analyzed to quantitatively determine correlations among the constructs established in the TAM2 model. The construct scales were structured on a five-point Likert scale. Quantifying external factors of surgeons were studied to determine correlations between these factors and subsequent surgeon adoption of 3D-printed technology as measured by the TAM2. This research expands upon previous research utilizing the TAM2 by adjusting for more relevant clinical and hospital factors that would affect surgeons' clinical adoption of surgical devices.

III.2 Theoretical Framework

The TAM2 represents the most robust model to utilize as a framework regarding its applicability to surgeon technology adoption. Surgeons' decision-making is often influenced by whom they trained, where they trained, and their impressionability by key opinion leaders concerning changing surgical techniques and technologies used in their procedures. These social interactions primarily determine how surgeons evaluate new technologies and procedures. The TAM2 addresses social interaction and its influence on adoption via social influence (subjective norms, image, experience, and voluntariness) and cognitive instrumental processes (job relevance, output quality, and result demonstrability). This is executed by measuring surgeons' perceptions of job effectiveness outputs when using the technology. These social and cognitive processes influence the overall TAM constructs of PU, PEOU, and IU.

Subjective norms, as discussed by Fishbein and Ajzen (1975), measure one's perception that most people who are important to him/her think that he/she should or should not perform the behavior in question. Surgeons are influenced by those who train them during residency or fellowship. Surgeons attend medical conferences to share and learn the latest surgical techniques and use of technologies to improve their clinical outcomes (Escarce, 1996), which often involves discussing the surgical outcomes that result from various techniques and technologies. Surgeons value the influence of key opinion leaders in the medical device industry (Gagliardi et al., 2017).

Moore and Benbasat (1991) researched image and defined it as the degree to which the use of an innovation is perceived to enhance one's image or status in one's social system. Surgeons may have the same image perceptions, as some want to be the first to develop or use new technology and want to subsequently teach on the lecture circuit regarding their technology usage and how it affects their clinical outcomes. However, many surgeons anecdotally state that they utilize technologies not because it makes them look favorable, but because it improves their surgical outcomes and ultimately positively impacts their patients.

Voluntariness measures the extent to which the potential adopters perceive the adoption decision to be non-mandatory, as described by Venkatesh and Davis (2000). Surgeons may feel that if surgeons in their hospital or regional locale have adopted certain technologies, then they must adopt them as well to remain competitive; otherwise, patients may seek other surgeons who utilize the technology.

As defined by Venkatesh and Davis (2000), job relevance concerns an individual's perception regarding the degree to which the target system applies to their job. Surgeons evaluate technologies that apply to the surgical procedures that they perform, and those surgeons are rarely exposed to technologies that they do not utilize outside of their domain of expertise.

Output quality was defined by Davis, Bagozzi, and Warshaw (1992) as to how well the system performs the tasks related to their job relevance. This variable closely matches a surgical variable called clinical efficacy, which measures how well a treatment or technology succeeds in achieving its goal of addressing the problem. The end-user often expects high-quality output, and thus the technology must allow the surgeon to perform a task with reproducibility and minimal errors. This variable also ties into clinical outcomes or post-operative patient results. Surgeons expect utilized technology to improve their clinical outcomes, and if it does not improve workflow, efficacy, or outcomes, they may cease using it altogether.

Result demonstrability was also defined by Moore and Benbasat (1991) as the tangibility of the results, of using the technology. This denotes the surgeon’s ability to understand the results provided by utilized technology and their ability to communicate this understanding to others.

The experience variable was studied by Venkatesh and Davis (2000), who concluded that social norms become lessened with increased system experience. This construct is not directly measured, and thus loyalty will serve in its place as a new variable added to the model and will be analyzed to determine any effect on subjective norms and intention to use. Loyalty was determined to align with the surgeon and subsequent sales representative and not necessarily with the hospital (Burns et al., 2009). The loyalty that a surgeon often develops for a sales representative or vendor can be correlated to the surgeon favoring their provided service (Burns et al., 2018).

The constructs of PU, PEOU, and IU are critical components of the TAM. This study will utilize construct scale items from research completed by Venkatesh and Davis (2000) as well as Porter and Donthu (2006). The TAM2 differs from the TAM in that TAM2’s external variables directly measure the PU rather than the PEOU. As stated by Venkatesh and Davis (2000), extensive empirical evidence shows that the PEOU is significantly linked to intention via its impact on perceived usefulness.

Hospital factors represent a new construct that must be measured to determine whether it has a moderating effect on the TAM2 model. Surgeons may have strong tendencies to adopt technology, but other factors that the surgeon cannot control include the hospital's impact on the decision-making of surgeons' technology usage (Gelijns & Rosenberg, 1994). Hospital systems attempt to control cost by evaluating the financial implications of new technologies through the use of value analysis committees. Unfortunately, there could be uncertainty in the sustainability, financially, and clinically, of the technology (Lettieri, 2009). Organizational characteristics or inputs thus impact adoption rates (Hikmet et al., 2008). This study's construct scale was adapted from Burns et al. (2009).

The final variable (dependent variable) regards the surgeon adoption of 3DP implant technology, in which the questions ask whether the surgeon adopted technology or not. The selection of adoption will equate to one, and the non-adoption of the technology will equate to zero.

The proposed framework (Figure 12) will be called TAM2-Clinical (TAM2-C). This research should provide insights into which of the constructs influence surgeon adoption of technology, which could highlight a new addition to the body of knowledge of TAM frameworks but from a clinician's viewpoint. For practitioners, this research could provide insights to firms developing new technologies regarding how to more precisely target their marketing efforts towards surgeons in the spine industry. This would also be applicable to other sectors in the medical device industry since they are all bound by the same constructs, as highlighted in the theoretical framework.

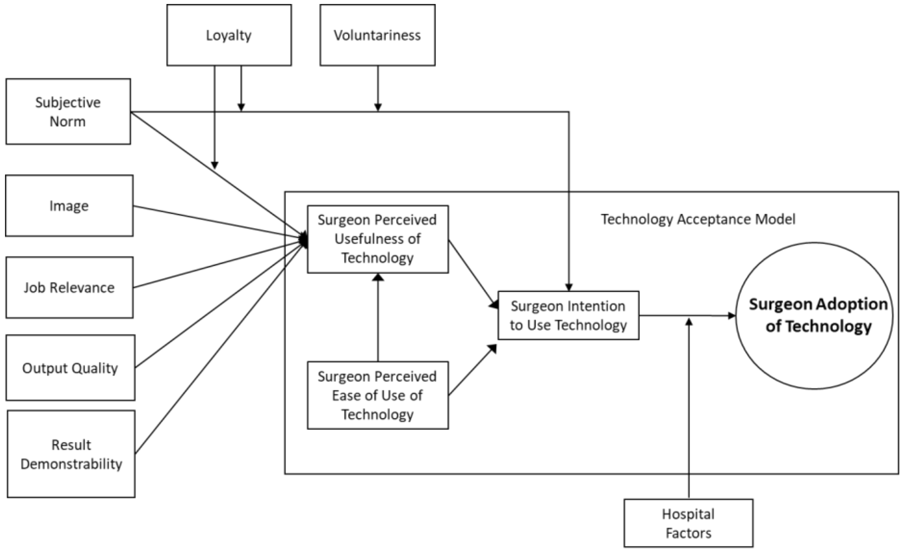

Figure 12 Proposed TAM2-C Framework Model

III.3 Research Questions and Hypothesis Testing

Research Question:

What factors influence the surgeon adoption of emerging technology in the spinal medical device industry?

Hypotheses and Rationale

TAM constructs such as PU, PEOU, and IU have been thoroughly investigated and shown to influence adoption positively. Although the TAM has been significantly studied in IT applications over the past 30 years, there has been limited research into its use in healthcare surgical applications. Regarding surgeons and their influences on 3D-printed implant adoption, the PU, PEOU, and IU are expected to have positive relationships similar to those observed in IT. This implies that the use of the TAM will apply to surgical technology beyond IT technology adoption.

H1: Surgeons' perceived usefulness positively influences the intention to use.

H2: Surgeons' perceived ease of use positively influences the intention to use.

H3: Surgeons' perceived ease of use positively influences perceived usefulness.

Subjective norms, as discussed by Fishbein and Ajzen (1975), measures one's perception that most people who are important to him/her think that he/she should or should not perform the behavior in question. Surgeons are influenced by their former proctors, influential key opinion leaders, and colleagues within their social and medical network. Surgeons will investigate what technologies others are using and measuring those surgeon's clinical success. These influences will impact how a surgeon views the adoptability of specific devices.

H4: Surgeons' subjective norms positively influence perceived usefulness.

H5: Surgeons' subjective norms positively influence intention to use.

Moore and Benbasat (1991) researched image and defined it as the degree to which the use of an innovation is perceived to enhance one's perception or status in one's social system. Users of innovations in the medical field are sometimes viewed favorably by others. Especially if their usage provides demonstrable improved clinical outcomes. Those individuals will become more visible as a result of discussing their clinical outcomes and technology usage in public forums. Thus, potentially enhancing their image among their social and medical networks.

H6: Surgeons' image positively influences perceived usefulness.

As defined by Venkatesh and Davis (2000), job relevance concerns an individual's perception regarding the degree to which the target system applies to their job. Surgeons will adopt technologies that provide them with clinical and procedural work-flow benefits. Surgeons choose technologies that, in general, will improve or enhance their surgical skill set.

H7: Surgeons' job relevance positively influences perceived usefulness.

Output quality was defined by Davis, Bagozzi, and Warshaw (1992) as to how well the system performs the tasks related to their job relevance. The technology should demonstrate outputs that are reproducible, measurable, and improves one's margin of error in the procedure. Surgeons will favor technology that improves the clinical outcomes for their patients and establishes improved clinical efficacy. If a technology does not demonstrate improved output quality, it's perceived usefulness will diminish.

H8: Surgeons' output quality positively influences perceived usefulness.

Result demonstrability was also defined by Moore and Benbasat (1991) as the tangibility of the results of using the technology. The surgeon must be able to understand the results provided by the technology and be able to communicate this understanding to others. If the surgeon perceives the technology to be useful, they should be able to communicate this result to others. This is important when surgeons must explain the benefits of the technology to decision-makers within the hospital to determine if the system will be approved for use by value analysis committees.

H9: Surgeons' result demonstrability positively influences perceived usefulness.

Prior research discussed in the literature review has shown that once a subject's behavioral intent to use IT technology has been established by PU and PEOU, the adoption of the technology more readily occurs. The same assumption can apply to surgeons' intention to use surgical technology clinically.

H10: Intention to use positively influences surgeon adoption of technology.

Loyalty represents a new variable added to the model to measure surgeons' corporate loyalty. The surgeon's relationship with a medical device organization or local sales representative may influence their perception of the technology's usefulness. Research has shown that loyalty is established by surgeons and local sales representatives based on service, training, and perceived trust (Burns et al., 2018, 2019; O'Connor et al., 2016). There is also interestingly supplemental evidence implying that loyalty is not established due to a lack of trust by the surgeon and sales representative (Gagliardi et al., 2017), which results in the following:

H11: Surgeons' loyalty moderates the relationship between subjective norms and perceived usefulness.

H12: Surgeons' loyalty moderates the relationship between subjective norms and intention to use.

Voluntariness measures the extent to which the potential adopters perceive the adoption decision to be non-mandatory, as described by Venkatesh and Davis (2000). Surgeons may believe they have no choice in adopting the technology for a potential number of reasons. In essence, hospital decision-makers have mandated it, well-informed patients may request it or go to another surgeon who does use the technology or their social and medical network all utilize the technology; thus they must adopt to minimize the perception that they are not providing the best therapeutic options for their patients.

H13: Voluntariness moderates the relationship between subjective norms and intention to use.

Hospital factors represent a new variable that will be measured to determine whether it has a moderating effect on the TAM2 model. While a surgeon may have intentions to adopt a technology, they do not purchase the technology. This is done by the hospital in which the surgeon is technically an employee. Thus, the hospital has control over the purchase of goods used in the facility. Hospital influence impacts technology adoption due to the hospital's need for improved clinical outcomes and hospital efficiencies (Gelijns & Halm, 1991). These decision criteria potentially mitigate surgeons' loyalty bias that may exist regarding the technology (O'Connor et al., 2016; Burns et al., 2016, 2018).

H14: Hospital factors moderate the relationship between intention to use and adoption of technology.

IV CHAPTER 4: METHODOLOGY

IV.1 Data Collection and Sampling

This research examines the factors that influence surgeon adoption of emerging technology in the medical device industry, more specifically, spinal surgeons' adoption of 3DP implants. Primary data collection was performed via a survey instrument, and the survey was created using the Qualtrics survey system. Although there are 6,524 spine surgeons globally (Falavigna, 2018), I utilized an email list server compiled from various surgeon conferences and an email list compiled by Stryker Spine Corporation, and the resulting list accounted for approximately 2,500 surgeons globally. I targeted a survey completion target of n = 300, which would equate to a 12% response rate. Surgeons were targeted via numerous methods: The first option was via the compiled email list server, where emails linking to the survey and inviting surgeons to complete it were distributed three times over three months. The second option was via surgeon visits to the Stryker Spine corporate office, where surgeons were invited to complete the survey at their leisure and were given a business card with the survey link information, including the addition of a quick response (QR) code. The third recruitment option concerned individual networking via LinkedIn connections, where surgeon contacts were emailed an invitation to complete the survey via LinkedIn messaging. A fourth recruitment activity involved surgeon participants at various surgeon conferences held in the United States, who were given the survey instrument business card as well. Finally, the fifth option was via assistance from select sales representatives who encouraged surgeon customers to complete the survey by visiting the survey link provided via email. All surgeons contacted via office visits, LinkedIn, or sales representative interaction were cross-referenced with the original surgeon email list. The final results consisted of 100 completed surveys out of 2,500 surgeons, representing an effective response rate of 4%. The participant strategy allowed the researcher to obtain responses from a variety of spinal surgeons. They were selected based on the following criteria: orthopedic or neurosurgeons operating weekly. Participants were provided the option to access the survey twenty-four hours per day and advised to complete the survey during non-business hours. Once the data were retrieved from the internet survey tool, it was entered into SPSS for analysis and reporting.

IV.2 Measures

The scales for the various theoretical constructs (subjective norms, image, job relevance, output quality, result demonstrability, experience, voluntariness, PU, PEOU, and IU) were utilized from previously established studies. The TAM scales of PU, PEOU, and IU are to be measured using items adapted from Davis (1989) and Davis et al. (1989). The measurements of subjective norms were adapted from Taylor and Todd (1995); result demonstrability and image from Moore and Benbasat (1991); job relevance and output quality from Davis et al. (1992); and hospital factors from Burns et al. (2009). However, some items in the hospital scale were adjusted to fit the focus and relevance of this study. Finally, loyalty was measured by utilizing a three-item scale that addressed corporate contracts, corporate product preferences, and sales representative relationships.

The survey instrument questions were further adjusted based on prior research by Chismar and Wiley-Patton (2003) as well as Burns, Housman, Booth, and Koenig (2009). These researchers made modifications appropriate for their research, and this research performed two similar adjustments. Sentences were reworded to incorporate the nomenclature of technology and the word surgeon to questions where applicable to increase interest by providing personal and professional appeal and thus enhance the response rate (Chismar & Wiley-Patton, 2003). This research also substituted the word “system” with technology. The full list of questions and their associated constructs are referenced in Appendix A. The survey was tested by three surgeons to ensure that the questions were clear and that the length of the survey was appropriate and maintained surgeon engagement. The estimated time required for the survey’s completion was five to ten minutes.

IV.3 Reliability

Reliability regards the internal consistency of items within the construct and is measured via Cronbach’s alpha. According to Venkatesh and Davis (2000), the constructs were determined to have internal consistency reliability coefficients greater than 0.70. Table 1 below highlights the Cronbach’s alpha coefficient for each scale. Initial testing of the original constructs of results demonstrability, loyalty, and hospital factors resulted in lower internal consistency. The results demonstrability construct resulted in a Cronbach’s alpha of 0.31. By removing item 4, “I would have difficulty explaining why using the technology may or may not be beneficial.”, the resultant Cronbach’s alpha was improved to 0.78. The loyalty construct resulted in a Cronbach’s alpha of 0.24. By removing item 3, “Do you have any corporate teaching and/or development contracts within the spine industry?”, the resultant Cronbach’s alpha was improved to 0.52. Finally, the hospital factors construct resulted in a Cronbach’s alpha of 0.69. By removing item 4, “I have influence on hospital vendor selection.”, the resultant Cronbach’s alpha was improved to 0.74. Thus, providing improved internal consistency for each of the three constructs.

Table 1 Source of Constructs

Construct	Source Reliability	α
Perceived Usefulness*	0.87 – 0.98	0.91
Perceived Ease of Use*	0.86 – 0.98	0.82
Intention to Use*	0.82 – 0.97	0.92
Subjective Norm*	0.81 – 0.94	0.85
Image*	0.80 – 0.93	0.91
Job Relevance*	0.80 – 0.95	0.86
Output Quality*	0.82 – 0.98	0.76
Results Demonstrability*	0.80 – 0.97	0.78
Voluntariness*	0.82 – 0.91	0.79
Loyalty	*NA*	0.52
Hospital Factors**	*NA*	0.74

*Source: Venkatesh & Davis (2000)

**Source: Burns et al. (2009)

IV.4 Validity

The validity of the constructs was measured by analyzing convergent validity within the measures. The resultant correlation coefficients were all significant at the 0.01 and 0.05 level, thus confirming validity (refer to Appendix B).

IV.5 Data Analysis

The data analysis process included the coding and cleaning of the data collected from the survey. Statistical calculations were then performed via SPSS to analyze the collected data. The hypothesized model was examined using regression analysis to test the relationships of the constructs.

Coding

The survey measurements of the TAM2 used a five-point Likert scale ranging from strongly disagree to agree strongly. Each point was assigned a numerical value, which was used to record the responses to each survey question. Each question was assigned a variable name, and each respondent a unique ID. All of this information was downloaded into SPSS for analysis and exported into Excel for Smart-PLS3 analysis.

Cleaning

The data from the spreadsheet were loaded into SPSS, and frequencies on all of the variables were calculated, and error tests were run. Based on the selected variables, the mean, median, mode, and standard deviation were determined. These tasks allowed validating the data and eliminating any surveys that were not valid (e.g., missing data or incorrect data entry). As each question required an answer before progressing forward in the survey, there were no issues of missing data. Text variables were correctly coded to reflect proper measurement.

Statistical Outputs

Frequency tests were performed on the cleaned data, which included reviewing the descriptive statistics. The technology acceptance factors in the TAM2 were captured on a Likert scale (1 to 5), and the overall scores for each factor were calculated by averaging the scores from each item. Correlations were performed using Pearson’s correlation to determine whether there was a relationship present between the independent and dependent variables. Also, Spearman's Rho calculations were performed to test the strength of the relationship between the variables. Linear regression was performed to address each null hypothesis using the testing procedures defined by Pallant (2016). First, the data were screened for outliers as the participants' residuals were standardized, and the resulting z-scores were utilized to identify outliers. The next step was to assess model linearity and homoscedasticity using a plot of standardized residuals. Finally, the regression coefficients statistics were calculated to determine whether the independent variables were significant predictors of the targeted dependent variables (e.g., perceived usefulness).

V CHAPTER 5: RESULTS

V.1 Descriptive Statistics

The number of subjects who participated in the study was 100, and the descriptive statistics for their demographics are listed in Table 2. Sixty-nine of the surgeon participants were orthopedic surgeons, while the remaining 31 were neurosurgeons. The majority of the surgeons were attending (97%), while the remaining 3% were residents. There were no fellows. Tenure was reported as follows: 0-10 years (38%), 11-20 years (29%), 21-30 years (23%) and 31+ years (10%). Age was distributed as follows: 25-34 (6%), 35-44 (33%), 45-54 (28%), 55-64 (27%) and 65+ (6%). 96% of the respondents were male, and 4% were female. Finally, 80% of the respondents were from various U.S. states, while the remaining 20% were from international countries (6% Australia, 12% Europe, 1% Middle East, 1% Southeast Asia).

The surgeon participants completed the 42-item TAM2-C survey. The descriptive statistics for the TAM2-C are listed in Table C1 (see Appendix C). The TAM variables in the TAM2-C identified in this research were recorded via a five-point Likert scale. The overall scores for each construct were calculated by averaging the scores for each item. In Table 3, the descriptive statistics for the traditional TAM variables (PU, PEOU, and IU) of the TAM2-C highlight that PU had the highest average value with a mean of 15.55 (*SD* = 3.21). Of the variables traditionally associated with the TAM2 (SN, I, V, JR, OQ, and RD), voluntariness had the highest average value with a mean of 12.89 (*SD* = 2.07).

Table 2 Surgeon Demographics

Variable	*n*
Specialty	
Ortho	69
Neuro	31
Clinical Position	
Attending	97
Fellow	0
Chief Resident	1
Resident	2
Tenure	
0-10	38
11-20	29
21-30	23
31+	10
Age	
25-34	6
35-44	33
45-54	28
55-64	27
65+	6
Gender	
Male	96
Female	4
Geographic Location	
United States	80
Australia, Victoria	1
Australia, NSW	4
Australia, Queensland	1
Italy	3
Germany	1
Ireland	3
UK	5
Israel	1
Thailand	1

Table 3 Descriptive Statistics for TAM-C Subscales

Subscale	*n*	Min	Max	*M*	SD
Perceived Usefulness	100	4.00	20.00	15.55	3.21
Perceived Ease of Use	100	4.00	20.00	14.83	3.09
Intention to Use	100	3.00	10.00	8.01	1.71
Subjective Norm	100	2.00	10.00	6.20	1.84
Voluntariness	100	3.00	15.00	12.89	2.07
Image	100	3.00	15.00	8.41	3.09
Job Relevance	100	2.00	10.00	8.09	1.64
Output Quality	100	2.00	10.00	7.32	1.63
Result Demonstrability	100	6.00	15.00	12.65	1.87
Loyalty	100	2.00	13.00	7.86	2.21
Hospital Factors	100	11.00	40.000	27.71	5.33

V.2 Correlation Analysis

Correlation analysis was conducted to determine the strength and direction of the linear relationship between the variables. Using SPSS, a bivariate calculation was performed to determine the direction (Spearman's Rho correlation) and strength of the relationships (the size of the value of the correlation coefficient). Strength is determined by the correlation reflecting either 0 (no relationship), 1 (positive relationship) or -1 (negative relationship). The results are shown in Table 4 below.

Table 4 Correlation Analysis

Scale	PU	PEOU	IU	SN	V	I	JR	OQ	RD	L	HF
PU	1.00										
PEOU	0.48**	1.00									
IU	0.62**	0.57**	1.00								
SN	0.35**	0.21*	0.38**	1.00							
V	0.14	0.12	0.08	0.09	1.00						
I	0.32**	0.11	0.29**	0.29**	-0.01	1.00					
JR	0.51**	0.33**	0.54**	0.38**	0.12	0.14	1.00				
OQ	0.46**	0.47**	0.53**	0.28**	0.05	0.30**	0.45**	1.00			
RD	0.46**	0.38**	0.43**	0.22*	0.38**	0.26*	0.50**	0.44**	1.00		
L	0.14	0.37**	0.17	0.16	0.10	0.15	0.06	0.12	0.25*	1.00	
HF	-0.07	-0.02	-0.00	0.05	0.06	0.14	0.05	0.08	0.06	0.16	1.00

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

V.3 Multicollinearity

Multicollinearity was tested to ensure that there was no overlapping of factors among the independent variables. The tolerance and variance inflation factor (VIF) were used to measure collinearity. Tolerance measures the amount of variability of the independent variable not being explained by the other variables in the model, while the VIF is the inverse of tolerance. “If the Tolerance is small (less than 0.10), then the multiple correlations are high among the variables, thus implicating there is multicollinearity. If collinearity is present among the variables by having VIF values greater than 10, then those variables would be removed" (Pallant, 2016, p. 159). The resultant tolerance values were all much higher than 0.10, while the VIF values were below 2.0, as represented below in Table 5.

Table 5 Multicollinearity

Factor	Tolerance	VIF
Subjective Norm	0.77	1.30
Image	0.79	1.26
Job Relevance	0.64	1.57
Output Quality	0.60	1.66
Result Demonstrability	0.70	1.43
Loyalty	0.99	1.01
Voluntariness	0.99	1.01
Perceived Usefulness	0.70	1.44
Perceived Ease of Use	0.71	1.41
Intention to Use	0.99	1.00
Hospital Factors	0.99	1.00

V.4 Regression Model Analysis

This research model is complicated due to the number of variables. Due to the n of 100 and eleven different variables, the power of the model is potentially compromised. The sampling should have been closer to 280. The analysis thus involved examining the linear regression effect of each of the model pathways via SPSS, which involved analyzing the independent variables' (IV) interaction with the dependent variables (DV). The first analysis involved analyzing the model effect on the independent variable of perceived usefulness, and the regression coefficients were calculated to determine whether the variable was a significant predictor for the said variable.

The first run involved testing the independent variables, subjective norms, image, job relevance, output quality, and results demonstrability for the dependent variable of perceived usefulness. The results are shown below in Tables 6 – 8:

Table 6 Perceived Usefulness Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.53[a]	0.28	0.24	2.79

a. Predictors: (Constant), Image, JR, SN, RD, OQ

Table 7 Perceived Usefulness ANOVA

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	285.60	5.00	57.12	7.32	.00[a]
	Residual	733.15	94.00	7.80		
	Total	1018.75	99.00			

Dependent Variable: PU

a. Predictors: (Constant), Image, JR, SN, RD, OQ

Table 8 Perceived Usefulness Coefficients

Model		B	SE	Beta	*t*	p
1	(Constant)	4.51	2.07	-	2.18	0.03
	SN	0.29	0.17	0.17	1.69	0.10
	JR	0.38	0.21	0.19	1.78	0.08
	OQ	0.38	0.21	0.19	1.83	0.07
	RD	0.22	0.18	0.13	1.26	0.21
	I	0.06	0.10	0.06	0.64	0.52

Dependent Variable: PU

Upon further analysis, it was determined that by removing the two variables with the largest non-significance (result demonstrability and image), the model became much more statistically significant, as demonstrated below in Tables 9 – 11:

Table 9 Perceived Usefulness Model Summary w/o RD & I

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.51[a]	0.26	0.24	2.80

a. Predictors: (Constant), Output Quality, SN, JR

Table 10 Perceived Usefulness ANOVA w/o RD & I

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	267.16	3.00	89.06	11.38	.00[a]
	Residual	751.59	96.00	7.83		
	Total	1018.75	99.00			

Dependent Variable: PU

a. Predictors: (Constant), OQ, SN, JR

Table 11 Perceived Usefulness Coefficients w/o RD & I

Independent Variable	*b*	SE	Beta	*t*	p
(Constant)	6.36	1.61		3.95	**0.00**
SN	0.34	0.17	**0.19**	2.04	**0.04**
JR	0.45	0.20	**0.23**	2.20	**0.03**
OQ	0.48	0.20	**0.24**	2.39	**0.02**

Dependent Variable: PU

Subjective norms, job relevance, and output quality were the only independent variables with p values lower than 0.05 and an adjusted R^2 of 0.24, thus having an effect on perceived usefulness. Image and results demonstrability demonstrated p values higher than 0.05, thus having no impact on perceived usefulness. By removing image and result demonstrability, the adjusted R^2 did not change, thus highlighting that these two predictors did not reliably contribute to PU.

The second analysis involved testing the relationship of PEOU on PU via linear regression. The results are shown below in Tables 12 – 14:

Table 12 PEOU & PU Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.47[a]	0.22	0.21	2.84

a. Predictors: (Constant), PU

Table 13 PEOU & PU ANOVA

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	228.39	1.00	228.39	28.32	.00[a]
	Residual	790.37	98.00	8.07		
	Total	1018.75	99.00			

Dependent Variable: PU

a. Predictors: (Constant), PEOU

Table 14 PEOU & PU Coefficients

Model		B	SE	Beta	t	p
1	(Constant)	8.26	1.40	-	5.90	0.00
	PEOU	0.49	0.09	**0.47**	5.32	**0.00**

Dependent Variable: PU

PEOU has a p-value lower than 0.05 and an adjusted R^2 of 0.21, thus having an effect on perceived usefulness and contributing 21% of the variance for PU.

The third analysis executed the linear regression model on the remaining TAM variables, which involves analyzing the SN, PU, and PEOU effects on IU. These results are shown below in Tables 15 - 17:

Table 15 Intention to Use Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.70[a]	0.49	0.47	1.24

a. Predictors: (Constant), PEOU, SN, PU

Table 16 Intention to Use ANOVA

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	140.81	3.00	46.94	30.41	.00[a]
	Residual	148.18	96.00	1.54		
	Total	288.99	99.00			

Dependent Variable: IU
a. Predictors: (Constant), PEOU, SN, PU

Table 17 Intention to Use Coefficients

Model		B	SE	Beta	t	p
1	(Constant)	1.08	0.74	-	1.45	0.15
	SN	0.16	0.07	**0.18**	2.24	**0.03**
	PU	0.15	0.05	**0.28**	3.29	**0.00**
	PEOU	0.24	0.05	**0.44**	5.23	**0.00**

Dependent Variable: IU

SN, PU, and PEOU all have p values lower than 0.05 and an adjusted R^2 of 0.47, thus having an effect on the intention to use and contributing 47% of the variance for intention to use.

Finally, the last regression was run on the relationship between intention to use and 3DP implant adoption. The results are presented in Tables 19 – 20.

Table 18 3DP Implant Adoption Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.230[a]	0.05	0.04	0.431

a. Predictors: (Constant), PEOU, SN, PU

Table 19 3DP Implant Adoption ANOVA

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	1.03	1	1.03	5.55	.02[a]
	Residual	18.21	98	0.19		
	Total	19.24	99			

Dependent Variable: 3DP Implant Adoption
a. Predictors: (Constant), IU

Table 20 3DP Implant Adoption Coefficients

Model		B	SE	Beta	t	p
1	(Constant)	0.26	0.21	-	1.26	0.21
	IU	0.06	0.02	**0.23**	2.35	**0.02**

Dependent Variable: 3DP Implant Adoption

Intention to use has a p-value lower than 0.05 and an adjusted R^2 of 0.04, thus having an effect on perceived usefulness, yet only contributing 4% of the variance for the actual adoption of 3DP implants.

The next analysis involved testing the moderator variables loyalty and voluntariness and their impact on the model. The analysis was conducted using the Process Analysis v3.4 created by Andrew Hayes (Hayes, 2017). This logistic regression path analysis modeling tool allows measurement of the effects of meditator and moderator models. The resulting series of logistic regression analysis is depicted below in Tables 21 – 23.

Table 21 Process Analysis of Loyalty on SN & PU

Model Summary of Outcome Variable PU (Y: PU, X: SN, W: L)

R	R^2	MSE	F	df1	df2	p
0.36	0.13	9.26	4.67	3.00	96.0	0.00

Model of Outcome Variable PU

Variable	Coefficient	SE	*t*	p	LLCI	ULCI
Constant	13.42	3.50	3.83	0.00	6.47	20.37
SN	0.28	0.55	0.50	0.62	-0.82	1.37
L	-0.22	0.47	-0.48	0.63	-1.15	0.70
SN X L	0.04	0.07	0.61	**0.54**	-0.09	0.18

Test(s) of highest order unconditional interaction(s)

Variable	R^2 Change	F	df1	df2	p
SN x L	0.00	0.38	1.00	96.0	0.54

Table 22 Process Analysis of Loyalty on SN & Intention to Use

Model Summary of Outcome Variable IU (Y: IU, X: SN, W: L)

R	R^2	MSE	F	df1	df2	p
0.40	0.6	2.54	5.94	3.00	96.0	0.00

Model of Outcome Variable IU

Variable	Coefficient	SE	*t*	p	LLCI	ULCI
Constant	5.06	1.83	2.76	0.0069	1.42	8.70
SN	0.34	0.29	1.18	0.24	-0.23	0.91
L	0.13	0.24	0.51	0.61	-0.36	0.62
SN X L	-0.003	0.04	-0.08	**0.94**	-0.08	0.07

Test(s) of highest order unconditional interaction(s)

Variable	R^2 Change	F	df1	df2	p
SN x L	0.00	0.01	1.00	96.0	0.94

Table 23 Process Analysis of Voluntariness on SN & Intention to Use

Model Summary of Outcome Variable IU (Y: IU, X: SN, W: V)

R	R^2	MSE	F	df1	df2	p
0.38	0.14	2.57	5.44	3.00	96.0	0.00

Model of Outcome Variable IU

Variable	Coefficient	SE	*t*	p	LLCI	ULCI
Constant	7.85	2.29	3.43	0.00	3.31	12.39
SN	0.05	0.36	0.14	0.89	-0.66	0.76
V	-0.16	0.18	-0.89	0.37	-0.52	0.20
SN X V	0.02	0.03	0.85	**0.39**	-0.03	0.08

Test(s) of highest order unconditional interaction(s)

Variable	R^2 Change	F	df1	df2	p
SN x V	0.01	0.73	1.00	96.0	0.39

The p-values are higher than 0.05 for loyalty and voluntariness for the subjective norms relationship with intention to use. Also, the p-value of loyalty for the subjective norms relationship with perceived use is higher than 0.05 as well. Thus, loyalty and voluntariness have no moderating effect on the model.

The hospital factors relationship was analyzed to determine whether it had a moderating effect on the relationship of intention to use with adoption. Adoption was based on either yes or no to the adoption of 3DP implants, and the p-value was lower than 0.05, thus showing a moderating effect on the IU to 3DP adoption relationship. The results are presented below in Table 24.

Table 24 Process Analysis of Hospital Factors on IU & 3DP Adoption

Model Summary of Outcome Variable 3DP Adoption (Y: 3DP Adoption, X: IU, W: HF)

Variable	Coefficient	SE	*z*	p	LLCI	ULCI
Constant	12.78	6.90	1.85	0.06	-0.75	26.30
IU	-1.54	0.84	-1.84	0.06	-3.18	0.10
HF	-0.50	0.24	-2.05	0.04	-0.98	-0.02
IU X HF	0.07	0.03	2.19	**0.03**	0.00	0.12

Test(s) of highest order unconditional interaction(s)

Variable	Chi^2	df	p
IU x HF	5.61	1.00	0.02

V.5 Hypothesis Findings

H1: Surgeons' perceived usefulness positively influences the intention to use.

H2: Surgeons' perceived ease of use positively influences the intention to use.

H3: Surgeons' perceived ease of use positively influences perceived usefulness.

The TAM constructs were analyzed to determine whether the use of TAM was a valid application for measuring surgeons' clinical adoption of surgical technology (e.g., 3DP implants). The standardized coefficients for the TAM constructs were found to be H1: $\beta = 0.28$, H2: $\beta = 0.44$

and H3: $\beta = 0.47$. All three hypotheses reported a significance of $p < 0.05$ and, therefore, were supported. Thus, perceived usefulness and perceived ease of use have positive relationships with the intention to use, while perceived ease of use has a positive relationship with perceived usefulness.

H4: Surgeons' subjective norms positively influence perceived usefulness.

The standardized coefficient for subjective norms' influence on perceived usefulness was $\beta = 0.19$, $p < 0.05$. This suggests that the independent variable, subjective norm, has a positive influence on perceived usefulness, and thus the hypothesis was supported.

H5: Surgeons' subjective norms positively influence intention to use.

The standardized coefficient for subjective norms' influence on intention to use was $\beta = 0.18$, $p < 0.05$. This suggests that the independent variable subjective norms has a positive influence on intention to use, and thus the hypothesis was supported.

H6: Surgeons' image positively influences perceived usefulness.

The standardized coefficient for surgeons' image on perceived usefulness was $\beta = 0.06$, $p > 0.05$. This suggests that the independent variable image does not have a positive influence on perceived usefulness, and thus the hypothesis was rejected.

H7: Surgeons' job relevance positively influences perceived usefulness.

The standardized coefficient for subjective norms' influence on perceived usefulness was $\beta = 0.23$, $p < 0.05$. This suggests that the independent variable job relevance has a positive influence on perceived usefulness, and thus the hypothesis was supported.

H8: Surgeons' output quality positively influences perceived usefulness.

The standardized coefficient for output quality's influence on perceived usefulness was $\beta = 0.24$, $p < 0.05$. This suggests that the independent variable output quality has a positive influence on perceived usefulness, and thus the hypothesis was supported.

H9: Surgeons' result demonstrability positively influences perceived usefulness.

The standardized coefficient for result demonstrability's influence on perceived usefulness was $\beta = 0.13$, $p > 0.05$. The results suggest that the independent variable result demonstrability does not have a positive influence on perceived usefulness, and thus the hypothesis was rejected.

H10: Intention to use positively influences surgeon adoption of technology.

The standardized coefficient for intention to use's influence on surgeon adoption of 3DP implant technology was $\beta = -1.54$, $p > 0.05$. The results suggest that the intention to use variable does not have a positive influence on surgeon adoption, and thus the hypothesis was rejected.

H11: Surgeons' loyalty moderates the relationship between subjective norms and perceived usefulness.

The standardized coefficient for loyalty's moderation influence on the relationship between subjective norm and perceived usefulness was $\beta = 0.04$, $p > 0.05$. The results suggest that the loyalty variable does not have a moderation effect on the relationship between subjective norms and perceived usefulness, and thus the hypothesis was rejected.

H12: Surgeons' loyalty moderates the relationship between subjective norms and intention to use.

The standardized coefficient for loyalty's moderation influence on the relationship between subjective norms and intention to use was $\beta = -0.03$, $p > 0.05$. This suggests that the loyalty variable does not have a moderation effect on the relationship between subjective norms and intention to use, and thus the hypothesis was rejected.

H13: Voluntariness moderates the relationship between subjective norms and intention to use.

The standardized coefficient for voluntariness' moderation influence on the relationship between subjective norm and intention to use was $\beta = 0.02$, $p > 0.05$. This suggests that the voluntariness variable does not have a moderation effect on the relationship between subjective norms and intention to use, and thus the hypothesis was rejected.

H14: Hospital factors moderate the relationship between intention to use and adoption of technology.

The standardized coefficient for hospital factors' moderation influence on the relationship between intention to use and surgeon adoption was $\beta = 0.07$, $p > 0.05$. This suggests that the hospital factors variable does have a moderation effect, albeit small, on the relationship between intention to use and surgeon adoption, and thus the hypothesis was supported.

The results for the hypotheses findings are represented in Table 5.24 below:

Table 25 Hypothesis Support (*p < 0.05)

Technology Acceptance Model (Validation)		**β**	**p**	**Supported**
H1	Surgeons' perceived usefulness positively influences intention to use	0.28	0.00*	Y
H2	Surgeons' perceived ease of use positively influences intention to use	0.44	0.00*	Y
H3	Surgeons' perceived ease of use positively influences perceived usefulness	0.47	0.00*	Y
Independent Variables Influences on Model		β	p	Supported
H4	Surgeons' subjective norms positively influence perceived usefulness	0.19	0.04*	Y
H5	Surgeons' subjective norms positively influence intention to use	0.18	0.03*	Y
H6	Surgeons' image positively influences perceived usefulness	0.06	0.52	N
H7	Surgeons' job relevance positively influences perceived usefulness	0.23	0.03*	Y
H8	Surgeons' output quality positively influences perceived usefulness	0.24	0.02*	Y
H9	Surgeons' result demonstrability positively influences perceived usefulness	0.13	0.21	N
H10	Intention to use positively influences surgeon adoption of technology	-1.54	0.06	N
Moderation Influences on Model		**β**	**p**	**Supported**
H11	Surgeons' loyalty moderates the relationship between subjective norms and perceived usefulness	0.04	0.54	N
H12	Surgeons' loyalty moderates the relationship between subjective norms and intention to use	0.00	0.94	N
H13	Voluntariness moderates the relationship between subjective norms and intention to use	0.02	0.39	N
H14	Hospital factors moderate the relationship between intention to use and adoption of technology	0.07*	0.03	Y

After analyzing the results, the initial model framework proposed for this research has been further defined to achieve a more straightforward framework for studying surgeons' behavioral intentions towards the clinical adoption of technology. The more simplified, empirically supported model is shown below (Figure 13):

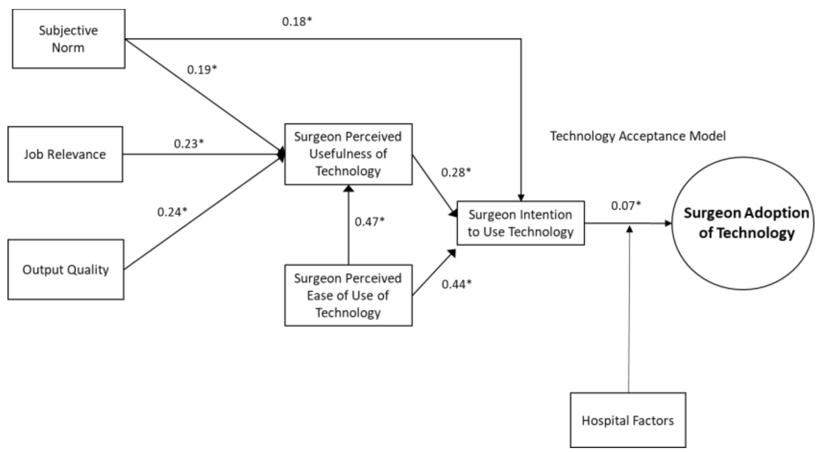

Figure 13 Empirically Supported TAM2-C Framework Model

The simplified model highlights that SN accounts for 19% of the variance for PU, while job relevance accounts for 23%, and output quality accounts for 24%. These three predictors account for 67% of the variance effect on PU. The variance effects on the TAM variables of PU and intention to use are also within range of the variance found in the initial study in which the TAM2 was validated (Venkatesh & Davis, 2000). Hospital factors' small moderation effect on the relationship between intention to use and adoption was 7%. Thus, hospital factors (costs, value analysis, etc.) can have a small positive effect on surgeons adopting the technology.

V.6 Additional Findings

This section elaborates on significant findings that were not hypothesized. Despite a lack of measurable outcomes for these findings, they could provide additional insight into the research. This overview denotes any findings concerning their relationship with the dependent variable of perceived usefulness.

V.6.1 Technology Readiness Index (TRI)

The Technology Readiness Index (TRI) was developed by Parasuraman (2000) to measure one’s motivations that may promote or minimize the adoption of new technologies. The developed scale measures dimensions of optimism, innovativeness, discomfort, and insecurity concerning various technological products. Comparing the TRI to perceived usefulness could serve as a valuable validation measure. If a surgeon has a high TRI score, then there may be a positive correlation with perceived usefulness and potentially positive link to adopting the technology. Capturing this measurement scale could lead to further research concerning surgeon's adoption of technology. Questions for the TRI were included in the survey study and can be found in Appendix A.

Reliability regards the internal consistency of items within the construct, which is measured via Cronbach’s alpha. As a result, the TRI shows internal consistency with a value of 0.83. Parasuraman (2000) showed a range of consistency within the construct of 0.74 – 0.81.

Correlation analysis was also conducted to determine the strength and direction of the linear relationship between perceived usefulness. Using SPSS, a bivariate calculation was performed to determine the direction (Spearman’s Rho correlation) and strength of the relationships (the size of the value of the correlation coefficient). Strength is determined by the correlation reflecting either 0 (no relationship), 1 (positive relationship) or -1 (negative relationship). The relationship between TRI and perceived usefulness was investigated using Spearman's Rho coefficient, which found a strong, positive correlation between the two variables, r = 0.56, n = 100, $p < 0.001$, with high levels of TRI associated with perceived usefulness.

Linear regression was performed to determine the ability of the TRI to predict perceived usefulness. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity, and homoscedasticity. The total variance explained by the model as a whole was 20%, F(1,98) = 25.92, $p < 0.001$. See Tables 26 – 28 below.

Table 26 TRI Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.46[a]	0.21	0.20	2.87

a. Predictors: (Constant), TRI

Table 27 TRI ANOVA

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	213.08	1	213.08	25.92	.00[a]
	Residual	805.67	98	8.22		
	Total	1018.75	99			

Dependent Variable: PU
a. Predictors: (Constant), TRI

Table 28 TRI Coefficient

Model		B	SE	Beta	T	p
1	(Constant)	6.83	1.74	-	3.93	0.00
	TRI	0.33	0.07	**0.46**	5.09	**0.00**

a. Dependent Variable: PU

These results show that there is a strong relationship between the TRI and perceived usefulness, and additional research efforts would help further define this phenomenon.

VI CHAPTER 6: DISCUSSION

This research aimed to study the behavioral intentions of surgeons in adopting clinical technology, more specifically, spine surgeons' adoption of 3DP implants. The TAM2 was utilized to test which behavioral intentions were significant while testing for additional environmental/economic factors that may additionally influence the model. The TAM has been extensively studied, few studies on adoption within healthcare. Unfortunately, there has been a dearth of application of the TAM or any of its subsequent models (e.g., TAM2, UTAUT, etc.) to the adoption patterns for clinicians concerning adopting surgical technologies.

By studying the various social and cognitive factors that can influence a surgeon's behavioral intent, subjective norms, job relevance, and output quality were determined to contribute 66% of the variance in the behavioral intent of perceived usefulness. These three constructs were expected to reflect a positive relationship with a surgeon's perceived usefulness of the technology.

For subjective norms, it is within reason to assume that its relationship with perceived usefulness and intention to use are due to a surgeon's influences from others. As discussed earlier in the theoretical framework, SN pertains to one's perception that most people who are important to him/her think that they should or should not perform the behavior in question (Fishbein & Ajzen, 1975). Surgeons are influenced by other surgeons throughout their careers, from residency and fellowship to post-training. After training, they continue to seek input from other surgeons within their hospital practice or by attending surgeon conferences to engage in evidence-based practice. This often involves analyzing the literature on technologies used and the clinical impact of these devices. 3DP implants are currently heavily promoted at surgeon conferences via corporations and surgeon panel discussions. Thus, these influences undoubtedly shape a surgeon's perception of a technology's usefulness and their subsequent intention to adopt.

The relationship of job relevance on perceived usefulness represents another predictor of surgeon behavior. JR is defined as one's perception of the degree to which the target system (in this case, 3DP implant technology) applies to their job (Venkatesh & Davis, 2000). The use of 3DP implants provide the same clinical application as older technologies (PEEK versions) and allow the surgeon to restore spinal alignment. These 3DP implants are thus strongly relevant to the job focus and within a surgeons' domain of expertise usage.

Output quality is another predictor that is capable of predicting surgeon behavior and is defined as one's perception of the degree to which the target system (in this case, 3DP implant technology) performs tasks related to their job relevance. This finding is also not surprising since output quality relates to a surgeon's determination to use a technology if it improves their procedural workflow or patient clinical outcomes. To improve a surgeon's procedural workflow, technology must be reproducible and minimize the potential for errors, and clinical efficacy and outcomes also need to be improved with the technology. 3DP implants can improve workflow in some instances, such as a custom implant that closely matches the patient's anatomy, which in turn minimizes the necessary prep work that a standard off-the-shelf PEEK or titanium block implant might require for insertion (Kim et al., 2017; Ventola, 2014). 3DP implants can also provide improved efficacy and outcomes since the material and structure may provide improved fusion rates compared to PEEK implants. The goal is for these implants is to provide the quickest and most efficient rate of fusion while providing stability to the spinal column (Seaman et al., 2017). Current research favorably views 3DP implants, and thus it is no surprise that spine surgeons are influenced via this construct (Brown, 2017; Garg & Mehta, 2018; Kim et al., 2017; Lal & Pratralekh, 2018; McGilvray et al., 2018; Mobbs et al., 2017; Mok et al., 2016; Tack et al., 2016).

The 72% variance in behavioral intent of “intention to use” was determined to be comprised of 28% contribution from perceived usefulness and 44% from perceived ease of use. This variance is aligned with results of previous TAM studies that have shown similar variance rates between 60–70% (Liang et al., 2003; Schaper & Pervan, 2007; Tung et al., 2008; Wu et al., 2007). The consistency of these findings with prior research utilizing the TAM to measure physician technology adoption in other fields suggests the TAM2 is a valid model to measure behavioral intents by surgeons when measuring the adoption of clinical technologies. However, other factors relevant to clinical practice may help elucidate surgeon technology adoption.

SN, JR, OQ, PU, PEOU, and IU suggest positive relationships and can be predictors of surgeons’ intention to adopt a technology. However, other variables that did not show a statistical relationship include image, results demonstrability, loyalty, and voluntariness.

It can be postulated that image is not a factor since it is defined as the degree to which the use of an innovation is perceived to enhance one’s image or status in one’s social system (Moore & Benbasat, 1991). Surgeons do not adopt technologies based on improving their image but instead choose technologies that will improve the procedure or clinical outcomes for the patient. They are also not swayed by others’ usage unless there are clinical outcomes to highlight the benefit of the technology.

Results demonstrability is not a predictor that influences surgeon adoption, and it is defined as one’s ability to understand results provided by the technology and one’s ability to communicate this understanding to others. Surprisingly, there was no relationship with perceived usefulness; however, there often may be conflicting information regarding the benefits of new technology.

There may be insufficient clinical outcome studies to show the technology's specific benefits, and thus surgeons may not have established a firm belief in the technology. It would be interesting to observe whether this result changes with a larger sampling of spine surgeons.

Another surprising outcome was that loyalty had no moderating effect on the relationship between SN and PU, as well as no moderating effect on the relationship between SN and IU. This outcome is unexpected since spine surgeons develop close relationships with their local sales representative and view the sales representative as a consultant who provides the necessary equipment and devices that allow them to operate successfully. There are instances in which the sales representative resigns from one organization to sell products for a different organization, but only if their surgeon customer agrees that he can utilize the new organization's equipment. Thus, exhibiting a clear example of loyalty from the sales representative. Also, some surgeons are consultants for medical device companies helping to design new products, leading one to assume that such a surgeon would prefer their organization's products. Surgeons ultimately utilize products and technology in which they believe and utilize multiple products from different companies within their armamentarium of surgical tools. Their loyalty is to the patient, which supersedes loyalty to the sales representative, company, or hospital.

The voluntariness construct showed no moderating effect on the relationship between SN and IU. Voluntariness measures the extent to which a potential adopter perceives the adoption decision to be non-mandatory (Venkatesh & Davis, 2000). It was originally proposed that this construct would impact surgeons' intention to use since environmental factors could influence surgeons. Examples include other surgeons' in the hospital adoption of the technology, or medically informed patients request for the usage of such technology, who may otherwise find a surgeon who does utilize them. Upon reflection, surgeons always have a choice of technologies to use and employ technologies that are familiar and have proven to provide them with satisfactory outcomes. Although some hospital organizations may have a limited vendor policy and require surgeons to use products and devices from a limited number of medical device manufacturers, they never force a surgeon to adopt new technology. On the contrary, hospitals would prefer to limit new technology adoption since it often entails a substantial increase in costs to the hospital.

Interestingly, the relationship between intention to use and adoption of 3DP implants was negative, which implies that the intention to use these implants does not necessarily lead to adoption. However, this result was not statistically significant (p-value of 0.06) and could be due to the fact that, although the surgeon intends to utilize 3DP implants, another factor impacts this adoption. It should be noted that of the 100 spine surgeons that completed the research survey, 74 had officially adopted 3DP implants in their practice. The final factor that somewhat influences 3DP implant adoption regards hospital factors, which showed a small moderating effect on the relationship between IU and the adoption of 3DP implants. This relationship was found to have a 7% variance effect on the relationship, and therefore hospital influences have affected the adoption rates. Hospitals control which vendors have access to their facilities in an attempt to control costs and inventory (Gelijns & Halm, 1991), which ultimately impacts the financial stability of many hospitals (Vizient, 2019). It is assumed that as more clinical data are obtained regarding the clinical efficacy and outcomes of 3DP implants, hospitals will favorably welcome their addition since they could provide procedural and workflow improvements as well as improved patient outcomes.

Overall, the resultant empirically supported model (TAM2-C) highlights that the intrinsic behaviors that influence surgeon adoption of technology includes social influence of subjective norms and cognitive influences of job relevance and output quality. Although the tested sampling of surgeons showed significant resultant TAM variables of perceived usefulness, perceived ease of use, and intention to use behaviors, their adoption of 3DP implants was moderated by hospital factors. Albeit a small relationship, this result theoretically supports the existing industry process whereby hospitals wish to exert control over the adoption of technology within their facilities.

VII CHAPTER 7: CONTRIBUTIONS, LIMITATIONS, FUTURE RESEARCH & CONCLUSION

VII.1 Implications for Researchers

Many researchers have investigated the behaviors of clinicians' acceptance of technology concerning IT healthcare applications (Ratten, 2015; Nagy, 2018; Escobar-Rodriguez, 2012). While the TAM has been extensively studied and validated to show that usefulness and ease of use are mediators to one's intention to use a technology (Venkatesh, 1999), there has been no attempt to apply TAM or subsequent models to non-IT related technologies. This research application suggests that the TAM is a useful model for measuring surgeons' behaviors towards the clinical adoption of technology, which in this case, is 3DP implants used for spinal procedures. Also, this study extends previous research by investigating the TAM2's use in clinicians' technology adoption since it has been used in an IT healthcare technology adoption study (Chismar & Wiley-Patton, 2003). Finally, this research contributes to the TAM framework by investigating other environmental/economic variables that the TAM has not accounted for in previous studies. Although loyalty was shown to lack a moderation influence, hospital factors showed a small moderating influence on the relationship between intention to use and adoption. This relationship should be further investigated and validated.

VII.2 Implications for Practitioners

Subjective norms constitute 37% of the adoption variance, thus contributing more to the effect on perceived usefulness than job relevance and output quality. While subjective norm is a social influencing variable, it can give companies guidance or provide support for continuing existing strategies that target or influence potential users. Companies could implement marketing campaigns that expand beyond typical sales collateral provided to surgeons by sales representatives or advertising utilized at surgeon conferences. By looking to other industries, medical device companies could use more behavioral marketing to further influence surgeon perceptions of perceived usefulness of new clinical technology. By utilizing digital marketing techniques from other industries, the medical device industry could further improve their marketing to include aspects of behavioral marketing. Numerous strategies could involve a more robust, interactive website strategy that goes further than just showing product images and features and benefits. Improvements could involve interactive links to further determine what information the surgeon is seeking to help influence their behavior. From this website improvement, data can be collected to help determine what information is most impactful. Another strategy could involve implementing social influence campaigns that target a surgeon influencer's network (Risselada, 2014). For example, companies could create educational pieces that surgeon key opinion leaders would post to social networks such as LinkedIn that highlight the clinical benefits of the product coupled with surgeon and/or patient testimonials. Also, utilizing new virtual conference call programs, surgeon to surgeon training courses could be utilized to extend the reach of influence by these key opinion leaders. Previous research validates that an individual's social network includes others similar to themselves, who tend to have opinion leaders or revenue leaders influencing their network (Haenlein & Libai, 2013). Marketing activities should be targeted towards these key opinion and revenue leaders since they could provide positive subjective norm influence on others. Finally, corporations or marketers could utilize this research by creating marketing strategies to influence the components of hospital influences. This should entail a dual approach of impacting subjective norms and hospital influencers since both can impact technology adoption.

Corporations can also implement more robust marketing to influence surgeons' subjective norms and hospital influences while highlighting the job relevance and output quality of the technology. Corporations can use this research to determine secondary strategies for the other variables that did not prove to have significant influence. Loyalty and result demonstrability could receive focus strategically after implementing plans for addressing the core variables of subjective norm, job relevance, and output quality.

VII.3 Limitations

It is essential to recognize the assumptions and limitations that can affect the accuracy of the research results. Several assumptions were made regarding this study, such as that participants had access to technical knowledgebases and were familiar with the terms presented in the survey. Another assumption was that participants would answer the survey questions truthfully and completely, and it was further assumed that this researcher would receive sufficient survey returns to measure the desired outcomes effectively.

One potential limitation is self-selection bias. Given the voluntary nature of the survey, surgeons who are interested in using or have used newer technology (3D-printed implants) for surgery may have been more likely to respond. Self-reporting bias could also have impacted the results if respondents did not feel comfortable accurately reporting their feelings, attitudes, and behaviors. Methods bias can also negatively affect results in studies relying on one type of data input.

The measurement of hospital factors could have limited validity because some surgeon respondents may have limited knowledge of institutional factors. Engaging hospital executives to answer the survey questions regarding hospital factors and cross-referencing these responses with surgeons' answers may improve accuracy. Another limitation is the limited number of international surgeon respondents; additional international surgeons could further determine whether there are impacts on adoption, which statistically vary by country.

Although the loyalty and hospital factor constructs were utilized in this research, further research is required to validate these results. The results could be strengthened by employing the Churchill (1979) reliability standard to validate the two constructs.

Finally, another limitation of this study is the sampling method. Purposive sampling could have resulted, which may not be representative of the population due to the potential subjectivity of the employed research collection methods.

VII.4 Future Research

Further research with a larger sample size can help to validate the constructs of loyalty and hospital factors. There are also opportunities to identify other clinical environmental factors that may influence surgeon adoption behavior. Factors such as technology costs or training variables required for learning new technology could also be studied concerning adoption and behavioral inputs. Finally, future research could validate the different versions of TAM (e.g., TAM2, TAM3, UTAUT) to determine whether one represents a more suitable model for measuring surgeons' clinical adoption of technology.

VII.5 Conclusion

The purpose of this research was to study factors that influence surgeons' behavioral intent to adopt technology for clinical use in surgery as measured by the theoretical framework of the TAM2. This study specifically examined spine surgeons and their adoption of 3D-printed implants for spinal surgeries. The findings suggest that the surgeon factors of subjective norms, job relevance, and output quality have a positive impact on surgeons' perceived usefulness, which impacts their intention to use the technology. Their intention subsequently led to the adoption of 3D-printed implants; however, environmental and economical hospital factors provide a small moderating effect on the adoption. It was discovered that variables expected to have influence (loyalty, voluntariness, image, and results demonstrability) were determined to have no impact on surgeon behavior.

Medical device innovation will continue to proliferate, and companies developing these technologies will need to continually re-evaluate how they influence the end-user to adopt them. The TAM2 helped to determine that subjective norms influence a surgeons' behavioral intent to adopt technology. Therefore, organizations should draft executable strategies that target their technologies towards surgeons' subjective norms while also highlighting how the technology appeals to their perceived usefulness and perceived ease of use. Finally, companies will need to continue to help educate and influence hospitals concerning their technologies since the hospitals will moderate the adoption practices of surgeons.

APPENDICES

Appendix A. Survey Instrument

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Experience (E)

Specialty (S): What is your specialty?

a. Orthopedics - 2
b. Neurosurgery - 1
c. Non-applicable - 0

Clinical Position (CP): Please select your current clinical status

a. Attending Surgeon - 4
b. Fellow - 3
c. Chief Resident - 2
d. Resident - 1

Clinical Focus (Complex, DG, MI) (CF): Please select all that apply regarding your spine clinical focus

a. Degenerative - 1
b. Complex - 1
c. Minimally Invasive - 1
d. Pediatrics - 1

Clinical Tenure (CT): Please select how many years you have been a practicing surgeon

a. 0 – 5 - 1
b. 6 – 10 - 2
c. 11 – 15 - 3
d. 16 – 20 - 4
e. 21 – 25 - 5
f. 26 – 30 - 6
g. 31 – 35 - 7
h. 36+ - 8

Surgical Volume (SV): Please select the average number of surgical cases you complete monthly

a. 1 – 10 - 1
b. 11 – 20 - 2
c. 21 – 30 - 3
d. 31+ - 4

Surgical/Teaching Leadership (SL1): Please select all your current academic positions

a. Professor - 1
b. Assistant Professor - 1
c. Associate Professor - 1
d. Other - 1
e. Non-Applicable - 0

Surgical/Teaching Leadership (SL2): Please select all activities in which you engage
a. Teach fellows/residents - 1
b. Write journal publications - 1
c. Speak at extramural meetings - 1
d. Non-applicable - 0

Do you currently hold any administrative leadership roles in your hospital?
a. Yes - 1
b. No - 0

Age (AG): Please select your age range
a. 18 – 24
b. 25 – 34
c. 35 – 44
d. 45 – 54
e. 55 – 66
f. 65 or older

Gender (G): Please select your gender
a. Male
b. Female
c. Other

Using the following scale, please fill in your response to each question below.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Perceived Usefulness (PU)
PU1 Using technology improves my performance in surgery.
PU2 Using technology in surgery increases my productivity.
PU3 Using technology enhances my effectiveness in surgery.
PU4 I find technology to be useful in surgery.

Perceived Ease of Use (PEOU)
PEOU1 My interaction with technology in surgery is clear and understandable.
PEOU2 Interacting with technology in surgery does not require a lot of my mental effort.
PEOU3 I find technology to be easy to use in surgery.

PEOU4 I find it easy to get technology to do what I want it to do in surgery.

Intention to Use (IT)
IT1 Assuming I have access to technology, I intend to use it in surgery.
IT2 Given that I have access to technology, I predict that I would use it in surgery.

Subjective Norm (SN)
SN1 People who influence my behavior think that I should use technology in surgery.
SN2 People who are important to me think that I should use technology in surgery.

Voluntariness (V)
V1 My use of technology in surgery is voluntary.
V2 My supervisor does not require me to use technology in surgery.
V3 Although it might be helpful, using technology is certainly not compulsory in surgery.

Image (I)
I1 People in my hospital who use technology in surgery have more prestige than those who do not.
I2 People in my hospital who use technology in surgery have a high profile.
I3 Using technology during surgery is a status symbol in my hospital.

Job Relevance (JR)
JR1 In my job, usage of technology in surgery is important.
JR2 In my job, usage of technology in surgery is relevant.

Output Quality (OQ)
OQ1 The quality of the output I get from the technology during surgery is high.
OQ2 I have no problem with the quality of the technology's output during surgery.

Result Demonstrability (RD)
RD1 I have no difficulty telling others about the results of using the technology in surgery.
RD2 I believe I could communicate to others the consequences of using the technology in surgery.
RD3 The results of using the technology in surgery are apparent to me.
RD4 I would have difficulty explaining why using the technology in surgery may or may not be beneficial.

Loyalty Influence (LI)
Using the following scale, please fill in your response to each question below.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

LI1 I prefer surgical products from a particular manufacturer/vendor.
LI2 I utilize surgical products based on my local sales representative relationship.
LI3 Do you have any corporate teaching, consulting, and/or product development contracts within the spine industry?

a. Yes - 1
b. No - 0

LI4 Please select all that apply with respect to your manufacturer/vendor relationships

a. Receive Consulting fees - 1
b. Receive Patent Royalties - 1
c. Receive Honoraria for talks, teaching, etc. – 1
d. Non-Applicable - 0

Using the following scale, please fill in your response to each question below.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Technology Readiness Index (TRI)
New technologies contribute to a better quality of life.
Technology gives people more control over their lives.
Technology makes people more productive.
Other people come to me for advice on new technologies.
In general, I am among the first in my circle of friends to acquire new technology when it appears.
I can usually figure out new high-tech products and services without help from others.
I keep up with the latest technological developments in my area.

Hospital Factors (HF) Please select the choices that best describe the primary hospital in which you perform greater than 75% of your surgical procedures:
HF1 My hospital has reduced the number of product vendors.
HF2 My hospital's purchasing staff approves all technology requests.
HF3 The cost of new technology influences our hospital's decision to acquire that particular technology.
HF4 I have influence on hospital vendor selection.
HF5 My hospital is restricting access to vendors of innovative technologies.
HF6 My hospital requires me to utilize innovative technologies from only select vendors.
HF7 Value analysis or new technology committees in the hospital influence my decision to use a given innovative technology or work with a given vendor.
HF8 Reimbursement rates for new technology will influence my use of the technology.
HF9 Reimbursement rates for new technology will influence my hospital's approval of the technology.

Please select all that describes the primary hospital in which you perform greater than 75% of your surgical procedures:

HFD1 System Membership (SM)

a. Academic - 1
b. Community - 1
c. Health System Affiliated
d. Non-Health System Affiliated
e. Veterans' Health Administration/Military
f. I do not know

HFD2 Hospital Size (# of Beds) (HS)

a. 1-100
b. 101-200
c. 201-500
d. 500+
e. I do not know

HFD3 Tax Status (TS)

a. Profit
b. Non-Profit
c. I do not know

HFD4 Geographic Location (GL)

a. Urban
b. Suburban
c. Rural

HFD5 State Location (S): Enter State

<u>Surgeon Adoption (SA)</u>

SA1 Have you adopted any of the following technologies in the last year for surgical use? Check all that apply

a. 3D Printed Implants - 1
b. Robotic technology - 1
c. MIS Navigation - 1
d. Other - 1

SA2 If you **<u>have not</u>** adopted any 3D printed implants in the last year for surgical use, check all that apply as to your reason for not adopting

a. High cost - 1
b. Reimbursement issues - 1
c. No perceived clinical benefit - 1
d. Negative clinical outcomes - 1
e. No perceived time savings in the surgical suite - 1
f. High learning curve - 1

g. Limited scope of usability - 1
h. Other - 1

Appendix B. Validity Statistics

Table B1

Validity Statistics for TAM-C Survey Items

Item	*n*	Min	Max	*M*	*SD*
Using technology improves my performance in surgery	100	1	5	3.92	0.884
Using technology in surgery increases my productivity	100	1	5	3.61	0.994
Using technology enhances my effectiveness in surgery	100	1	5	3.87	0.928
I find technology to be useful in surgery	100	1	5	4.15	0.809
My interaction with technology in surgery is clear and understandable	100	1	5	3.93	0.795
Interacting with technology in surgery does not require a lot of my mental effort	100	1	5	3.32	1.171
I find technology to be easy to use in surgery	100	1	5	3.86	0.899
I find it easy to get technology to do what I want it to do in surgery	100	1	5	3.72	0.933
Assuming I have access to technology, I intend to use it in surgery	100	1	5	3.94	0.930
Given that I have access to technology, I predict that I would use it in surgery	100	2	5	4.07	0.844
People who influence my behavior think that I should use technology in surgery	100	1	5	3.06	0.983
People who are important to me think that I should use technology in surgery	100	1	5	3.14	0.995
My use of technology in surgery is voluntary	100	1	5	4.45	0.657
My supervisor does not require me to use technology in surgery	100	1	5	4.27	0.839
Although it might be helpful, using technology is certainly not compulsory in surgery	100	1	5	4.17	0.954
People in my hospital who use technology in surgery have more prestige than those who do not	100	1	5	2.75	1.132
People in my hospital who use technology in surgery have a high profile	100	1	5	3.01	1.105
Using technology during surgery is a status symbol in my hospital	100	1	5	2.65	1.114
In my job, usage of technology in surgery is important	100	1	5	4.00	0.888
In my job, usage of technology in surgery is relevant	100	1	5	4.09	0.866
The quality of the output I get from the technology during surgery is high	100	1	5	3.75	0.821
I have no problem with the quality of the technology's output during surgery	100	1	5	3.57	0.987
I have no difficulty telling others about the results of using the technology in surgery	100	2	5	4.31	0.706
I believe I could communicate to others the consequences of using the technology in surgery	100	2	5	4.35	0.657

Table B1

Continued

Item	*n*	Min	Max	*M*	*SD*
The results of using the technology in surgery are apparent to me	100	1	5	3.99	0.859
I would have difficulty explaining why using the technology in surgery may or may not be beneficial	100	1	5	2.27	1.062
I prefer surgical products from a particular company	100	1	5	3.39	0.931
I utilize surgical products based on my local sales representative relationship	100	1	5	3.19	1.107
Do you have any corporate teaching, consulting and/or product development contracts within the spine industry?	100	1	2	1.41	0.494
Manufacturer/vendor relationships Receive consulting fees	100	0	1	0.46	0.501
Manufacturer/vendor relationships Receive patent royalties	100	0	1	0.38	0.488
Manufacturer/vendor relationships Receive honoraria for talks, teaching, etc.	100	0	1	0.44	0.499
Manufacturer/vendor relationships Non-applicable	100	0	1	0.40	0.492
My hospital has reduced the number of product vendors	100	1	5	3.48	1.235
My hospital’s purchasing staff approves all technology requests	100	1	5	3.33	1.264
The cost of new technology influences our hospital’s decision to acquire that particular technology	100	1	5	4.30	0.785
I have influence on hospital vendor selection	100	1	5	3.74	1.031
My hospital is restricting access to vendors of innovative technologies	100	1	5	3.18	1.184
My hospital requires me to utilize innovative technologies from only select vendors	100	1	5	2.86	1.146
Value analysis or new technology committees in the hospital influence my decision to use a given innovative technology	100	1	5	3.53	1.049
Reimbursement rates for new technology will influence my use of the technology	100	1	5	3.10	1.193
Reimbursement rates for new technology will influence my hospital’s approval of the technology	100	1	5	3.93	1.037

Appendix C. Descriptive Statistics

Table C1

Descriptive Statistics for TAM-C Survey Items

Item	*n*	Min	Max	*M*	*SD*
Using technology improves my performance in surgery	100	1	5	3.92	0.88
Using technology in surgery increases my productivity	100	1	5	3.61	0.99
Using technology enhances my effectiveness in surgery	100	1	5	3.87	0.93
I find technology to be useful in surgery	100	1	5	4.15	0.81
My interaction with technology in surgery is clear and understandable	100	1	5	3.93	0.79
Interacting with technology in surgery does not require a lot of my mental effort	100	1	5	3.32	1.17
I find technology to be easy to use in surgery	100	1	5	3.86	0.90
I find it easy to get technology to do what I want it to do in surgery	100	1	5	3.72	0.93
Assuming I have access to technology, I intend to use it in surgery	100	1	5	3.94	0.93
Given that I have access to technology, I predict that I would use it in surgery	100	2	5	4.07	0.84
People who influence my behavior think that I should use technology in surgery	100	1	5	3.06	0.98
People who are important to me think that I should use technology in surgery	100	1	5	3.14	0.99
My use of technology in surgery is voluntary	100	1	5	4.45	0.66
My supervisor does not require me to use technology in surgery	100	1	5	4.27	0.84
Although it might be helpful, using technology is certainly not compulsory in surgery	100	1	5	4.17	0.95
People in my hospital who use technology in surgery have more prestige than those who do not	100	1	5	2.75	1.13
People in my hospital who use technology in surgery have a high profile	100	1	5	3.01	1.10
Using technology during surgery is a status symbol in my hospital	100	1	5	2.65	1.11
In my job, usage of technology in surgery is important	100	1	5	4.00	0.89
In my job, usage of technology in surgery is relevant	100	1	5	4.09	0.87
The quality of the output I get from the technology during surgery is high	100	1	5	3.75	0.82
I have no problem with the quality of the technology's output during surgery	100	1	5	3.57	0.99
I have no difficulty telling others about the results of using the technology in surgery	100	2	5	4.31	0.71
I believe I could communicate to others the consequences of using the technology in surgery	100	2	5	4.35	0.66

Table B1

Continued

Item	*n*	Min	Max	*M*	*SD*
The results of using the technology in surgery are apparent to me	100	1	5	3.99	0.86
I would have difficulty explaining why using the technology in surgery may or may not be beneficial	100	1	5	2.27	1.06
I prefer surgical products from a particular company	100	1	5	3.39	0.93
I utilize surgical products based on my local sales representative relationship	100	1	5	3.19	1.11
Do you have any corporate teaching, consulting and/or product development contracts within the spine industry?	100	1	2	1.41	0.49
Manufacturer/vendor relationships Receive consulting fees	100	0	1	0.46	0.50
Manufacturer/vendor relationships Receive patent royalties	100	0	1	0.38	0.49
Manufacturer/vendor relationships Receive honoraria for talks, teaching, etc.	100	0	1	0.44	0.50
Manufacturer/vendor relationships Non-applicable	100	0	1	0.40	0.49
My hospital has reduced the number of product vendors	100	1	5	3.48	1.23
My hospital's purchasing staff approves all technology requests	100	1	5	3.33	1.26
The cost of new technology influences our hospital's decision to acquire that particular technology	100	1	5	4.30	0.79
I have influence on hospital vendor selection	100	1	5	3.74	1.03
My hospital is restricting access to vendors of innovative technologies	100	1	5	3.18	1.18
My hospital requires me to utilize innovative technologies from only select vendors	100	1	5	2.86	1.15
Value analysis or new technology committees in the hospital influence my decision to use a given innovative technology	100	1	5	3.53	1.05
Reimbursement rates for new technology will influence my use of the technology	100	1	5	3.10	1.19
Reimbursement rates for new technology will influence my hospital's approval of the technology	100	1	5	3.93	1.04

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VITA

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