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Accessibility of Innovative Services in Radiation Oncology

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2019

Abstract

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by

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MS, Columbia University, 2004

BS, Aristotle University, 2003

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health

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Abstract

The field of radiation oncology (RO) involves the use of highly advanced techniques to treat cancer and safely spare healthy organs. The discipline has experienced rapid growth in the past 25 years, with technological advancement as the driving force. Available data and an instrument to effectively measure the accessibility of innovation in the field were lacking. The purpose of this study was to investigate the accessibility of innovative services in RO in the United States and assess possible diffusion patterns. Two hundred and forty medical physicists practicing in RO in the United States completed a custom Internet-based survey. The diffusion of innovation theory was used as the theoretical framework for the study. A quantitative cross-sectional analysis was performed to assess how innovation scores may vary depending on individual and organizational factors. ANOVA, Spearman correlation, and multiple linear regression were used to analyze the data. University affiliation, urbanicity, appreciation, and motivation were found to be statistically significant factors affecting accessibility to innovative services. Statistically significant barriers preventing innovation were lack of evidence, increased complexity, staffing constraints, lack of interest from others, lack of interoperability, and lack of reimbursement. Medical physicists are in a leadership position to influence the adoption of innovative services in RO. Encouraging the utilization of innovative and Food and Drug Administration-approved techniques may improve cancer outcomes and consequently have a positive social change effect on public health.

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Dedication

To my husband, Will, an awesome partner and my biggest supporter. To my son, Alexander, I hope my absence the past 4 years did not traumatize you. And to my parents for somehow giving me the confidence to think I could actually do this.

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Chapter 1: Introduction to the Study

Introduction

The field of radiation oncology (RO) involves using high-energy radiation to target cancer lesions while sparing the surrounding healthy tissues (American Cancer Society, 2018). The field experienced rapid growth in the early 2000s, with the development of innovative techniques, such as intensity-modulated radiation therapy (IMRT). This technique allowed clinicians to “bend” radiation and customize each patient treatment by creating concave dose distributions that spare healthy tissues (Chen, 2014). This rapid growth paved the way for an array of other innovative techniques, such as advances in imaging and oncology informatics (Chetty et al., 2015).

Many fields in health care struggle to implement innovative techniques such as these in the clinical workflow. The adaptation of innovation within discrete organizations is well understood, yet how the entire health care system transforms to accept health care innovations and thus improve population health is abstruse (Parston et al., 2015). Morris, Wooding, and Grant (2011) estimated that it takes 17 years for an innovation to spread throughout the health care industry. This time lag is more prominent in low-resource settings, leading to inequalities (Keown et al., 2014). In RO, differences in treatment modalities have a notable impact on cancer survival, yet centers offering innovative treatment techniques are inaccessible to part of the population, leading to health care disparities (Chen, 2014).

Jacobs et al. (2016) investigated the innovations adopted in Dutch RO centers. The authors found that in the Netherlands, RO centers implement on average 12 innovations per year. In reviewing the literature, there are no current studies quantifying the diffusion of innovation in RO across the United States. The purpose of this study was to fill this gap in the literature. University affiliation and urbanicity were investigated as possible predictors. The role of medical physicists was also investigated by using an array of demographic parameters and context-specific antecedents to develop a predictive model for accessibility of innovative services in RO in the United States.

There are numerous examples of innovative practices, policies, and products that improve health care provision (Darzi & Parston, 2013). The methods by which an innovation gains momentum and diffuses (or spreads) throughout a specific population or social system over time is typically referred to as diffusion of innovation (Rogers, 2003). Diffusion is a passive spread, as opposed to dissemination, which is active (Rogers, 2003). Public health researchers often overlook the possible lack of diffusion of innovation in efforts to improve population health (Darzi & Parston, 2013). Developing a tool to measure innovation in RO can be the first step in developing a predictive model for improving the diffusion of innovation in the field. This quantitative assessment may contribute to the improvement of accessibility and quality of RO services across the United States, improve cancer outcomes, and thus contribute to positive social change.

Background

Innovation and its implementation are actively studied across many disciplines. The implementation of innovative methods in health care and how these methods reach the general population is an active field of research. For example, the researchers who undertook the Global Diffusion of Health Care Innovation study investigated the effects of rapid adoption of innovations on public health worldwide (Darzi & Parston, 2013). Parston et al. (2015) identified three phases of change management: (a) creating a climate for change by having vision, strategy, and a specific agency to promote diffusion, transparency, and communication channels; (b) engaging and enabling the whole organization by having incentives and rewards; and (c) implementing and sustaining by making time and space for learning. The authors emphasize that implementing change in health care is both an art and a science (Parston et al., 2015). Parston et al. explored quantitative and qualitative parameters that affect innovative technique implementation in a variety of socio-demographic environments. In health care, the adoption of innovative techniques is not an academic exercise, it can save lives.

Clinical effectiveness in RO is by necessity retrospective, and there have been no long-term clinical trials for the majority of innovative techniques used in health care. The adoption of new techniques is primarily based on reasonable theoretical long-term benefits (Chen, 2014). Assessing cancer survivorship as a whole using big-data analyses and defined value is still ongoing (Nardi et al., 2016). Smith et al. (2017) discussed the definition of the value of innovation implementation from multiple stakeholders and how scientific evidence enters the marketplace of RO. Value can mean (a) societal value, such as lost wages, lost productivity, and willingness to pay; (b) care value, such as disease control, quality of life and long-term theoretical benefits; or (c) system value, such as incremental costs, budget impact, and affordability. Nardi et al. (2016) investigated the value of comprehensive cancer centers designated by the National Cancer Institute (NCICCC). The authors found that for specific cancers, such as hepatobiliary, lung, pancreas, gastric, breast, cervical, oral, and colorectal cancer, patients had a 20-30% higher 5-year survival when treated at an NCICCC (Nardi et al., 2016). NCICCCs are disproportionally located in the Eastern United States, which means that for many patients, it is simply not an option to receive treatment at these facilities (Nardi et al., 2016). Additionally, many health care plans do not cover services at university hospitals or NCICCCs at all (Nardi et al., 2016). The majority of Americans, therefore, do not have access to centers that provide better cancer outcomes, either because of geographical limitations or because their insurance does not cover treatment at institutions with proven better outcomes (Nardi et al., 2016). Lack of access to care is one of the many challenges in the contemporary United States, and there are no existing studies addressing this issue in the field of RO, according to the review of the literature. This study measured the accessibility of innovative services in RO in the United States and attempted to fill this literature gap.

Problem Statement

The field of RO has experienced rapid growth in the past 25 years, with technological advancement as the driving force. The need for innovation in health care is broadly accepted as necessary, with current innovation considered insufficient at this point (Parston et al., 2015). Implementing innovative techniques requires significant resources, and community hospitals are trailing behind (Nardi et al., 2016; Pfister et al., 2015). Fragmented data on innovation are available from vendors and professional societies such as the American College of Radiology (ACR) and the American Society for Radiation Oncology (ASTRO), but there has been limited analysis of the barriers to developing and implementing new technology in RO (Mayo et al., 2016).

The study of the mechanism by which innovations spread geographically and across time is of particular interest in health care and is an active field of research. These diffusion patterns are explained using various theoretical models, one of which is the diffusion of innovation theory, as described by Rogers (2003). Diffusion patterns can be assessed by sampling a variety of stakeholders. In this study, the problem of diffusion of innovation was addressed from the point of view of medical physicists (MPs), who are responsible for the acceptance, commissioning, and implementation of innovative techniques in RO. MPs are emerging into leadership positions in RO facilities across the United States, not only as technical experts but as the leaders in quality management (Delis et al., 2017). In the study, MPs were evaluated as the adopters of innovations in RO.

MPs are not passive recipients of innovation: They seek innovations, assess them, find meaning in them, develop positive or negative opinions about them, gain experience with them, complain about them, work around them, modify them, and circle back to the beginning, beginning the process once again (Rogers, 2003). The main adopter categories may be broadly defined as innovators, early adopters, early majority, late majority, or laggards (Rogers, 2003). There is extensive literature on how cognitive and social psychological antecedents affect the individual's adoption (Greenhalgh, Robert, Macfarlane, Bate, & Kyriakidou, 2004). The psychological antecedents included in this study were motivation, appreciation, self-efficacy and leadership style.

As discussed in the "Background" section, innovative techniques are not accessible equally by all patients, as they are typically available at higher rates in university hospitals or urban centers (Pfister et al., 2015). This lack of access is directly related to inferior survival outcomes (Nardi et al., 2016). Jacobs et al. (2016) studied the implementation frequency of innovative techniques in the Netherlands and found a wide range across all centers. They found differences between university and community hospitals and emphasized the lack of national recommendations for prioritizing innovations, setting goals, and societal interventions as long-term solutions (Jacobs et al., 2016). There is a literature gap, however, on the extent of accessibility of innovations in RO in the United States and its impact on public health. The accessibility of innovative services in RO across the United States as an indicator of public health outcomes was further assessed in this study by exploring the role and involvement of MPs.

Purpose of the Study

The purpose of this study was to investigate the accessibility of innovative services in RO in the United States and assess possible diffusion patterns. These patterns were used to create a predictive model of the factors that may affect MPs' role in the diffusion of innovation. An Internet-based survey was conducted with a convenience sample of MPs practicing in RO in the United States. A quantitative cross-sectional analysis of survey data was conducted to gain insight on the accessibility of Food and Drug Administration (FDA)-approved innovative techniques in RO. The dependent variable was innovation score, defined as the number of techniques available to or purchased by a department divided by the number of techniques used clinically, weighed by partial implementation factors. Independent variables were geographic location; practice details (university affiliation, reporting structure, size of physics group); demographics (age, gender, DABR status, residency status, meeting attendance, and education level); and context-specific psychological antecedents (motivation, appreciation, and leadership).

Research Questions and Hypotheses

The research questions (RQs) and hypotheses were as follows:

RQ 1: What are the differences in accessibility to innovation in RO based on location and type of practice in the United States?

RQ 2: What are the statistically significant factors (demographics, practice details, context-specific psychological antecedents) that predict the accessibility to innovation in the RO clinic?

RQ 3: What are the statistically significant barriers that MPs practicing in RO in the United States face in implementing innovations?

Hypothesis 1a

$H1a_0$: There is no statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

$H1a_1$: There is a statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

Dependent variable: innovation score (continuous).

Independent variable: university affiliation (categorical, two levels: has university affiliation, does not have university affiliation).

Hypothesis 1b

$H1b_0$: There is no statistically significant difference in the accessibility to innovation in RO between metropolitan and nonmetropolitan hospitals.

$H1b_1$: There is a statistically significant difference in accessibility to innovation in RO between metropolitan and nonmetropolitan hospitals.

Dependent variable: innovation score (continuous).

Independent variable: urbanicity (categorical: metropolitan, nonmetropolitan).

Hypothesis 2

$H2_0$: There are no statistically significant factors predicting innovation score.

$H2_1$: There are statistically significant factors predicting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: reporting structure, size of physics group, age, gender, DABR status, residency status, meeting attendance, education level, leadership (categorical), appreciation, and motivation (continuous).

Hypothesis 3

$H3_0$: There are no statistically significant barriers affecting innovation score.

$H3_1$: There are statistically significant barriers affecting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: barriers (continuous).

Theoretical Framework for the Study

"Evidenced-based decision making" is a frequently used phrase in health care fields, yet research shows a disconnect between strong scientific support and diffuse clinical usage. Pedersen (2015) discussed that health care fields are different in their adoption of innovations due to contextual sense-making: engagement, materialization and scientification of innovations provides meaning to users. Wisdom, Chor, Hoagwood, and Horwitz (2014) defined innovation adoption as a complex quality improvement intervention and categorized the mechanistic constructs for the individual to accept innovation and implement it in their organization; adoption of innovations is a dynamic process. The unit in this study was MPs. The MPs, as individuals, accept or reject innovations and in turn facilitate their RO departments in fully utilizing innovations. The assessment of the role the MPs play in the diffusion of new products and practices across the modern RO clinic health care system in the United States was studied by measuring diffusion patterns of these products and practices. Diffusion is defined as “the process in which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 2003, p. 5). Rogers developed the diffusion of innovation theory in 1962 (Rogers, 2003). The theory is based on principles of communication of participants in a social system (Rogers, 2003). There are four elements that influence diffusion: the innovation itself, the communication channels, time, and the social system (Rogers, 2003).

In health care, clinical practices are often labeled *evidenced-based*, yet there is a significant gap between clinical practice and recent scientific developments. Health care innovations are not simple to implement in most clinical settings and require differential resource allocation across multiple levels of the organization. Omachonu and Einspruch (2010) developed a health care-specific conceptual framework involving various stakeholders such as physicians and caregivers, patients, organizations, and regulatory agencies. Physician acceptance, the complexity of innovation, partnerships and collaboration, organizational culture, regulatory acceptance, and organizational leadership all contribute to the probability of acceptance of an innovation (Omachonu & Einspruch, 2010). In the field of RO, there has been a broad discussion on how technological advances can lead to improved patient outcomes, and stakeholders are encouraged to embrace innovation (Chetty et al., 2015). Yet there is no framework to quantify or improve the accessibility of innovative techniques. For this study, accessibility of innovative RO services was measured using the innovation score, as described in the "Nature of the Study" and "Definitions" sections that follow.

Nature of the Study

This study was a quantitative numerical assessment of the extent of accessibility of innovative techniques across the United States. The dependent variable was the accessibility of innovative techniques: how many end-users have each technique, how many of them use it, and to what extent. It is common to have partial implementations of innovative technologies (Smith et al., 2017). For participants who did not use techniques that were available to them, influencing variables were investigated. Correlating the accessibility with the type of hospital revealed if community hospitals were trailing behind. Reviewing the zip code entries relative to the innovation score revealed if rural areas were indeed less likely to utilize innovative techniques. Age, gender, DABR status, residency status, meeting attendance, and education level of the MPs and correlation with the availability of innovative techniques revealed how these factors affect innovation. This information is pertinent to overcoming real and perceived barriers in technology implementation in RO.

In 2018, the AAPM directory listed approximately 7,500 members in total, and approximately 5,500 members are listed as active in the United States (not student, retired, associate, or corporate members) (American Association of Physicists in Medicine, 2018). Seventy-seven percent of the membership reported being active in RO (American Association of Physicists in Medicine, 2018); thus, there were about 4,200 eligible MPs. The survey was posted on LinkedIn, the MedPhysUSA user forum, and the AAPM Blackboard forum. The MedPhysUSA is a listserv hosted by Wayne University. It is a highly active online community for MPs, where surveys are frequently posted, with over 4,000 members. Users must subscribe, and there are volunteer moderators. Unofficial surveys typically garner an approximate 5-10% response rate and official surveys an approximate 30-35% response rate. (American Association of Physicists in Medicine, 2017) Considering this response rate and the estimated number of AAPM members, approximately 200 responses were expected for this survey.

Definitions

*American Association of Physicists in Medicine (*AAPM*)*: A scientific and professional organization composed of more than 8,000 scientists whose clinical practice is dedicated to ensuring accuracy, safety, and quality in the use of radiation in medical procedures such as medical imaging and radiation therapy (American Association of Physicists in Medicine, 2019) .

Context-specific psychological antecedents: For the purposes of this study, motivation (the internal process that makes a person move toward a goal), appreciation (recognition), and leadership.

Diffusion of innovation: The study of the spread of new ideas and technologies among individuals and groups (Rogers, 2003).

Diagnostic radiology (DR): The field of medicine that specializes in the diagnosis of disease using ionizing and non-ionizing radiation (American College of Radiology, 2011).

Intensity-modulated radiation therapy (IMRT): A subset of advanced methods used in RO to manipulate the area of treatment and conform to the shape of individualized tumors and spare critical organs (National Cancer Institute, 2011).

Innovation: For the purposes of this study, innovation will be broadly defined to cover products (for example, new technology, inventions, drugs, etc.); practices (ways of working, clinical protocols, workforce changes, etc.); and policies (those things that regulate/influence the use of products and practices). The idea that an innovation is "new" is relative: It is defined as previously unknown to the relevant unit, not new on an absolute time scale (Rogers, 2003).

Innovation Score: The total score of measured innovation indicators for product, technology, and organizational innovation. This is a continuous variable.

Innovation Utilization Score: The total score of measured innovation utilization indicators for product, technology, and organizational innovation. This is a continuous variable.

Medical oncology (MO): The field of medicine that specializes in the treatment of malignant cancers using pharmaceutical agents (National Cancer Institute, 2011).

Radiation oncology (RO): The field of medicine that specializes in the treatment of malignant cancers using ionizing radiation (National Cancer Institute, 2011).

Assumptions

There are inherent assumptions for this study. As primary data were collected, it was assumed that enough MPs will participate in the study to achieve statistical significance or at least make the results as representative as possible. It was also assumed that participants answered truthfully to all the questions of the study. Further, it was assumed that MPs play a vital role in the diffusion process.

Scope and Delimitations

It is important to note the difference between availability and accessibility. Availability of innovative techniques is undoubtedly essential. After all, if something is not available at all, it cannot be used and implemented. Yet the availability of innovative techniques in RO would be more of interest in marketing studies, not public health. The focus of this study is on accessibility, in the context of equitable distribution when taking into account demographic composition, urbanicity and under-served populations (World Health Organization, 2018).

The survey was sent to the entire database of the MedPhysUSA listserv, the AAPM Blackboard, and also posted on LinkedIn. Only MPs practicing in RO were included. Participants practicing in U.S. territories or internationally were excluded. Participants with both Master's and Doctoral degrees were included. Participants were assumed to be fluent in English.

Limitations

Selection Bias

A possible source of selection bias is the exclusion of physicists who are not participating in the online forums mentioned in the "Nature of the study" section. This possible selection bias was minimized by using LinkedIn in a snowball fashion, to attempt to reach MPs who do not participate at the MedPhysUSA or AAPM Blackboard. Similarly, MPs in rural community hospitals may have been too embarrassed to participate, if they feel the technology they are utilizing is not adequate. Both of these could be a serious source of error, as the MPs in the areas with the most need for new technology may not participate. To minimize selection bias, results were reviewed in total and in a weighted average from university and community centers, based on known proportions, when needed.

Information Bias

One of the possible sources of information bias in this study was recall bias. Szklo and Nieto (2014) define recall bias as inaccurate recall of past exposure. In the context of this study, the respondents may have inaccurately recalled the exact details of the implementation of new techniques. The recall bias may be entangled with social desirability bias. MPs are highly skilled and highly paid professionals, and admitting that they have something available but not using it clinically may be ignominious. This may have influenced them to report that they are using a technique, or that they have been using it more than what is actually the reality. Questions were posed on a sliding scale in an attempt to make it more likely for the respondents to answer more truthfully.

Confounding

University affiliation and urbanicity were assessed as possible confounders for the study. All these factors may affect both the exposure and the outcome separately, and they are not directly in the causal pathway.

Statistical Limitations

Based on the expected participant number, 5% chance of Type I error and 20% chance of type II error is reasonable. The statistical power of 80% is a reasonable initial goal as well Type II errors, not detecting an effect that is actually there, or false negative, have more significant social implications than Type I errors in this study. Not detecting an under-performance in community and rural RO centers would lead to lack of supplemental efforts from AAPM to boost their utilization of new techniques. This would be a disservice to the patients as discussed in the section below.

Significance

There is a limited ability for hospitals to purchase innovative techniques, as RO medical devices are extremely expensive. Even though there is insurance-based reimbursement, the capital investment is beyond reach for many hospitals. For example, a linear accelerator costs $1.5 million to $6 million, and the innovative techniques under consideration cost $50,000 to $500,000 (Modern Technology, n.d.). These capital investment amounts require years of strategic planning and significant budget amounts. Since RO treatments are delivered daily over several weeks, patients commonly select facilities close to their area of residence (Pfister et al., 2015). Innovative techniques provide an improvement in survival; thus disparities in accessibility to these innovative techniques is a public health problem.

Survival rate numbers have significantly improved over the past ten to twenty years on the global level, and the reason is largely attributed to improved targeting methods, through the use of innovative techniques such as IMRT (Cancer Research UK, 2015). Providing RO care of the highest quality to all patients by improving the utilization of innovative FDA-approved techniques can contribute to the improvement of accessibility and quality of RO services across the United States and subsequently improve cancer outcomes. Better health outcomes are directly related to a gain in hours worked and an increase in individual income up to 30% (Marquez & Farrington, 2013). These results are even more pronounced in low-income settings, when health costs may be out of pocket. Declining health costs is often a reason quoted for crossing the poverty line (World Health Organization, 2010). Healthier people are more efficient in the workplace, and this affects government and commercial sector alike (General Electric, 2014). Innovative techniques are available, but may not be accessible to all patients. There are enormous inequalities within and between nations in health care in general and the public health effects of this at the global level are being investigated by the Global Diffusion of Health care Innovation study (Darzi & Parston, 2013). This public health problem is in alignment with the ninth essential public health service to "evaluate effectiveness, accessibility, and quality of personal and population-based health services" (Centers for Disease Control and Prevention, 2017). There are currently no studies measuring the accessibility of innovative services in RO in the United States. Measuring the accessibility of innovative services in RO and developing a predictive model to offer a foundation to improve it is a contribution to positive social change.

Summary

The National Cancer Institute (2018a) estimated that in 2018 alone, there were 1.7 million new cancers and approximately 609,000 deaths due to this disease in the United States. Cancer incidence in the United States is 439.2 per 100,000 people, and mortality is 163.5 per 100,000, with higher mortality in men (196.8 per 100,000) than women (139.6 per 100,000). Mortality is highest in

African American men (239.9 per 100,000). Throughout their lifetimes, 38.4% of Americans will be diagnosed with cancer, leading to $147.3 billion in national expenditures for cancer care. As the population ages, the number of new cancer cases per year is predicted to be 23.6 million by the year 2030. There are quantitative demands, such as the number of cancer centers and relative staff (Aneja & Yu, 2012; Yang et al., 2014), and the challenges of rural cancer care in the United States is well documented, with multiple studies correlating driving distance to RO center with treatment decisions and outcomes (Charlton, Schlichting, Chioreso, Ward, & Vikas, 2015).

There are approximately 2,500 RO centers in the United States, 5,500 radiation oncologists, and 4,000 MPs specializing in RO (Ballas, Elkin, Schrag, Minsky, & Bach, 2006). Little is known, however, about the different techniques used in every RO center. While the majority of patients are treated using national standards (National Comprehensive Cancer Network, n.d.), the guidelines provide a wide range of options, allowing customized clinical decisions.

Even though products may receive FDA approval, little is known about their implementation in the clinical setting. It is well demonstrated that the majority of health care spending is due to the cost of technological innovations (Dybczak & Przywara, 2010). In turn, there are many publications on how specific innovations improve output, such as survival, toxicity, safety, service, efficiency, or cost-effectiveness. In the next chapter, a literature review was conducted on the diffusion of innovation in health care in general, and RO specifically. Systematic reviews and cross-sectional studies were reviewed. Results were thematically synthesized to the diffusion of innovations in health care in general, diffusion of specific innovations in RO, effects of innovations on value, effects of innovations in quality and patient outcomes, and social impact.

Chapter 2: Literature Review

Introduction

The purpose of this study was to investigate the accessibility of innovative services in RO in the United States and assess possible diffusion patterns. These patterns were used to create a predictive model of the factors that may affect MPs' role in the diffusion of innovation in RO. From the literature review presented in this chapter, it is evident that RO has a push-pull relationship with innovation. Innovation is readily available, yet not extensively utilized, at least not in all settings. For innovative technologies that are purchased as part of a package, as well as those with no upfront costs, health care professionals appear hesitant to undertake implementation. To some extent, the hesitancy to embrace innovation is understandable, as outcomes have been improving using traditional techniques (Chen, 2014; Jagsi et al., 2012; Smith et al., 2017). For practitioners in suburban or rural areas, who are not in direct contact with opinion leaders and research findings, it may indeed appear this way that outcomes are improving with continuous use of traditional techniques. Even though errors leading to patient death exist in all medical fields, in RO there are many catastrophic errors that can occur on any day of the long treatment path, typically lasting weeks. Despite the importance of this topic, there are currently no assessments of the diffusion of innovation in RO in the United States. This study will contribute to filling this literature gap.

The chapter begins with an overview of the literature search strategy, theoretical foundation, and methodology used in the study. In the literature review that follows, the theoretical foundation of the study, diffusion of innovation, and how it applies to health care and RO are presented. Previously published systematic reviews and cross-sectional studies were used to develop a thematic synthesis of key literature for the review. Topics include the diffusion of innovations in health care in general, diffusion of specific innovations in RO, effects on value, effects on quality and outcomes, social impact, and predictive parameters.

Literature Search Strategy

Walden University Library and Google Scholar were used to conduct searches of the literature. Search terms included radiation oncology, oncology, diffusion of innovation, early adopters, medicine, health care, radiology, equity, and public health. Key words were based on key concepts in previously identified published reviews. Diffusion of innovation is sometimes referred to by other terms, and thus, similar key word items were also used, such as innovation, adoption rate, new technology, and new technology accessibility. The key words were combined in various ways using Boolean operators in context--for example, early adopters in radiation oncology, new technology in radiation oncology, diffusion of innovation in healthcare, new technology in radiation oncology innovation, health equity, and accessibility to new technology. After the initial review of the results, further parameters were identified that were considered to possibly be influential. Additional searches were conducted using the following terms: academic, academic cancer centers, university hospital, community hospital, rural/rurality, city/urban/urbanicity, demographics, reporting structure, employment type, appreciation, motivation, and leadership. These were combined with innovation, adoption rate, new technology, and new technology accessibility using Boolean operators as described. Only articles published in English were included. The date range was limited to articles published since 2013, with the exception of seminal works on the theory of diffusion and well-established psychological context-specific antecedents.

The various search parameters produced over 200 results. These were screened manually and articles were excluded when not directly pertinent. Additional studies were identified by following the references. This step was performed by using the "cited by" function in Google Scholar and by manually looking up references within the selected articles, when applicable. Due to the narrow focus on RO, the search was expanded to other fields of medicine and health care. Studies were included when they addressed diffusion of innovation patterns of clinical innovations in other medical fields, especially DR and MO, which are the closest fields to RO. Results were thematically analyzed as described in the following sections.

Theoretical Foundation

Health care practitioners have a long and beguiling history of accepting or rejecting innovations. The basic principles of hygiene were developed from

Hippocratic medicine in ancient Greece. These principles may be considered elementary today, but they were innovative at the time. They received considerable criticism and skepticism and, to this day, are not accepted in certain parts of the world (Tountas, 2009). More recently, the resolution of scurvy was much delayed in the 18th century, as the British Royal Navy stubbornly refused to accept and diffuse the practice of vitamin C supplementation. The fable may be well known to public health practitioners, but the details of the delayed implementation circa 1793-1800 as described by Vale (2008) paint a picture full of political intrigue. The influence of a few forward-thinking physicians was the catalyst needed for the widespread adoption of vitamin C against scurvy (Tountas, 2009). Public health history is full of similar examples, from the distant past until present day.

Schumpeter (1989) described the continuous generation of innovations as "creative destruction" (p. 83) and concluded that adaptation to innovation is the rule, not the exception. Increasing health care costs, aging populations, and more demanding consumers are compelling organizations to offer innovative solutions (Herzlinger, 2006; Varkey, Horne, & Bennet, 2008). However, less than 50% of all evidence-based practices are effectively implemented in the health care system (Alexander & Hearld, 2011; M. Jacobs et al., 2017). Innovation implementation is an area that needs improvement in health care in general and in RO as well.

Diffusion of Innovation

Rogers first introduced diffusion of innovation theory in 1962, while studying rural sociology in the Midwestern United States and the adoption rates of hybrid seeds in the area (Rogers, 2003). He combined over 500 studies from a variety of fields, including anthropology, early sociology, rural sociology, education, industrial sociology, and medical sociology, and the synthesis was his seminal diffusion of innovation theory (Rogers, 2003). The theory has expanded into social network analysis and is currently frequently used in communications, marketing, development studies, health promotion, organizational studies, knowledge management, conservation biology, and complexity studies, particularly in the medical field and health communication studies (Rogers, 2003). There are five stages in implementing an innovation, as described by Rogers (2003):

1. Knowledge. The individual is exposed to an innovation for the first time but does not have significant knowledge about the specifics of the innovation. There is not yet any motivation from the individual to pursue the innovation.
2. Persuasion. The individual is actively interested in the innovation and is beginning to consciously explore related information/details.
3. Decision. The individual begins to study the advantages and disadvantages of using the innovation and decides whether to either adopt or reject the

innovation. This stage is the most individualistic and thus the most difficult to collect empirical evidence on.

4. Implementation. The individual begins to use the innovation to a smaller or larger degree, depending on the situation. The individual also determines their personal opinion on the usefulness of the innovation and may research additional information on the innovation.
5. Confirmation. The individual finalizes the decision to continue using the innovation. This stage is both intrapersonal and interpersonal, confirmation the group has made the right decision.

The degree by which innovation is accepted by individuals depends on both the individual's characteristics and on the characteristics of the organization in which the innovation is going to take place and typically follows an S-curve (Rogers, 2003). Rogers classified individuals within a social system as being in one of five categories:

1. Innovators. This group is willing to take risks, has the highest social status, has financial liquidity, is social, is in touch with scientific sources, and has frequent interaction with other innovators. They have high-risk tolerance for adopting new technologies.
2. Early adopters. These are typically the opinion leaders among all the categories. They may have higher social status, financial freedom, higher education and may be more socially open than late adopters. They are more thoughtful in adoption choices than innovators.

3. Early majority. This group adopts an innovation after significantly larger amount of time than the innovators and early adopters. They may have above average social status, contact with early adopters and are less likely to hold positions of opinion leadership in a system.
4. Late majority. This group adopts an innovation much later than the average participant. They view innovation with cautiously and with a high degree of skepticism and even after the majority of society has adopted the innovation. The Late Majority group are below average social status, have little financial liquidity, in contact with others in late majority and the early majority and little opinion leadership.
5. Laggards. This group is the last to adopt an innovation. Contrary to the other categories, Laggards show little to no opinion leadership. Individuals belonging to this group typically have a strong dislike for change-agents. Laggards typically tend to be focused on "traditional ways," have the lowest social status, lowest financial liquidity may typically be older than adopters, and are in contact with only family and close friends.

Rogers (2003) recognizes five qualities that determine the success of an innovation.

1. Relative advantage. This is the degree to which an innovation is perceived as better than what is currently available, relative to the actual users, for example in terms of economic advantage, social

prestige, convenience, or satisfaction. If the innovation has a high perceived relative advantage, it will get adopted at a more rapid pace. Relative advantage is subjective and may carry a different meaning for different individuals or groups. It depends on the particular needs and dynamics of the user group.

2. Compatibility with existing values and practices. This is the degree to which an innovation is perceived as being consistent with the values, past experiences, and needs of potential adopters. If innovation is comparable with the group's values, norms or practices, it will be adopted more rapidly.
3. Simplicity and ease of use. This is the degree to which an innovation is perceived as difficult to understand and use. If an innovation is simple and easy to understand it will be adopted more rapidly than innovations requiring increased understanding and new skills.
4. Trialability. This is the degree to which an innovation can be experimented with on a limited basis. If innovation can be trialed out by the individual considering it, without being bound in it, it will be more likely that the individual will consider it.
5. Observable results. If the results of an innovation are easily visible to users, they are more likely they are to adopt it. When the results are clearly visible, there is lower uncertainty and increased peer discussion of a new idea, as more people seek information about the innovation.

According to Rogers (2003), these five qualities determine between 49 and 87% of the variation in the adoption of new products.

Reinvention is one of the leading principles in the diffusion of innovation. The success of an innovation is highly dependent on how well it evolves to meet the needs of the more risk-averse individuals in a population. The innovation does not have to be new in an absolute sense; it just has to be new to the individual.

Organizational and Personal Antecedents

Organizational and personal characteristics dynamically influence the outcome of successful innovative behavior. The organizational and personal constructs related to innovation are increasingly investigated across many research fields such as information systems, psychology, organizational and management science and multidisciplinary science (Najaftorkaman, Ghapanchi, Talaei-Khoei, & Ray, 2015). The organizational constructs affecting innovation were summarized by Wisdom et al. (2014) to be absorptive capacity, leadership style, networking, culture, size and structure, social climate, social network, training readiness and effort, and traits and readiness for change. The individual characteristics affecting innovation were summarized by Wisdom et al. (2014) to be affiliation with organizational culture, attitudes, motivation, readiness for improvement and reward, feedback on execution and fidelity, awareness, social networking, knowledge/skill, competence, and demographic factors. Context-specific psychological antecedents, such as appreciation, motivation, and leadership are also well-studied to influence the individual's response to innovation (Greenhalgh et al., 2004; Pedersen, 2015; Wisdom et al., 2014).

Adoption and Diffusion of Innovation in Health Care

The adoption and diffusion of innovative services in health care is distinct from other fields. The lack of effective implementation of innovations in health care affects the lives of patients. Reinhardt, Hietschold, and Spyridonidis (2015) analyzed Roger's classical diffusion of innovation framework and how it pertains to health care. The authors investigated the five qualities that determine the success of an innovation mentioned before and found them to be valid in the health care setting: relative advantage translates to focus on "hard" numbers, compatibility translates to leaving non-core processes unchanged, complexity translates to using easy-to-use innovations and shifting the point of care, trialability translates to making parts of the innovation trialable in a small scale, and observability translates to successful communication of outcomes to all relevant stakeholders. The authors also pointed out the distinction between individuals and organizations as highly important in the health care setting. Individuals may be innovative in one or many domains, thus making them more likely to adopt an innovation in their health care role, but they can also be resistant when confronted with barriers. On the other hand, organizations are motivated by gains and resistance on the organizational level may become evident when the implementation of an innovation is misinterpreted to coincide with individual or group loss of power or status. The authors concluded that the various stakeholders in health care form a complex network, and a wide array of different professions needs to collaborate to ensure widespread use of an innovation. They also emphasized that formal and informal partnerships are often needed and that champions or "celebrity hospitals" are influential in innovation adoption and diffusion.

Methodology

A broad review of the selected articles was conducted. The methods used can be categorized into two main groups: systematic reviews, cross-sectional studies, and surveys.

Systematic Reviews

In systematic reviews, authors collect and summarize previously published studies and present it in a concise format. Even though there is no clear definition of what constitutes a systematic review, the main characteristics are typically (a) clear objectives with specific methodology that can be reproduced by others; (b) an exploration of existing literature including methodology to attempt to find all possible studies fitting the eligibility criteria; (c) validity assessment of the studies included, for example for bias etc; and (d) a presentation of the results as a synthesis (Moher et al., 2015). The use of systematic reviews is increasingly common, and the quality of these reviews is improving through reporting standardization, especially after the adoption of the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols (PRISMA-P). Strengths of systematic reviews include more precise estimates of effects than those derived from individual studies and a cohesive approach to the research problem. The main limitations are possible erroneous conclusions if all studies were not identified. For example, Parston et al. (2015) did a systematic review of successful innovations in health care with a significant impact on public health and assessed the factors affecting rapid adoption. In another example, M. Jacobs et al. (2017) conducted a literature review on the frequency of output evaluation of innovations in RO. Output was defined as survival, toxicity, safety, service, efficiency or cost-effectiveness. The authors looked for publications in three ways: innovations in general health care, radiotherapy-specific innovations, i.e., organizational innovations and general implementation of innovations, and innovations per tumor group/radiotherapy technique. Smith et al. (2017) did a review of the current appropriateness of the use of advanced technologies for radiation therapy and surgery in oncology. They focused their study on the definition of the value of innovation implementation from multiple stakeholders and how scientific evidence enters the marketplace of radiation oncology. The authors specifically studied the adoption rate of two distinct innovative techniques, IMRT in the 1990s and early 2000s and proton therapy in the 2000s. Some of the articles cited in these systematic reviews are not explicitly mentioned in this section, yet will be used in the synthesis section below.

Cross-Sectional Studies

Cross-sectional studies are a type of observational study that analyzes data from a population or population sample at a specific point in time and draws conclusions on the state of affairs at that moment in time. Strengths of this type of study include a relatively low cost, rapid completion, and relative ease to achieve large sample sizes. Limitations of cross-sectional studies are the inability to determine causation and follow through to develop changes in the observed patterns (Cresswell, 2018). For example, Jacobs et al. (2016) studied the degree of innovation routinely implemented in the Netherlands by doing a descriptive cross-sectional study. The authors used semi-structured interviews to collect information on product innovation (number of introductions of new or significantly improved treatments, number of new positioning devices, percent of patients on phase I-II randomized trials, percent of patients in phase III trials), technological innovation (frequency of implementation of new medical devices, number of products purchased), market innovation (percentage of patients from outside the market area, percent of referring hospitals) and organizational innovation (new practices for organizing procedures, new methods for organizing work responsibilities, new methods for organizing external relationships with organizations or public institutions). Pfister et al. (2015) used Surveillance, Epidemiology, and End Results (SEER) Medicare data to study risk-adjusted mortality by cancer category in the Medicare population and investigated the difference in outcomes based on university affiliation status. Pollack, Soulos, and Gross (2015) studied peer exposure the adoption of a new cancer treatment modality (breast brachytherapy) by using SEER data and correlated the exposure of early brachytherapy adopted among non-early adopters by investigating their shared patients. Nardi et al. (2016) did a cross-sectional analysis of five-year survival between specialty and non-specialty cancer hospitals. Keown et al. (2014) did a two-phase qualitative and quantitative cross-sectional study in eight countries (Australia, Brazil, England, India, Qatar, South Africa, and the United States) and compared cultural factors enabling health care innovation.

Surveys

While there is no research done on validating web-based surveys specifically on MPs, Dykema, Jones, Piché, and Stevenson (2013) analyzed the use of web-based surveys in clinicians and other health care providers and concluded to achieve good response rate, high incentives are needed. The authors summarize their findings to equate web-based surveys to traditional ones, assuming a rigorous methodology and clarity in result reporting.

Literature Review Related to Key Concepts and/or Variables

Results of the literature review were thematically synthesized. Diffusion of innovations in science and health care in its entirety is presented. Subsequently, RO-specific implementations are assessed. Each of the following categories is then presented as separate entities: effects on value, quality and outcomes, social impact and predictive parameters.

Diffusion of Innovation in Science

Innovation and science have a tight-knit relationship. The terms science, technology, and innovation are frequently used interchangeably. For example, the United Nations Educational, Scientific and Cultural Organization (UNESCO) has an entire program devoted to science, technology, and innovation, as means for economic development and social progress (UNESCO, 2018). In the classic linear models discussed by Eizagirre, Rodríguez, and Ibarra (2017), there is an expectation that funding science will lead to innovation, through technological advancements. However, this narrow approach fails to include socio-economic context and the role of government in allowing deviation from traditional models so mutually responsive co-responsibility can emerge between social actors. Eizagirre et al.(2017) concluded that the relationship between science and innovation is converging to inertia and a new paradigm is needed. The blurring of the lines between neoliberalism and economization in the United States is blatantly apparent when reviewing the accessibility of innovative services in health care (Berman, 2014).

Diffusion of Innovation in Health Care in General

Over the past twenty years, there has been an exponential increase in innovative policies, products, and practices aiming to increase life expectancy, quality of life, effectiveness of treatment, efficiency of treatment, and equity of delivery (Frenk, 2013). How innovations are actualized to improve public health is often referred to as translational research. The time lag between an introduction of an innovation and its diffuse clinical practice was estimated to be on average 17 years, however the way this time lag is measured varies depending on content and exact research questions (Morris et al., 2011). It is logical to attempt to shorten this time so the benefits can be maximized; in fact there is an extensive body of literature on the individual and organizational characteristics that promote acceptance and proliferation of innovation in health care (Parston et al., 2015). Different countries are adopting different strategies to do so. Darzi and Parston (2013) studied the local context of spreading innovations for eight different countries and found substantial differences in cultural dynamics. In the United States, the authors found that standards and protocols along with incentives and rewards were the most important enabling factors for innovation, followed by funding for research development and diffusion, communications channels across and beyond health care, transparency of findings and data demonstrating success and informatics. Vision and strategy, along with specific resources to identify and promote innovation were ranked as the least important parameter for the diffusion of innovation among expert users on the panel (Darzi & Parston, 2013).

The need for innovation in health care is broadly accepted not to be sufficient (Harris, Bhatti, Prime, del Castillo, & Parston, 2018; S. R. Jacobs et al., 2015). There is general agreement that innovation implementation improves patient outcomes (Daniels & Capouya, 2017; Parston et al., 2015). There are numerous examples of adverse patient outcomes due to ineffective implementation of innovation in the health care setting (Reinhardt et al., 2015). The majority of criticism against innovation is related to high costs; innovation is often described as being too costly, as research and development alone cost billions. These simplistic approaches often underestimate the complexity of cost-benefit and the lower downstream costs of improved health at the individual and societal level (Dzau, Asch, Hannaford, Aggarwal, & Pugh, 2017). There needs to be a distinction, however, with low-cost yet proven approaches, especially at low resource settings; high-cost innovative approaches are only beneficial if they outperform their pre-existing solutions and are affordable enough to lead to improved population health. Innovations need to sustainably show benefits to be meaningful (Dzau et al., 2017).

The health care setting provides an excellent field to emphasize the difference of the different levels that innovation can take place in. In their seminal work on health care diffusion of innovation, Greenhalgh, Robert, Macfarlane, Bate, and Kyriakidou (2004) make a health care industry-specific distinction on the adoption by individuals and adoption by organizations. Organizational innovativeness is affected by the administrative intensity, centralization, complexity, internal and external communications, formalization, functional differentiation, managerial attributes toward change, managerial tenure, professionalism, slack resources, specialization, technical capacity, and vertical differentiation. The individual is influenced by general antecedents (tolerance of ambiguity, intellectual ability, motivation, values, and learning style) and context-specific psychological antecedents (values, goals, specific skills, etc.). The majority of publications focus on the science of diffusion, and few on the art of change (Pedersen, 2015). There are also significant differences in how innovation is implemented in low-resource settings (Harris et al., 2018).

Diffusion of Innovation in RO

RO prides itself as a high technology field. Linear accelerators, atomic particles, and algorithms work harmoniously to cure cancer. There is currently extensive usage of many advanced cutting-edge technologies: (a) computational advances using graphics processor units (GPUs), cloud-based methods, and parallel processing have improved calculation speed and are being used for automated knowledge-based treatment planning; (b) high performance imaging systems such as positron emission tomography (PET) allow tumor identification and radiotherapy response measurement, and onboard magnetic resonance imaging (MRgRT) improves real-time monitoring; (c) heavy particle treatments better spare healthy tissues, especially in pediatric populations. However, the field has not universally accepted these innovations (Chetty et al., 2015) and little is known about the factors that may influence groups and individuals (Pollack et al., 2015). This may be partly affected by the fact that few publications include the term "innovation," while in reality, they are actually describing an innovative technique (M. Jacobs et al., 2017).

M. Jacobs et al. (2015) applied the Delphi method to determine indicators for innovation in RO and derived 13 indicators in four categories:

- Product innovation: number of introductions of new or significantly improved treatments, number of new positioning devices for patient treatments, number of approved patents, percentage of patients in phase III randomized trials approved by an IRB, percentage of patients in phase I-II trials approved by an Institutional Review Board (IRB)

- Technological innovation: frequency of implementation of new medical devices, number of products for which royalties have been obtained or which have been sold to the industry, number of regulatory agency approved marked products that have been produced by the department (for example regulated by the Food and Drug Administration (FDA), or the Conformité Européenne (CE))
- Market Innovation: percentage of patients from outside the market area, number and percentage of new general hospitals that refer to the desired patient population.
- Organizational innovation, new practices and for organizing procedures, new methods of organizing work responsibilities and decision making, new methods of organizing external relationships with other organizations or public institutions

The authors suggest that these indicators are most useful when measured in the past three calendar years. These indicators are useful in an attempt to study innovation in RO. Yet, there is currently no study that systematically quantified the diffusion of innovation in RO in the United States. Innovation implementation has been more successfully quantified in the Netherlands with a small number of centers. Jacobs et al. (2016) studied 15 Dutch RO cancer centers (75% of the total in the Netherlands) and found that they implement on average12 innovations per year (range 5-25). The authors will attempt to repeat at three-year increments. The average number is sufficiently large and the authors concluded that Dutch radiotherapy centers are highly accepting of innovation. The wide range, however, suggests a non-homogenous distribution, which the authors did not find to be attributed to academic status. The authors concluded that systematic collaboration between centers and a national registry would be beneficial to improving innovation implementation even further.

Value of Innovation

The definition of value in health care is not very clear. As mentioned before, some of these innovations are extremely expensive and frequently out of reach for standalone community hospitals. Even though one can argue that the investment in innovative technologies translated to increased income for the providers and hospitals and to increased quality-adjusted life-years, the math is not straightforward in RO. In MO, the development of new pharmaceuticals may increase the cost of treatment for new, promising chemotherapy agents directly improves outcomes (Roubou & Alexopoulou, 2015). In RO, innovations need long-term investments to sustain the appropriate use of the technology in the form of upgrades, service contracts, staff education, etc (Smith et al., 2017). There is also a broad discussion of reimbursement for innovative techniques. If the innovative technique has an associated financial motive, then the decision to implement it may be spurious at best. The higher reimbursement rates for IMRT discussed previously were certainly a contributing factor to its fast and successful diffusion across the United States. Conversely, some of the innovative techniques available reduce the number of total treatments and the overall provider and hospital reimbursement. A common example is the use of hypo-fractionated versus conventional whole breast irradiation in the United States: despite supportive 10-year data from the United Kingdom, only 11% of eligible patients received this shorter and less costly regiment in 2008 and 35% in 2013 (Bekelman et al., 2014). In the absence of financial incentives, providers are less likely to adopt innovative treatments that may improve outcomes but reduce their direct financial benefit. In health care in general, value can mean societal value, such as lost wages, lost productivity, and willingness to pay, care value, such as disease control, quality of life and theoretical long-term benefits, or system value, such as incremental costs, budget impact and affordability (Smith et al., 2017). All these three constitute a cost-effective ratio to consider an innovative technique to be of better value than the established technique, and there is little agreement on the calculation of this ratio. Usage of lower cost but better techniques does have successful examples from DR. The Joint Task Force on Adult Radiation Protection was created by the collaboration between the American College of Radiology and the Radiological Society of North America with the purpose addressing the public's concern about exposure to ionizing radiation from medical imaging. The Joint Task Force collaborated with the American Association of Physicists in Medicine and the American Society of Radiologic Technologists to develop standards and launch an extensive awareness campaign under the slogan

"Image Wisely" for adults and "Image Gently" for pediatric patients (American College of Radiology, 2011). These efforts are focused on optimizing existing techniques to limit unnecessary exposure, and often inadvertently highlight the limitations of older equipment. Approaches such as this provide a clear statement to the market and to practitioners that they need better and different innovations.

Effects on quality and outcomes. In the field of RO, innovative techniques are often implemented based on the "as low as (is) reasonably achievable" principle (ALARA). This principle means "making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest" (Nuclear Regulatory Commission, 2018). In RO, innovations are frequently implemented using this principle, in the absence of clinical trials, and there is broad agreement that this improves quality and outcomes (M. Jacobs et al., 2017). While clinical trials are typically the gold standard for evidence-based approaches (Daniels & Capouya, 2017), the implementation of innovative techniques using ALARA is extensive in RO (Chen, 2014). Since there are no clinical trials to drive nationwide recommendations, users can choose their own methods on how to treat patients, within the broad standards described by the National Comprehensive Cancer Network (National Comprehensive Cancer Network, n.d.). This leads to significant differences in outcomes for different populations and leads to the conclusion that quality of cancer care in the United States is inconsistent, with patients treated at specialty cancer hospitals having an adjusted 10% lower mortality at one year than patients treated at community hospitals (Pfister et al., 2015). This inequality to access to appropriate cancer care may not be solely due to innovations, but it is certainly a parameter (Nardi et al., 2016). Additionally, there is little innovation implementation in using big data in RO. Since the advent of electronic medical records (EMR), there has been little or no standardization of specific field entry. The most basic example is the radiation prescription: after ten years of discussion, there is barely a draft in progress (personal communication, RO-SSI group, July 16, 2019). This makes data extraction and comparison extremely difficult and often meaningless. Data elements such as survival, recurrence, diagnosis and staging, provider-reported toxicities, dosimetric data from delivered plans, and use of innovative technologies (such as breath-hold, image-guided radiation therapy, immobilization devices) are largely missing as elements in most EMRs. Extracting this data automatically would lead to self-evaluation and scoring relative to national standards, thus improving the adoption of standards (Mayo et al., 2016).

Social impact. Different cancer care treatments especially in hepatobiliary, lung, pancreas, gastric, breast, cervical, oral, and colorectal cancer, where patients five-year survival is higher by 20-30% for patients treated at comprehensive cancer centers designated by the National Cancer Institute (NCICCC) (Nardi et al., 2016). These NCICCCs are disproportionally located in the eastern United States and major cities across the country (National Cancer Institute, 2018b). The average American living in a rural area has to travel an hour to reach specialized oncology care, and an hour and a half to reach a university hospital (Charlton et al., 2015). Many patients live so far away from an NCICCC, they simply do not have the option to seek treatment there. Additionally, many health care plans do not cover services at university hospitals or NCICCCs at all (Nardi et al., 2016). This translates to the majority of Americans not having access to centers that provide better cancer outcomes, either because of geographical limitations or because their insurance does not cover treatment at institutions with proven better outcomes. This is one of the many challenges in modern America, especially in rural areas. One of the ten essential services of public health is to "evaluate effectiveness, accessibility, and quality of personal and population-based health services" (Centers for Disease Control and Prevention, 2017). The possible lack of diffusion of innovation in RO is a factor that is often overlooked in improving population health. Providing RO care of the highest quality to all patients by improving the utilization of innovative FDA-approved techniques wound contribute to the improvement of accessibility and quality of RO services across the United States and subsequently improve cancer outcomes. This would be a contribution to positive social change.

Organizational Predictive Parameters

Academic affiliation status has been shown to have a positive main effect on innovation and accessibility of services, possibly through slack staffing resources and increased financial resources (Wisdom et al., 2014). Urbanicity has been shown to have a positive effect on innovation and accessibility of services, possibly through competition (Angst, Agarwal, Sambamurthy, & Kelley, 2010; Charlton et al., 2015). Employment type details and type of practice have an unclear relationship with innovation. Organizational structure and climate have been shown to influence innovation adoption, possibly through fecund management tiers (Angst et al., 2010; Wisdom et al., 2014); the number of physicists and reporting structure will be used to assess the organizational structure and climate for MPs.

Individual Predictive Parameters

Gender has a complicated relationship with innovation and there are conflicting results in the literature (Lee, 2016). Recent research focuses on entrepreneurship and gender ratios on the executive level and its relationship to organizational innovation and success (Belghiti-Mahut, Lafont, & Yousfi, 2016). The possible influence of gender in MPs practicing in RO is not certain, and it will thus be interesting to include this parameter in the analysis. On the contrary, the effects of education and age are well studied. Age typically has a negative main effect on innovation adoption (younger people are more likely to adopt innovations) and education typically has a positive main effect on innovation adoption (people with higher education levels are more likely to adopt innovations) (Arts, Frambach, & Bijmolt, 2011). Social status typically has a positive main effect on innovation adoption (people with higher status are more likely to adopt innovations) (Rogers, 2003); affiliation with academic institutions will be used to assess the social status in MPs. Interpersonal channels typically have a positive main effect on innovation implementation (people with more intrapersonal channels are more likely to adopt innovations) (Rogers, 2003); the number attendances in national meetings will be used to assess interpersonal channels in MPs. Organizational structure and climate have been shown to influence innovation adoption (people in larger, well-organized groups are more likely to adopt innovation) (Wisdom et al., 2014); the number of physicists and reporting structure will be used to assess the organizational structure and climate for MPs. Motivation and appreciation are two individual characteristics that are frequently used to assess the position of the individual in the stages previously described by Rogers (2003) (Wisdom et al., 2014); the sense of appreciation and motivation will be directly assessed in the study participants as context-specific psychological antecedents. Appreciation and motivation typically have a positive main effect on innovation adoption, as they may increase the individual's tolerance of risk (people who feel appreciated and motivated are more likely to adopt innovations). Similarly, opinion leadership typically has a positive main effect on innovation adoption (people who consider themselves opinion leaders are more likely to adopt innovations) (Arts et al., 2011); volunteering in AAPM committees will be used to assess the opinion leadership of MPs.

Summary and Conclusions

Innovation implementation is an area that needs improvement in science, health care in general and in RO specifically. The diffusion of innovation theoretical framework is one of the oldest social science theories, and it is well studied in health care, thus grounding the literature review. In this study, the results of the literature review were thematically synthesized to diffusion of innovations in health care in general, diffusion of specific innovations in RO, effects on value, effects on quality and outcomes, social impact, organizational and personal predictive parameters.

The state of diffusion of innovation in RO in the United States is currently not measured, but it is suspected to follow the low rates experienced in other health care fields. There are many underutilized innovations in RO that can enhance patient and staff safety and improve patient outcomes simultaneously. Developing a tool to measure innovation will be the first step in developing a predictive model to improving its diffusion. There is currently no systematic quantification of diffusion of innovation in RO in the United States, and no existing secondary dataset that can be used to extract this information. Understanding the individual and organizational real and perceived barriers to implementing innovations would create the framework to overcome them. If something is not measured, there is no opportunity to study it and further improve it. There needs to be enhanced understanding of how innovative techniques are adopted in RO specifically and assess any disparities in technology implementation in RO in the United States.

To this end, the following chapter describes the methods used to systematically collect this data. A custom-designed online survey was created to conduct a quantitative cross-sectional analysis of how MPs practice and utilize FDA-approved innovative techniques in the academic vs. community setting and rural vs. urban geographic locations. This provided the framework to develop a predictive model assessing possible barriers at the individual (MPs) and organizational (RO clinic) level, based on the previously discussed constructs. Details of the survey design, sampling procedures, power analysis, data analysis, threats to validity, and ethical procedures will be presented in the next chapter.

Chapter 3: Research Method

Introduction

As stated in Chapter 1, the purpose of this study was to investigate the accessibility of innovative services in RO in the United States and assess possible diffusion patterns using a quantitative cross-sectional survey. Surveying MPs to measure the diffusion of innovation in RO is in alignment with the ninth essential function of public health services to "evaluate effectiveness, accessibility, and quality of personal and population-based health services" (Centers for Disease Control and Prevention, 2017). As there are currently no indicators or instrument for measuring the accessibility of innovative services in RO in the United States, according to the literature review, this study quantified this issue and attempted to explain the barriers to adoption of innovative technologies in RO. In this chapter, the focus is on explaining the research design and rationale and the methodology used. The sampling and recruitment procedures are also discussed, as are the instrumentation and operationalization of constructs as they relate to the specific topic. Last, the threats to validity and ethical procedures are addressed.

Research Design and Rationale

This study aimed to measure the innovation score in RO in the United States. Innovation score is the dependent variable. For the purposes of this study, innovation score is defined as the sum of innovation indicators on product, technology, and organizational innovation. Product and technological innovation were measured as the ratio of the number of innovative techniques available or purchased by a department divided by the number of the innovative techniques used clinically, weighed by partial implementation factors. Organizational innovation was measured as the weighted average of innovations used to reorganize procedures, work responsibilities, and decision-making.

Independent variables in this study included variables at both the organizational and individual level. At the organizational level, independent variables included university affiliation and urbanicity. At the personal level, independent variables included gender, age, education, attendance of residency, certification status, interpersonal channels, leadership structure, group size, opinion leadership, appreciation, and motivation.

The research design selected to investigate the possible connections between the dependent and independent variables was a quantitative cross-sectional survey. Survey research is typically used for exploration, explanation, or description and involves the collection of descriptive, behavioral, and attitudinal data (Burkholder, 2015). In this study, survey research was used for explanatory purposes by collecting descriptive and behavioral data. Innovation score is not directly measured by any organization or vendor; thus, the only way to measure it was to ask MP responders to describe how they use innovations in their work and design a custom survey. Even if there were existing data on organizational characteristics and innovation implementation, individual level characteristics would not have been included. It was, therefore, necessary to reach out to individual MPs and collect self-reported data.

The survey was conducted exclusively online. This type of design is predominant in studies by health professionals, especially doctoral students (Rudestam & Newton, 2014). Web survey research has been shown to have lower costs, shorter length of time for field research, more flexible questionnaire design, higher percentage of questions answered completely and accurately, higher ability to administer complex instruments, shorter date processing time, lower error due to manual data entry, faster survey deployment, and a larger amount of available para-data (Dykema, Jones, Piché, & Stevenson, 2013). Potential disadvantages of Web survey designs include required access to Internet and email, the requirement of high computer literacy, increased likelihood of incomplete and erroneous contact information, lower response rates, slightly lower demographic representativeness, and decreased ability to administer incentives effectively (Dykema et al., 2013). For the purposes of this study, a web survey was selected because email communication is extensively used by and the preferred method of communication of MPs (American Association of Physicists in Medicine, 2017). Coincidentally, the use of a web survey aligned with the time and resource limitations of the study.

Methodology

Population

In 2018, the AAPM directory listed approximately 7,500 members in total, and approximately 5,500 members are listed as active in the United States (not student, retired, associate, or corporate members) (American Association of

Physicists in Medicine, 2018). Seventy-seven percent of the membership reported being active in RO (American Association of Physicists in Medicine, 2018); thus, there were about 4,200 eligible MPs. Unofficial surveys typically garner an approximate 5-10% response rate and official surveys an approximate 30-35% response rate. (American Association of Physicists in Medicine, 2017) Considering this response rate and the estimated number of AAPM members, approximately 200 responses were expected for this survey.

Sampling and Sampling Procedures

Primary data was collected for this study using total population convenience sampling because the population is finite and a list was readily available. The MedPhysUSA listserv and AAPM Blackboard were used to recruit participants. The MedPhysUSA listserv is used extensively among MPs for survey dissemination, exchange of ideas, and general discussion. The listserv is hosted by Wayne University and had over 4,000 members at the time of study. Users must subscribe, and there are volunteer moderators. Forum policies were followed; no official permission was needed to post. The AAPM Blackboard is hosted by the AAPM and is open to all members for exchange of ideas and general discussion. No special permission was needed to post the survey. The survey was also posted on LinkedIn. LinkedIn retains data on user activity, as described in its privacy policy ("Privacy Policy, LinkedIn," n.d.). All users agree to this policy as a condition of using the platform. The survey was designed using an online survey research platform called SurveyMonkey (SurveyMonkey, 2019). The invitation post included brief description of the study and a link to the survey.

Based on the expected participant number, a 5% chance of a Type I error and a 20% chance of a Type II error was reasonable. Statistical power of 80% was a reasonable initial goal as well. The typical four-to-one weighting was a good starting point for this study, and it will be further assessed after data collection. If the preliminary analysis reveals disproportional response rates between the categories of interest, these numbers may need to be altered. Type II errors, which encompass not detecting an effect that is actually there, or a false negative (Salazar, Crosby, & DiClemente, 2015), posed more significant social implications than Type I errors in this study. Not detecting an underperformance in community and rural RO centers might have led to a lack of supplemental efforts from AAPM to boost their utilization of new techniques and continuing population inequalities. Effect sizes are unknown since innovation in the United States has not been previously measured. Small to medium effect size of 0.2 were assumed. Based on these assumptions, G-Power (Faul, Erdfelder, Lang, & Buchner, 2007) calculated that approximately 200 responses were needed.

Procedures for Recruitment, Participation, and Data Collection

Participants were contacted passively by using the forums mentioned above. The invitation contained a brief description, incentive information, and a link to participate. Two reminders were sent approximately 10 days apart. The survey remained open for a total of thirty days. When participants opened the link, they were taken to the introductory study page, where they were asked to consent to participate in the study. The survey contained a total of 70 questions and took approximately 5-10 minutes to complete (SurveyMonkey, 2018). Participants were asked multiple demographic and practice information as described in other sections. Participants were asked to enter an email address if they wish to receive a $10 Amazon gift card as an incentive to participate. This is a reasonable amount, as MP's salaries start at $140,000 (American Association of Physicists in Medicine, 2018). The incentive was used to encourage participation. Dykema et al. (2013) analyzed the use of web surveys in clinicians and other healthcare providers and concluded that to achieve good response rate, incentives are needed to improve participation rates. Participants will exit the study after they complete the survey. No follow-up procedures are applicable.

Instrumentation and Operationalization of Constructs

Studies attempting to define and measure innovation in RO rely on custom survey design, as there is no centralized reporting mechanism. This was described in Chapter 2 as discussed by M. Jacobs et al. (2015) and Jacobs et al. (2016). This survey is an extension of the work done by these groups, who validated their innovation indicators using the Delphi method. Briefly, this Dutch group used consensus guidelines among RO chairpersons to define innovation in RO and used semi-structured interviews across 15 RO centers.

Reliability and validity. Reliability was measured using inter-item reliability and split-half method. Chronbach's alpha of 0.7 or higher was be used to assess sufficient evidence of internal reliability (Salazar, Crosby, & DiClemente, 2015). Face validity and content validity were demonstrated by an expert panel. The expert panel was used to assess clarity of wording, applicability of answers, etc. Five MPs who fit the eligibility criteria were contacted in November 2018 and asked to review the survey and identify any ambiguity in the wording of the questions. Each expert panel participant was contacted via email and sent a preliminary version of the survey. Feedback was requested in writing within a week. Comments were received during a two-week period. Comment examples included the anonymity of the survey, stratification techniques, and length of the consent form. Additionally, comments were requested from the AAPM Technology Assessment office and received within 2 weeks in January 2019. Four blinded field experts reviewed the survey and provided feedback on the structure and levels of measurement. All comments were used to improve the survey questions before deploying the study to the target population and enhance the study's validity, as discussed in subsequent sections. Construct validity was demonstrated using principal component analysis (PCA) after data collection.

Operationalization of Constructs. The dependent variable in this study is innovation score, which is defined as the sum of innovation indicators on product, technology, and organizational innovation. Product and technological innovation were measured as the ratio of the number of innovative techniques available or purchased by a department divided by the number of the innovative techniques used clinically, weighed by partial implementation factors. Organizational innovation was measured as the weighted average of innovations used to re-organize procedures, work responsibilities, and decision making. This is a continuous variable. For example, assume that there are ten indicators for product, technology, and organizational innovation and one of the responders has five available for use in their clinic. Out of those five, they use the first two all the time (100%), the third one most of the time (75%) and the last two half of the time (50%). The innovation score for this respondent will be (5/10)*[(100+100+75+50+50)/5] = 0.5*0.75 = 0.375.

The independent variables are described in detail in Table 1. University affiliation was measured as a binary yes or no. Zip code text entry was converted to categorical using the RUCA continuum (USDA, 2013), explained in Appendix C. Gender was binary male or female. Age was measured as a continuous variable and was recoded into categorical. Education was measured as Master's, Doctoral or other. Residency status was measured as a categorical variable, (yes, no, no didn't need). ABR status was measured as yes, yes/other, or no. Interpersonal channels were measured as a continuous variable, using the number of meetings attended. Organizational structure was be measured as a categorical variable as physicist, physician, administrator. Group characteristics were measured as a categorical variable based on the size of the group. Opinion leadership was measured as a binary variable as yes or no. Appreciation was measured as a continuous variable. Motivation was measured as a continuous variable. Barriers were measured as continuous variables.

Table 1

Operationalization of Constructs

Question	Variable	Level of measurement	RQ
Q3-57	Innovation score (dependent variable)	Continuous	1, 2 3
Q1: university affiliation	University affiliation	Binary	1a
Q2: location	Zip code	Categorical	1b
Q3-57	Barriers	Continuous	3
Q58: gender	Gender	Categorical	2
Q59: Age	Age	Continuous	2
Q60: degree	Degree	Binary	2
Q61: residency	Residency	Categorical	2
Q62: ABR status	ABR status	Categorical	2
Q63: meeting attendance	Interpersonal channels	Continuous	2
Q64: reporting	organizational structure	Categorical	2
Q65: # of physicists	Group characteristics	Categorical	2
Q66: volunteering	Opinion leadership	Categorical	2
Q67: appreciation	Appreciation	Continuous	2
Q68: motivation	Motivation	Continuous	2
Q69: final thoughts	Free text	-	-
Q70: gift card	Free text	-	-

Data Analysis Plan

After completing data collection, SPSS version 25 was used for statistical analysis. Data were screened for duplicates. Missing entries were reviewed for randomness, and data were removed pairwise when applicable. The RQs and hypotheses were as follows:

RQ 1: What are the differences in accessibility to innovation in RO based on location and type of practice in the United States?

RQ 2: What are the statistically significant factors (demographics, practice details, context-specific psychological antecedents) that predict the accessibility to innovation in the RO clinic?

RQ 3: What are the statistically significant barriers that MPs practicing in RO in the United States face in implementing innovations?

Hypothesis 1a

$H1a_0$: There is no statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

$H1a_1$: There is a statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

Dependent variable: innovation score (continuous).

Independent variable: university affiliation (categorical, two levels: has university affiliation, does not have university affiliation).

Hypothesis 1b

$H1b_0$: There is no statistically significant difference in the accessibility to innovation in RO between metropolitan and non-metropolitan hospitals.

$H1b_1$: There is a statistically significant difference in accessibility to innovation in RO between metropolitan and non-metropolitan hospitals.

Dependent variable: innovation score (continuous).

Independent variable: urbanicity (categorical, metropolitan and non-metropolitan).

Hypothesis 2

H2_0: There are no statistically significant factors predicting innovation score.

H2_1: There are statistically significant factors predicting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: reporting structure, size of physics group, age, gender, DABR status, residency status, meeting attendance, education level, leadership,(categorical) appreciation, and motivation (continuous).

Hypothesis 3

H3_0: There are no statistically significant barriers affecting innovation score.

H3_1: There are statistically significant barriers affecting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: barriers (continuous).

Analysis plan. For RQ 1 the purpose is to compare groups, thus *t*-test and ANOVA were used (Frankfort-Nachmias & Leon-Guerrero, 2015). T-test was used to compare innovation score for type of hospital variable and ANOVA was used to compare innovation between the RUCA urbanicity continuum. The *t* and *F* values and *p*-value were reported, along with means and standard deviations for all groups. Alternative non-parametric tests, such as the Mann-Whitney U and Kruskal-Wallis H tests, would have been selected if the dataset was found to have a significant deviation from normality. If homogeneity of variance was met, Tukey's honestly significant difference (HSD) post hoc test was used to assess which specific groups differed. If the data did not meet the homogeneity of variances assumption, the Games Howell post hoc test would have been considered.

For research question 2, multiple linear regression was initially planned to be used if the assumptions of linearity were met. The dependent variable was innovation score. This is a continuous variable. Independent variables in the model were respondents' age, gender, education level, ABR status, residency status, interpersonal channels, appreciation level, motivation level, opinion leadership, practice organizational structure, and group characteristics. Alternative non-parametric tests were selected because the data did not meet normality criteria. To do so, the dependent variable (innovation score) was recoded to be binary categorical (below median, above median) and binomial logistic regression was used instead.

For research question 3, correlation testing was used. The dependent variable was innovation utilization score. The independent variables are the individual barriers (lack of evidence, complexity, lack of time or staffing, lack of training or support, lack of interest, lack of interoperability, and lack of reimbursement. Pearson's correlation was selected if the relationship between the dependent and independent variable is linear. Spearman correlation was selected if the data did not meet normality criteria.

Threats to Validity

Threats to External Validity

This study will reach the entire MPs population in the United States, thus threats to external validity due to sampling are limited (Cresswell, 2018). There is, however, the problem of volunteer bias, as participants who volunteer to be in a study about innovation may inherently be more innovative. The respondents may not be representative of the general population in regards to innovation practice or other characteristics. Additionally, there is inherent generalization across constructs on how the constructs apply to MPs specifically. For example, opinion leadership as a construct will be measured using volunteering in the AAPM. While participation in professional association leadership is a measure of opinion leadership in other disciplines (B. L. Jacobs et al., 2017), there is an inherent assumption that this connection transfers to MPs as well. This generalization across constructs may lead to extraneous or confounding variables in MPs.

Threats to Internal Validity

Extraneous effects may pose a threat to the internal validity of this study, as there may be excluded extraneous variables that were elusive during the literature review. This threat was minimized by the use of an expert panel who reviewed the survey before implementation. Additionally, there may be personal biases, which should be minimal due to the quantitative nature of the study. Participant reactivity may also be present in the study, as participants may respond as being more innovative than they really are, suspecting that this is the desired behavior. This may affect the measurement of the dependent variable This is unlikely to have significant effects on an online professional survey, as this is most often observed in laboratory settings. These possible effects will be minimized as much as possible with the use of the appropriate multivariable analysis (Frankfort-Nachmias & Leon-Guerrero, 2015).

Ethical Procedures

Ethical considerations for the participants. Research participants have a moral obligation to answer truthfully. There are many surveys performed through the AAPM, including salary surveys for workforce forecasting, and confidentiality is not really a concern among members. The participant obligation will be emphasized at the beginning of the study, where the study's scope and rationale will be explained, in addition to the time commitment expected by the participants. Participants will be asked to acknowledge the expectations of their participation. This acknowledgment will serve as consent and as a “contract” between the participant and the researcher (Rudestam & Newton, 2014). Participants who are not MPs practicing in RO in the United States, yet participated for various reasons, would have violated the ethics of the consent.

Various methods were used to positively reinforce truthful answers. Using a continuous, dependent-response scale (0-100 values) instead of a discrete, Likert-type scale for partial implementation is expected to have participants answer more truthfully, versus a yes or no answer that may not be indicative of how exactly they are using these techniques.

Ethical considerations for the researcher. The survey poses minimal risk to the participants, as the questions do not fall into the "traditional" sensitive information areas. Information can be perceived as sensitive when it involves cultural taboos, the threat of disclosure, or social desirability. What information is too private, or taboo, is extremely subjective and highly dependent on the culture (Epstein, Santo, & Guillemin, 2015). Participants were asked questions about how they perform their daily work duties, and none of the questions is of sensitive nature. The survey questions can, however, be seen as a surrogate to professional performance, and thus affect the respondent's view of performance and self-worth. Additionally, some of the questions will be about feelings of appreciation in the workplace. This may affect participants, as they typically may not have to think about something like that (Rudestam & Newton, 2014). This effect may be positive or negative, depending on the person and the situation. Possibility feeling uncomfortable was thus included in the study consent.

Concerns over privacy will be handled using the anonymity features of the survey provider. The custom link will be provided along with the introductory text for the email. Email addresses will not be tracked. Additionally, concerns over Internet Protocol address (IP) tracking will be addressed by turning the feature off in the survey provider.

Institutional approval to conduct research. The Walden University Institutional Review Board (IRB) approved this study on April 24, 2019 (approval number 04-24-19-0603259, expiring April 23rd, 2020).

Summary

In this chapter, a detailed discussion of the research design and rationale as a total population convenience sampling cross-sectional survey was presented. The methodology, population, sampling procedures, instrumentation, and operationalization of constructs, data analysis plan were discussed. Possible threats to validity were also explored. The results of the study will be presented in Chapter 4.

Chapter 4: Results

Introduction

The purpose of this research study was to examine the diffusion of innovation in RO in the United States. To assess diffusion, a variety of statistical tests was used to compare innovation score with organizational and personal characteristics. A summary of the results is presented in this chapter. The following RQs were answered:

RQ 1: What are the differences in accessibility to innovation in RO based on location and type of practice in the United States?

RQ 2: What are the statistically significant factors (demographics, practice details, context-specific psychological antecedents) that predict the accessibility to innovation in the RO clinic?

RQ 3: What are the statistically significant barriers that MPs practicing in RO in the United States face in implementing innovations?

Data Collection

The survey was posted on Saturday, April 27, 2019. The invitation is listed in Appendix B. During the first two weeks of the survey, 136 responses were collected. The first reminder was sent on Saturday, May 11, 2019, and the last reminder was sent on Wednesday, May 22, 2019. The survey closed on Saturday, June 1, 2019, at 11:50 pm. At the survey closure, 265 responses were collected. Twenty-five responses contained no answers at all. Thus, the final sample size was 240. Incomplete data entries were excluded pairwise when applicable. The analysis was conducted using SPSS 25.

Descriptive Statistics

Independent variables were recoded as needed, taking into account the number of responses received. ZIP codes entered in the survey were converted to county, and the Rural-Urban Continuum Codes (Appendix C) were used to categorize locations as metropolitan and nonmetropolitan (USDA, 2013), as shown in Table 2. Most responses were received from metropolitan areas. University affiliation is also listed in Table 2; the sample contained approximately equal responses between university and non university facilities. Sample demographics for gender, education and age are shown in Table 3. Descriptive statistics for respondent appreciation and motivation are shown in Table 4. Sample professional characteristics for residency, DABR status, number of meetings in the past 10 years, reporting, number of physicists and volunteering are shown in Table 5. Principal component analysis was found to not a suitable test, as the overall Kaiser-Meyer-Olkin measure ranged from 0.588 to 0.634 depending on the factors entered in the model.

Table 2

MPs Characteristics for RO center University Affiliation and Urbanicity

Characteristic	*N*	*f*	%
University Affiliation	240		
Yes		111	46.3
No		129	53.8
Urbanicity	220		
RUCA Cat 1		138	62.7
RUCA Cat 2		50	22.7
RUCA Cat 3		17	7.7
RUCA Cat 4		4	1.8
RUCA Cat 5		4	1.8
RUCA Cat 6		4	1.8
RUCA Cat 7		3	1.4
Urbanicity Binary 1	220		
RUCA Cat 1		138	62.7
RUCA Cat 2-9		82	37.3
Urbanicity Binary 2	220		
RUCA Categories 1-3		205	93.2
RUCA Categories 4-9		15	6.8

Table 3

MPs Demographics for RO

Characteristic	*N*	*f*	%
Gender	188		
Male		155	82.4
Female		33	17.6
Education	190		
Master’s		118	62.1
Doctoral		72	37.9
Age distribution	183		
< = 30		23	12.6
31-40		70	38.3
41-50		36	19.7
51-60		30	16.4
> 60		24	13.1

Table 4

Descriptive Statistics for RO Appreciation and Motivation in MPs

	N	*M*	*SD*
Appreciation	190	69.16	26.728
Motivation	190	76.35	23.463

Table 5

MPs Professional Characteristics

Characteristic	*N*	*f*	%
Residency	185		
Yes		77	41.6
No		108	58.4
DABR status	188		
DABR		150	79.8
not DABR/other		38	20.2
Number of meetings in the past 10 years	179		
0-5		104	58.1
6-9		42	23.5
> = 10		33	18.4
Reporting	189		
Another physicist		114	60.3
Physician		22	11.6
Administrator		37	19.6
VP/CEO		16	8.5
Number of physicists	191		
1-3		98	51.3
≥ 4		93	48.7
Volunteer	185		
Yes		72	38.9
No		113	61.1

Dependent variable coding. The dependent variable, innovation score, was measured using 20 unique indicators in five categories: patient positioning, patient treatment, treatment planning, quality assurance, and workflow, as shown in Appendix D. Participants answers were entered using a slider with scale 0-100. For values entered as 0 or 1 on the slider, it was assumed that the respondents meant to not move the slider at all and that the type of innovation was not available. For values entered as 2 to 100 on the sliding scale, it was assumed that the respondents had the technology available to them. This categorized each respondent as having or not having the innovation. The innovation indicators were summed to calculate the innovation score for each category and the total innovation score for each respondent. This provided a measure for the diffusion of available innovative techniques and will be subsequently referred to as *innovation score*. The distribution is shown in Figure 1, and it appears to be normally distributed.

Further, the exact number on the scale of individual responses was used to assess how respondents actually used the innovations available to them. This will be subsequently referred to as *innovation utilization score*, and it is distinctly different from the previously defined innovation score. A similar method described for innovation score was used for the innovation utilization score. The mean of the responses in each of the indicators in each category was used to calculate the innovation utilization score in each category separately. The innovation utilization score was calculated by adding the innovation utilization score in the five categories. The distribution is shown in Figure 2, and it appears to be normally distributed.

The Shapiro-Wilk test for normality was performed for innovation score and innovation utilization score, using university affiliation and urbanicity as factors. The results of the Shapiro-Wilk test were not statistically significant for the innovation score (p = 0.611) and for the innovation utilization score (p = 0.699). Thus, the data were normally distributed. The Q-Q plots were also normal.

The 20 parameters used to measure innovation were assessed for the reliability of the construct. The scale had a high level of internal consistency, as determined by a Cronbach's alpha of 0.963.

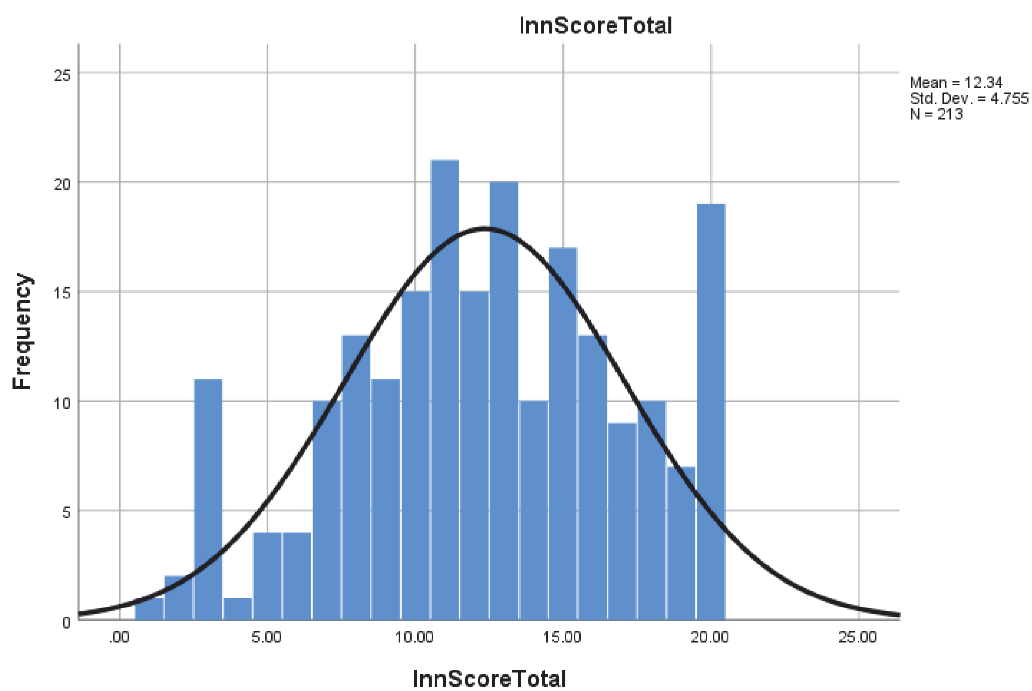

Figure 1. Distribution of RO innovation score.

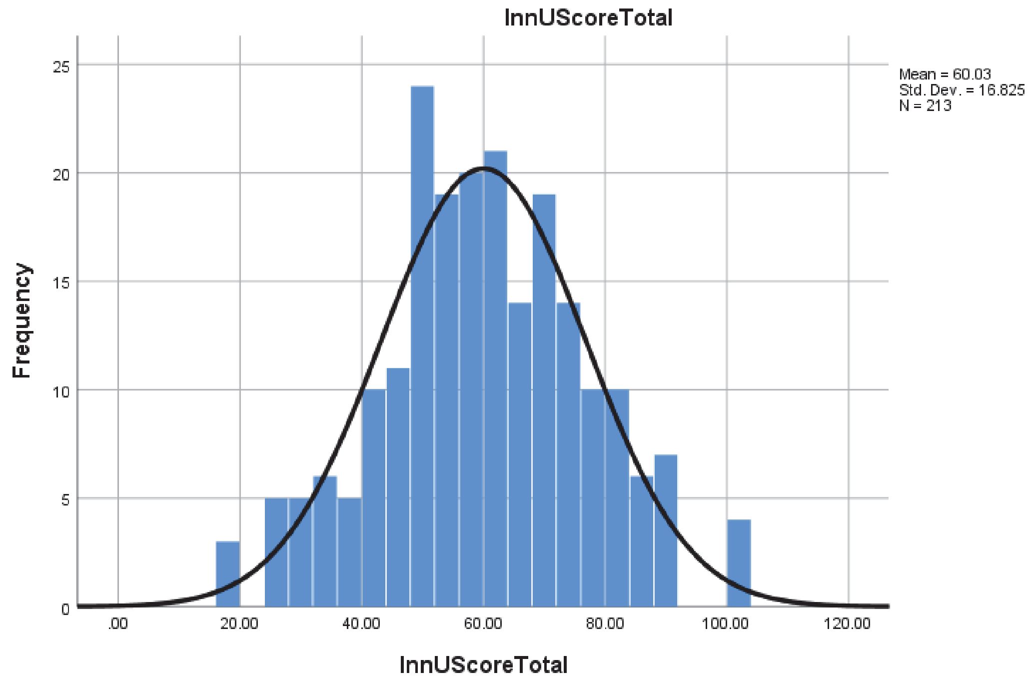

Figure 2. Distribution of RO innovation utilization score.

Study Results

Research Question 1 Results

Research Question (RQ) 1: What are the differences in accessibility to innovation in RO based on location and type of practice in the United States?

*H*1a0: There is no statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

*H*1a1: There is a statistically significant difference in accessibility to innovation in RO between university and non-university hospitals.

Dependent variable: innovation score (continuous).

Independent variable: university affiliation (categorical, two levels: has university affiliation, does not have university affiliation).

Results for Hypothesis 1a. An independent *t*-test was performed to determine if there were differences in innovation score between university and non-university centers for the total innovation score and for the innovation utilization score. There were no outliers in the data, as assessed by inspection of a boxplot. There was homogeneity of variances, as assessed by Levene's test for equality of variances for both the total innovation score ($p = 0.689$) and the innovation utilization score ($p = 0.129$).

The mean innovation score difference for centers with university affiliation ($M = 13.19$, $SD = 4.76$) is higher than the mean innovation score for centers without a university affiliation ($M = 11.55$, $SD = 4.63$), a statistically significant difference $MD = 1.65$, 95% CI[0.38,2.917], $t(211) = 2.56$, $p = 0.011$, $d = 0.351$. Additionally, the patient treatment innovation score for university centers ($M = 3.04$, $SD = 1.43$) is higher than the patient treatment innovation score for non-university centers ($M = 2.64$, $SD = 1.34$), a statistically significant difference $MD = 0.39$, 95% CI[0.021,0.76], $t(217) = 2.083$, $p = 0.038$, $d = 0.282$; the workflow innovation score for university centers ($M = 2.96$, $SD = 1.51$) is higher than the workflow innovation score for non-university centers ($M = 2.50$, $SD = 1.55$), a statistically significant difference $MD = 0.46$, 95% CI[0.05,0.86], $t(217) = 2.217$, $p = 0.028$, $d = 0.188$. Results are presented in Tables 6 and 7. Cohen's *d* was calculated manually.

Table 6

Group Statistics for RO center Innovation Score and University Affiliation

Category	University Affiliation	*N*	*M*	*SD*	*SEM*
Patient Positioning	Yes	106	2.217	1.087	.106
	No	113	2.018	1.035	.097
Patient Treatment	Yes	106	3.038	1.434	.139
	No	113	2.646	1.349	.127
Treatment Planning	Yes	106	2.292	1.441	.139
	No	113	2.115	1.361	.128
Quality Assurance	Yes	106	2.311	1.539	.149
	No	113	1.956	1.454	.137
Workflow	Yes	106	2.962	1.505	.146
	No	113	2.504	1.548	.146
Total	Yes	103	13.194	4.757	.469
	No	110	11.546	4.635	.442

Table 7

Independent Samples T- Test for RO center Innovation Score and University Affiliation

Category		Levene's Test for Equality of Variances		t-test for Equality of Means					95% CI	
		F	*p*	t	df	*p*	MD	SED	LL	UL
Patient Positioning	Equal variances assumed	1.009	.316	1.390	217	.166	.199	.144	-.083	.485
	Equal variances not assumed			1.388	214	.167	.199	.144	-.084	.482
Patient Treatment	Equal variances assumed	.003	.953	2.083	217	**.038**	.392	.188	.021	.762
	Equal variances not assumed			2.079	211	.039	.392	.188	.0203	.763
Treatment Planning	Equal variances assumed	1.510	.221	.937	217	.350	.177	.189	-.196	.550
	Equal variances not assumed			.935	214	.351	.177	.189	-.196	.551
Quality Assurance	Equal variances assumed	1.966	.162	1.758	217	.080	.356	.202	-.043	.754
	Equal variances not assumed			1.755	214	.081	.356	.203	-.044	.755
Workflow	Equal variances assumed	1.152	.284	2.217	217	**.028**	.458	.207	.051	.865
	Equal variances not assumed			2.219	217	.028	.458	.206	.051	.864
Total	Equal variances assumed	.160	.689	2.562	211	**.011**	1.649	.644	.379	2.917
	Equal variances not assumed			2.559	209	.011	1.649	.644	.379	2.919

The mean innovation utilization score for centers with university affiliation (*M* = 59.39, *SD* = 17.74) is similar to the mean innovation utilization score for centers without a university affiliation (*M* = 60.62, *SD* = 15.97). The innovation utilization score difference is not statistically significant based on university affiliation. However, for the five categories measured, the mean workflow innovation utilization score for centers with university affiliation (*M* = 54.05, *SD* = 22.85) is higher than the mean workflow innovation utilization score for centers without a university affiliation (*M* = 46.95, *SD* = 19.92), a statistically significant difference *MD* = 7.09, 95% CI[0.78,13.39], $t(178) = 2.217$, $p = 0.028$, $d = 0.330$. Results are presented in Tables 8 and 9. Cohen's *d* was calculated manually. Thus, the null hypothesis $H_{1a,0}$ is rejected, and the alternate $H_{1a,1}$ is accepted.

Table 8

Group Statistics for RO center Innovation Utilization Score and University Affiliation

Category	University Affiliation	*N*	*M*	*SD*	*SEM*
Patient Positioning	Yes	90	60.985	25.089	2.645
	No	98	63.908	23.681	2.392
Patient Treatment	Yes	96	76.195	24.681	2.519
	No	102	76.769	25.208	2.496
Treatment Planning	Yes	91	48.092	26.226	2.749
	No	95	51.637	24.973	2.562
Quality Assurance	Yes	85	56.022	28.503	3.092
	No	86	61.565	23.893	2.576
Workflow	Yes	90	54.045	22.859	2.410
	No	90	46.959	19.921	2.099
Total	Yes	103	59.393	17.749	1.749
	No	110	60.619	15.970	1.523

Table 9

Independent Samples T-Test for RO center Innovation Utilization Score and University Affiliation

Category		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% CI	
		F	*p*	t	df	*p*	MD	SED	LL	UL
Patient Positioning	Equal variances assumed	.172	.679	-.822	186	.412	-2.923	3.557	-9.941	4.095
	Equal variances not assumed			-.820	182	.413	-2.923	3.566	-9.956	4.113
Patient Treatment	Equal variances assumed	.588	.444	-.162	196	.872	-.575	3.546	-7.573	6.423
	Equal variances not assumed			-.162	196	.871	-.575	3.546	-7.568	6.419
Treatment Planning	Equal variances assumed	.269	.605	-.944	184	.346	-3.545	3.754	-10.952	3.861
	Equal variances not assumed			-.943	182	.347	-3.545	3.758	-10.960	3.869
Quality Assurance	Equal variances assumed	3.361	.069	-1.38	169	.170	-5.544	4.020	-13.481	2.392
	Equal variances not assumed			-1.38	163	.170	-5.544	4.024	-13.491	2.402
Workflow	Equal variances assumed	2.542	.113	2.217	178	**.028**	7.086	3.196	.771	13.39
	Equal variances not assumed			2.217	175	.028	7.086	3.196	.778	13.40
Total	Equal variances assumed	2.317	.129	-.531	211	.596	-1.227	2.311	-5.782	3.33
	Equal variances not assumed			-.529	205	.597	-1.227	2.319	-5.798	3.345

Hypothesis 1b

$H1b_0$: There is no statistically significant difference in the accessibility to innovation in RO between metropolitan and non-metropolitan hospitals.

$H1b_1$: There is a statistically significant difference in accessibility to innovation in RO between metropolitan and non-metropolitan hospitals.

Dependent variable: innovation score (continuous)

Independent variable: urbanicity (categorical, metropolitan, and non-metropolitan)

Results for Hypothesis 1b. An independent *t*-test was performed to determine if there were differences in innovation score between metropolitan and non-metropolitan centers for the total innovation score and for the innovation utilization score. There were no outliers in the data, as assessed by inspection of a boxplot. There was homogeneity of variances, as assessed by Levene's test for equality of variances for both the total innovation score ($p = 0.478$) and the innovation utilization score ($p = 0.855$). It is noted that total innovation score was assessed using binary RUCA categorization 1 and 2-9, while innovation utilization score was assessed using binary RUCA categorization 1-3 and 4-9. Results are presented in Tables 10 to 13.

The mean innovation score for metropolitan centers ($M = 12.94$, $SD = 4.65$) is similar to the mean innovation score for non-metropolitan centers ($M = 11.69$, $SD = 4.37$). The innovation score difference is not statistically significant based on metropolitan or non-metropolitan status, even though $d = 0.275$.

However, for the five categories measured, the mean patient positioning innovation score for metropolitan centers (*M* = 2.21, *SD* = 1.02) is higher than the mean patient positioning innovation score for non-metropolitan centers (*M* = 1.89, *SD* = 1.12), a statistically significant difference *MD* = 0.31, 95% CI[0.011,0.612], $t(203) = 2.043$, $p = 0.042$, $d = 0.293$. Additionally, the mean patient treatment innovation score for metropolitan centers (*M* = 3.08, *SD* = 1.36) is higher than the mean patient treatment innovation score for non-metropolitan centers (*M* = 2.47, *SD* = 1.33), a statistically significant difference *MD* = 0.62, 95% CI[0.23,1.00], $t(203) = 3.145$, $p = 0.002$, $d = 0.457$. Results are presented in Tables 10 and 11. Cohen's *d* was calculated manually.

Table 10

Group Statistics for RO center Innovation Score and Urbanicity

Category	UrbanicityBinary1	*N*	*M*	*SD*	*SEM*
Patient Positioning	RUCA 1	130	2.208	1.025	.090
	RUCA 2-9	75	1.893	1.122	.130
Patient Treatment	RUCA 1	130	3.085	1.364	.120
	RUCA 2-9	75	2.467	1.340	.155
Treatment Planning	RUCA 1	130	2.354	1.375	.121
	RUCA 2-9	75	2.000	1.356	.157
Quality Assurance	RUCA 1	130	2.169	1.536	.135
	RUCA 2-9	75	2.160	1.395	.161
Workflow	RUCA 1	130	2.823	1.553	.136
	RUCA 2-9	75	2.707	1.431	.165
Total	RUCA 1	127	12.937	4.653	.413
	RUCA 2-9	72	11.694	4.375	.516

Table 11

Independent Samples T-Test for RO center Innovation Score and Urbanicity

Category		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% CI	
		F	*p*	t	df	*p*	MD	SED	LL	UL
Patient Positioning	Equal variances assumed	1.090	.298	2.043	203	**.042**	.314	.154	.011	.618
	Equal variances not assumed			1.994	143	.048	.314	.158	.003	.626
Patient Treatment	Equal variances assumed	.176	.675	3.145	203	**.002**	.618	.196	.230	1.005
	Equal variances not assumed			3.161	157	.002	.618	.196	.232	1.004
Treatment Planning	Equal variances assumed	.536	.465	1.784	203	.076	.354	.198	-.037	.745
	Equal variances not assumed			1.791	156.273	.075	.354	.198	-.036	.744
Quality Assurance	Equal variances assumed	1.997	.159	.043	203	.966	.009	.216	-.416	.434
	Equal variances not assumed			.044	167	.965	.009	.210	-.405	.424
Workflow	Equal variances assumed	3.040	.083	.532	203	.595	.116	.219	-.315	.548
	Equal variances not assumed			.544	165	.587	.116	.214	-.306	.539
Total	Equal variances assumed	.505	.478	1.849	197	**.066**	1.243	.672	-.083	2.568
	Equal variances not assumed			1.881	155	.062	1.243	.660	-.062	2.547

The mean innovation utilization score for metropolitan centers (*M* = 60.73, *SD* = 16.67) is similar to the mean innovation utilization score for non-metropolitan centers (*M* = *55.41*, *SD* = 15.38). The total innovation utilization score difference is not statistically significant based on metropolitan or non-metropolitan status, even though $d = 0.331$. However, for the five categories measured, the mean patient positioning innovation utilization score for metropolitan centers (*M* = 63.96, *SD* = 23.78) is higher than the mean patient positioning innovation utilization score for non-metropolitan centers (*M* = 47.73, *SD = 29.28*), a statistically significant difference *MD* = 16.22, 95% CI[0.73,31.72], $t(173) = 2.067$, $p = 0.04$, $d = 0.608$. Results are presented in Tables 12 and 13. Cohen's *d* was calculated manually. Thus, the null hypothesis $H_{1b,0}$ is rejected, and the alternate $H_{1b,1}$ is accepted.

Table 12

Group Statistics for RO center Innovation Utilization Score and Urbanicity

Category	UrbanicityBinary2	*N*	*M*	*SD*	*SEM*
Patient Positioning	RUCA 1-3	165	63.958	23.784	1.852
	RUCA 4-9	10	47.733	29.287	9.262
Patient Treatment	RUCA 1-3	175	78.023	23.493	1.776
	RUCA 4-9	11	72.897	25.561	7.707
Treatment Planning	RUCA 1-3	166	50.171	25.228	1.958
	RUCA 4-9	11	43.606	28.433	8.573
Quality Assurance	RUCA 1-3	152	57.803	25.949	2.105
	RUCA 4-9	11	69.955	25.739	7.761
Workflow	RUCA 1-3	164	50.896	21.894	1.710
	RUCA 4-9	8	40.042	18.073	6.390
Total	RUCA 1-3	186	60.726	16.673	1.223
	RUCA 4-9	13	55.416	15.385	4.267

Table 13

Independent Samples T- Test for RO center Innovation Utilization Score and Urbanicity

	Category	Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% CI	
		F	*p*	t	df	*p*	MD	SED	LL	UL
Patient Positioning	Equal variances assumed	1.463	.228	2.067	173	**.040**	16.22	7.849	.732	31.72
	Equal variances not assumed			1.718	10	.117	16.22	9.445	-4.90	37.35
Patient Treatment	Equal variances assumed	.067	.795	.698	184	.486	5.13	7.339	-9.35	19.61
	Equal variances not assumed			.648	11	.530	5.13	7.909	-12.3	22.52
Treatment Planning	Equal variances assumed	.221	.639	.829	175	.408	6.56	7.915	-9.06	22.19
	Equal variances not assumed			.747	11	.471	6.56	8.794	-12.8	25.91
Quality Assurance	Equal variances assumed	.043	.836	-1.50	161	.135	-12.15	8.098	-28.1	3.84
	Equal variances not assumed			-1.51	12	.158	-12.15	8.041	-29.8	5.45
Workflow	Equal variances assumed	.214	.644	1.379	170	.170	10.86	7.875	-4.69	26.40
	Equal variances not assumed			1.641	8	.139	10.86	6.614	-4.38	26.09
Total	Equal variances assumed	.034	.855	1.115	197	.266	5.310	4.762	-4.1	14.70
	Equal variances not assumed			1.196	14	.251	5.310	4.439	-4.2	14.83

Research Question 2 Results

Research Question (RQ) 2: What are the statistically significant factors (demographics, practice details, context-specific psychological antecedents) that predict the accessibility to innovation in the RO clinic?

$H2_0$: There are no statistically significant factors predicting innovation score.

$H2_1$: There are statistically significant factors predicting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: reporting structure, size of physics group, age, gender, DABR status, residency status, meeting attendance, education level, leadership, (categorical) appreciation, and motivation (continuous).

Bivariate analysis for appreciation, motivation, and number of meetings. The Shapiro-Wilk test for normality was performed for innovation score and innovation utilization score using appreciation, motivation, and number of meetings as factors (continuous variables). The results of the Shapiro-Wilk test were statistically significant for all three parameters ($p < 0.001$). Thus, the data are not normally distributed. The Q-Q plots were also not normal. Spearman correlation was used to perform bivariate analysis for appreciation and motivation. There was a positive correlation between innovation utilization and participant appreciation ($r_s = 0.224$, $p = 0.002$) and motivation ($r_s = 0.215$, $p = 0.003$). Both correlations are of small to medium effect size class, according to Cohen's criteria (Ellis, 2010). There was a small negative correlation between innovation utilization and the number of meetings attended (r_s = -0.186, p = 0.013). Since this result is unexpected, the relationship with total innovation score was also investigated. Results were not statistically significant (r_s = 0.067, p = 0.371). Thus, the number of meetings will not be included in the final regression model.

Bivariate analysis for gender, opinion leadership, education, and residency status. The Shapiro-Wilk test for normality was performed for innovation score and innovation utilization score using gender, opinion leadership, education, and residency as factors (binary variables). The results of the Shapiro-Wilk test were not statistically significant for gender (p = 0.433), opinion leadership (p = 0.172), education (p = 0.922), and residency (p = 0.981). Thus, the data are normally distributed. The Q-Q plots were also normal. An independent sample *t*-test was performed for gender, opinion leadership, education, and residency. Results were not statistically significant for gender (p = 0.828), opinion leadership (p = 0.921), and residency (p = 0.402). Results were statistically significant for education. The mean innovation utilization score for Master's degree (M = 61.42, SD = 16.11) is higher than the mean innovation utilization score for Doctoral degree (M = 56.37, SD = 17.22), a statistically significant difference MD = 5.06, 95% CI[0.18,9.94], $t(188)$ = 2.046, p = 0.042, d = 0.278.

Bivariate analysis for age, DABR status, number of meetings, reporting structure, and number of physicists. The Shapiro-Wilk test for normality was performed for innovation score and innovation utilization score using age, DABR status, number of meetings, reporting structure, and number of physicists as factors (categorical variables). The results of the Shapiro-Wilk test were not statistically significant for meetings ($p = 0.425$), age ($p = 0.768$), DABR status ($p = 0.573$), reporting structure ($p = 0.739$), and the number of physicists ($p = 0.431$). There was no statistically significant effect of age ($p = 0.38$), DABR status ($p = 0.10$), reporting status ($p = 0.06$), and the number of physicists in practice ($p = 0.57$).

Binary logistic regression. Three parameters were found to be statistically significant in affecting innovation implementation: degree, motivation, and appreciation. Since the two latter are non-linear, a binomial logistic regression was performed. The dependent variable, innovation utilization, was recoded to binary (1 = below median, 2 = above median, Mdn = 60.03). Linearity of the continuous variables with respect to the logit of the dependent variable was assessed using the Box-Tidwell procedure. The interaction term was not statistically significant for motivation ($p = 0.587$), and for appreciation ($p = 0.338$), thus these two independent variables are linearly related to the logit of the dependent variable. No corrections were applied. Results of the binary logistic regression are presented in Tables 14 to 18.

Table 14

Binary Logistic Regression Omnibus Tests of Model Coefficients

		χ^2	df	p
Step 1	Step	10.861	3	.013
	Block	10.861	3	.013
	Model	10.861	3	**.013**

Table 15

Binary Logistic Regression Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	250.720[a]	.056	.075

a. Estimation terminated at iteration number 3 because parameter estimates changed by less than .001.

Table 16

Binary Logistic Regression Hosmer and Lemeshow Test

Step	χ^2	df	p
1	6.187	8	.626

Table 17

Binary Logistic Regression Classification Table

Observed			Predicted		
			Innovation Utilization Score		
			Below Median	Above Median	Percent Correct
Step 1	Innovation Utilization Score	Below Median	60	34	65.7
		Above Median	40	50	55.6
	Overall Percentage				60.8

a. The cut value is .500

Table 18

Binary Logistic Regression Results and Variables in the Equation for Innovation Utilization (outcome variable)

								95% CI.for *OR*	
		B	S.E.	Wald	df	*p*	*OR*	LL	UL
Step 1[a]	Education	-.600	.315	3.620	1	.057	.549	.296	1.018
	Appreciation	.013	.008	2.385	1	.122	1.013	.997	1.030
	Motivation	.001	.009	.005	1	.944	1.001	.983	1.019
	Constant	-.821	.560	2.151	1	.142	.440		

a. Variable(s) entered on step 1: Education, Appreciation, Motivation.

There were no cases with studentized residuals greater than 2.0. The Hosmer and Lemeshow Test was not statistically significant (p = 0.626), thereby suggesting a model fit. The logistic regression model was statistically significant, $\chi^2(3) = 10.861$, $p = 0.013$. The model explained 7.5% (Nagelkerke R^2) of the variance in innovation utilization and correctly classified 60.8% of cases. Sensitivity was 55.6%, specificity was 65.7%, positive predictive value was 59.5%, and the negative predictive value was 38.1%. None of the predictor variables was statistically significant. Thus, the null hypothesis $H_{2,0}$ is accepted, and the alternate $H_{2,1}$ is rejected.

Research Question 3 Results

RQ 3: What are the statistically significant barriers that MPs practicing in RO in the United States face in implementing innovations?

$H3_0$: There are no statistically significant barriers affecting innovation score.

$H3_1$: There are statistically significant barriers affecting innovation score.

Dependent variable: innovation score (continuous).

Independent variables: barriers (continuous).

Seven measured barriers across five categories and in total were assessed for normality. The results of the Shapiro-Wilk test were mixed, with some values being statistically significant, and some not being statistically significant (data not shown). Thus, the data are assumed to not be normally distributed as a group. The Q-Q plots were also not normal. The seven parameters used to assess barriers were assessed for the reliability of the construct. The scale had a high level of internal consistency, as determined by a Cronbach's alpha of 0.882. Spearman correlation was used to perform bivariate analysis across each category and in total. Spearman's rho results are presented in Tables 19 to 25.

There are statistically significant barriers in patient treatment, treatment planning, quality assurance, workflow, and innovation utilization total. Lack of interest is a small statistically significant barrier in patient treatment innovation utilization (r_s = 0.199, p<0.05). Lack of inter-operability is a small statistically significant barrier in workflow innovation utilization (r_s = 0.218, p<0.05). Lack of time and staffing is a small statistically significant barrier in quality assurance innovation utilization (r_s = -0.178, p<0.05). The negative correlation sign is noted and will be further discussed in Chapter 5. There are multiple small statistically significant barriers in treatment planning, such as lack of evidence (r_s = 0.203, p<0.05), complexity (r_s = 0.175, p<0.05), lack of time and staffing (r_s = 0.237,

$p<0.01$), lack of inter-operability ($r_s = 0.203$, $p<0.05$), and lack of reimbursement ($r_s = 0.269$, $p<0.01$). There are multiple small statistically significant barriers in total innovation utilization, such as lack of evidence ($r_s = 0.161$, $p<0.05$), lack of interest ($r_s = 0.264$, $p<0.01$), lack of inter-operability ($r_s = 0.214$, $p<0.01$), and lack of reimbursement ($r_s = 0.176$, $p<0.05$). All statistically significant correlations in the study were of small to medium effect size class, according to Cohen's definition (Ellis, 2010). Thus, the null hypothesis $H_{3,0}$ is rejected, and the alternate $H_{3,1}$ is accepted.

Table 19

Correlations for Barriers in RO Patient Positioning Innovation Utilization

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	-.010	-.084	-.014	-.008	.005	.040	.068
	P	.	.915	.331	.870	.929	.949	.644	.459
	N	188	118	135	149	131	144	138	121
Evidence	r_s	-.010	1.000	.475**	.199*	.441**	.279**	.271**	.272**
	P	.915	.	.000	.032	.000	.003	.005	.007
	N	118	127	115	116	109	111	107	96
Complexity	r_s	-.084	.475**	1.000	.430**	.553**	.265**	.352**	.161
	P	.331	.000	.	.000	.000	.003	.000	.093
	N	135	115	146	134	119	125	123	110
Time/ Staffing	r_s	-.014	.199*	.430**	1.000	.535**	.387**	.208*	.218*
	P	.870	.032	.000	.	.000	.000	.018	.018
	N	149	116	134	165	136	142	130	117
Training/ Support	r_s	-.008	.441**	.553**	.535**	1.000	.527**	.404**	.299**
	P	.929	.000	.000	.000	.	.000	.000	.002
	N	131	109	119	136	142	128	117	105
Interest	r_s	.005	.279**	.265**	.387**	.527**	1.000	.432**	.357**
	P	.949	.003	.003	.000	.000	.	.000	.000
	N	144	111	125	142	128	162	131	119
Inter Operability	r_s	.040	.271**	.352**	.208*	.404**	.432**	1.000	.469**
	P	.644	.005	.000	.018	.000	.000	.	.000
	N	138	107	123	130	117	131	150	111
Reimbursement	r_s	.068	.272**	.161	.218*	.299**	.357**	.469**	1.000
	P	.459	.007	.093	.018	.002	.000	.000	
	N	121	96	110	117	105	119	111	134

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

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

Table 20

Correlations for Barriers in RO Patient Treatment Innovation Utilization

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	.187	-.009	.032	.054	.199*	.170	.177
	P	.	.066	.927	.721	.595	.030	.086	.085
	N	198	97	118	129	101	119	103	96
Evidence	r_s	.187	1.000	.560**	.452**	.547**	.426**	.413**	.385**
	P	.066	.	.000	.000	.000	.000	.000	.001
	N	97	102	91	91	82	86	82	75
Complexity	r_s	-.009	.560**	1.000	.534**	.664**	.270**	.471**	.402**
	P	.927	.000	.	.000	.000	.007	.000	.000
	N	118	91	122	112	95	99	93	86
Time/ Staffing	r_s	.032	.452**	.534**	1.000	.558**	.367**	.280**	.364**
	P	.721	.000	.000	.	.000	.000	.005	.000
	N	129	91	112	132	100	106	98	90
Training/ Support	r_s	.054	.547**	.664**	.558**	1.000	.455**	.545**	.407**
	P	.595	.000	.000	.000	.	.000	.000	.000
	N	101	82	95	100	105	92	86	80
Interest	r_s	.199*	.426**	.270**	.367**	.455**	1.000	.474**	.519**
	P	.030	.000	.007	.000	.000	.	.000	.000
	N	119	86	99	106	92	122	95	85
Inter Operability	r_s	.170	.413**	.471**	.280**	.545**	.474**	1.000	.513**
	P	.086	.000	.000	.005	.000	.000	.	.000
	N	103	82	93	98	86	95	107	83
Reimbursement	r_s	.177	.385**	.402**	.364**	.407**	.519**	.513**	1.000
	P	.085	.001	.000	.000	.000	.000	.000	.
	N	96	75	86	90	80	85	83	100

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

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

Table 21

Correlations for Barriers in RO Treatment Planning Innovation Utilization

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	.203*	.175*	.092	.237**	.129	.203*	.269**
	P	.	.030	.042	.255	.005	.140	.030	.004
	N	186	115	135	155	136	133	114	111
Evidence	r_s	.203*	1.000	.361**	.308**	.456**	.344**	.529**	.357**
	P	.030	.	.000	.001	.000	.000	.000	.001
	N	115	119	107	112	102	105	91	91
Complexity	r_s	.175*	.361**	1.000	.470**	.495**	.392**	.517**	.532**
	P	.042	.000	.	.000	.000	.000	.000	.000
	N	135	107	143	138	126	120	101	98
Time/ Staffing	r_s	.092	.308**	.470**	1.000	.580**	.426**	.295**	.477**
	P	.255	.001	.000	.	.000	.000	.002	.000
	N	155	112	138	163	135	131	108	108
Training/ Support	r_s	.237**	.456**	.495**	.580**	1.000	.399**	.574**	.376**
	P	.005	.000	.000	.000	.	.000	.000	.000
	N	136	102	126	135	144	120	105	100
Interest	r_s	.129	.344**	.392**	.426**	.399**	1.000	.477**	.543**
	P	.140	.000	.000	.000	.000	.	.000	.000
	N	133	105	120	131	120	145	105	101
Inter Operability	r_s	.203*	.529**	.517**	.295**	.574**	.477**	1.000	.522**
	P	.030	.000	.000	.002	.000	.000	.	.000
	N	114	91	101	108	105	105	119	90
Reimbursement	r_s	.269**	.357**	.532**	.477**	.376**	.543**	.522**	1.000
	P	.004	.001	.000	.000	.000	.000	.000	.
	N	111	91	98	108	100	101	90	119

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

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

Table 22

Correlations for RO Quality Assurance Innovation Utilization

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	.124	.037	-.178*	-.083	-.168	-.105	-.027
	P	.	.225	.707	.036	.388	.059	.264	.800
	N	171	97	108	140	110	128	116	91
Evidence	r_s	.124	1.000	.503**	.383**	.470**	.377**	.466**	.338**
	P	.225	.	.000	.000	.000	.000	.000	.002
	N	97	108	90	99	87	96	92	81
Complexity	r_s	.037	.503**	1.000	.531**	.582**	.355**	.442**	.312**
	P	.707	.000	.	.000	.000	.000	.000	.005
	N	108	90	117	113	101	99	97	78
Time/ Staffing	r_s	-.178*	.383**	.531**	1.000	.651**	.538**	.490**	.222*
	p	.036	.000	.000	.	.000	.000	.000	.038
	N	140	99	113	155	115	130	114	88
Training/ Support	r_s	-.083	.470**	.582**	.651**	1.000	.626**	.573**	.234*
	p	.388	.000	.000	.000	.	.000	.000	.042
	N	110	87	101	115	120	105	95	76
Interest	r_s	-.168	.377**	.355**	.538**	.626**	1.000	.507**	.482**
	p	.059	.000	.000	.000	.000	.	.000	.000
	N	128	96	99	130	105	147	107	89
Inter Operability	r_s	-.105	.466**	.442**	.490**	.573**	.507**	1.000	.416**
	p	.264	.000	.000	.000	.000	.000	.	.000
	N	116	92	97	114	95	107	125	80
Reimbursement	r_s	-.027	.338**	.312**	.222*	.234*	.482**	.416**	1.000
	p	.800	.002	.005	.038	.042	.000	.000	.
	N	91	81	78	88	76	89	80	102

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

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

Table 23

Correlations for RO Workflow Innovation Utilization

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	.111	.118	-.051	-.050	-.034	.210*	-.034
	p	.	.303	.209	.525	.581	.679	.033	.746
	N	180	88	115	155	125	149	103	91
Evidence	r_s	.111	1.000	.420**	.295**	.411**	.546**	.543**	.387**
	p	.303	.	.000	.006	.000	.000	.000	.001
	N	88	91	87	86	85	82	80	75
Complexity	r_s	.118	.420**	1.000	.475**	.642**	.278**	.539**	.309**
	p	.209	.000	.	.000	.000	.003	.000	.004
	N	115	87	120	115	103	109	92	84
Time/ Staffing	r_s	-.051	.295**	.475**	1.000	.625**	.497**	.202*	.407**
	p	.525	.006	.000	.	.000	.000	.042	.000
	N	155	86	115	161	122	146	102	92
Training/ Support	r_s	-.050	.411**	.642**	.625**	1.000	.486**	.437**	.319**
	p	.581	.000	.000	.000	.	.000	.000	.003
	N	125	85	103	122	130	119	98	83
Interest	r_s	-.034	.546**	.278**	.497**	.486**	1.000	.278**	.428**
	p	.679	.000	.003	.000	.000	.	.005	.000
	N	149	82	109	146	119	156	101	89
Inter Operability	r_s	.210*	.543**	.539**	.202*	.437**	.278**	1.000	.352**
	p	.033	.000	.000	.042	.000	.005	.	.002
	N	103	80	92	102	98	101	106	74
Reimbursement	r_s	-.034	.387**	.309**	.407**	.319**	.428**	.352**	1.000
	p	.746	.001	.004	.000	.003	.000	.002	.
	N	91	75	84	92	83	89	74	95

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

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

Table 24

Correlations for RO Innovation Utilization Score Total

		Innovation Utilization Score	Evidence	Complexity	Time/ Staffing	Training/ Support	Interest	Inter Operability	Reimbursement
Innovation Utilization Score	r_s	1.000	.161*	.085	.111	.027	.264**	.214**	.176*
	p	.	.038	.254	.120	.722	.000	.005	.025
	N	213	166	183	199	180	195	174	162
Evidence	r_s	.161*	1.000	.458**	.353**	.517**	.391**	.495**	.445**
	p	.038	.	.000	.000	.000	.000	.000	.000
	N	166	166	159	165	155	161	152	145
Complexity	r_s	.085	.458**	1.000	.424**	.596**	.252**	.478**	.372**
	p	.254	.000	.	.000	.000	.001	.000	.000
	N	183	159	183	183	169	177	164	150
Time/ Staffing	r_s	.111	.353**	.424**	1.000	.609**	.500**	.393**	.394**
	p	.120	.000	.000	.	.000	.000	.000	.000
	N	199	165	183	199	178	191	171	159
Training/ Support	r_s	.027	.517**	.596**	.609**	1.000	.469**	.505**	.355**
	p	.722	.000	.000	.000	.	.000	.000	.000
	N	180	155	169	178	180	173	160	149
Interest	r_s	.264**	.391**	.252**	.500**	.469**	1.000	.384**	.435**
	p	.000	.000	.001	.000	.000	.	.000	.000
	N	195	161	177	191	173	195	165	157
Inter Operability	r_s	.214**	.495**	.478**	.393**	.505**	.384**	1.000	.569**
	p	.005	.000	.000	.000	.000	.000	.	.000
	N	174	152	164	171	160	165	174	147
Reimbursement	r_s	.176*	.445**	.372**	.394**	.355**	.435**	.569**	1.000
	p	.025	.000	.000	.000	.000	.000	.000	.
	N	162	145	150	159	149	157	147	162

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

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

Table 25

Summary of RO Barrier Coefficients in all Categories for MPs

	Patient positioning	Patient Treatment	Treatment Planning	QA	Workflow	Total
Evidence			0.203*			0.161*
Complexity			0.175*			
Time/Staffing			0.237**	-0.178*		
Training/Support						
Interest		0.199*				0.264**
Interoperability			0.203*		0.218*	0.214**
Reimbursement			0.269**			0.176*

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

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

Summary

The three research questions posed were answered. The null hypotheses H_{1a}, H_{1b}, and H_3were rejected, and null hypothesis H_2 was accepted. There are statistically significant differences in the accessibility of innovative services based on hospital university affiliation and urbanicity, with more innovative services being available to patients treated in urban, university hospitals. There are statistically significant predicting factors that affect the accessibility of innovative services, with MP appreciation and motivation having a weak predictive relationship with increased accessibility of innovative services, albeit the model is not statistically significant. There are statistically significant barriers MPs face in providing access to innovative services to patients. In Chapter 5 there will be a detailed discussion on the implications of these results and recommendations for future research.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

The purpose of this study was to investigate the accessibility of innovative services in RO in the United States and assess possible diffusion patterns using an online survey of MPs practicing in the United States. The dependent variable was innovation score. Independent variables were geographic location; practice details (university affiliation, reporting structure, and size of physics group); demographics (age, gender, DABR status, residency status, meeting attendance, and education level); and context-specific psychological antecedents (motivation, appreciation, and leadership).

There were statistically significant differences in the accessibility of innovative services based on hospital university affiliation and urbanicity, with more innovative services being available to patients treated in urban, university hospitals. Also, there are statistically significant predicting factors that affect the accessibility of innovative services, with MP appreciation and motivation having a weak predictive relationship with increased accessibility of innovative services. Finally, there were statistically significant barriers in patient treatment, treatment planning, quality assurance, and workflow. Findings indicate that MPs face challenges in providing access to innovative services to patients. In this chapter, the results are discussed in context, the study limitations, and recommendations for future research are made. The chapter concludes with a conclusion to the study.

Sample Characteristics

Known proportions of organizational and personal characteristics were retrieved from the most recent salary survey for RO MPs (American Association of Physicists in Medicine, 2018). This report lists primary employment settings as private or community hospital, government hospital, medical school or university hospital, college or university, government hospital, medical physics service group, physician group, industrial or commercial firm, and cancer center. It is unclear if some categories are correlated--for example, there can be a cancer center with a university affiliation. This self-identification can be subjective; this is the reason this classification was not selected for this study. The report is useful, however, in providing some baseline descriptive statistics. Based on this report, 17% of master's-level MPs work in centers with university affiliation, and 83% of PhD physicists work in centers with university affiliation. On average, 50% of MPs are employed by centers with a university affiliation, 26% of MPs are women, 55% hold a master's degree, 89% are certified by the ABR, and 28% graduated from a residency.

In analyzing the sample descriptive statistics and comparison to known proportions, it is concluded that there are similarities in percentages of university affiliation, type of degree, and DABR status, but not for gender and residency. The respondent gender ratio was higher for male and higher for residency graduates. There are no publicly available proportions for age distribution, but the respondent age distribution appears to be skewed towards younger respondents, which is in alignment with the higher response rate for residency graduates. No exact known proportions are known for urbanicity, meetings attended, reporting structure, number of physicists, volunteer status, appreciation or motivation. It is thus concluded that the sample was overall representative of the population.

Open-Ended Feedback

The study included a free-text comment section at the end of the survey. Many of the comments revolved around the cost of innovation, which was expected. An unexpected common thread, however, was concerns about maintaining safety. MP participants were highly concerned that using innovations and changing the status quo might be inconsistent with maintaining patient safety. This finding was unexpected because all innovations in question are FDA-approved and commercially available. The pathway to deteriorating safety would be possible only through poor implementation. This circles back to workflow innovation. A conclusion is that MPs do not feel innovation improves patient safety and/or they do not know how to safely implement innovations in the clinic.

Interpretation of the Findings

University Affiliation and Innovation

In Research Question 1a it was demonstrated that centers with a university affiliation have a higher mean innovation score than centers without a university affiliation (MD = 1.65, 95% CI [0.38,2.917], $t(211) = 2.56$, $p = 0.011$, $d = 0.351$). As discussed in the literature review in Chapter 2, there are many outcome differences between academic and nonacademic centers. While the difference in innovation score is likely not the only factor contributing to outcome differences, it is a factor that needs to be incorporated in future models. The results of this study are in congruence with similar studies performed in the United States (see Pfister et al., 2015). It is interesting to note that the two categories with statistically significant results are patient treatment and workflow. The parameters affecting the patient treatment innovation score (stereotactic body radiosurgery, stereotactic cranial radiosurgery, robotic radiosurgery, intraoperative radiation therapy, and flattening free beams) are techniques that are only available in newer accelerators, which are in their majority multimillion-dollar investments.

In Research Question 1a it was also demonstrated that centers with university affiliation have a higher mean workflow utilization score than centers without a university affiliation ($MD = 7.09$, 95% CI [0.78,13.39], $t(178) = 2.217$, $p = 0.028$, $d = 0.330$). This finding is interesting because organizational innovation has not previously been studied in RO in the United States, as typically publications focus on technological differences (see Chen, 2014)). The results of this study are in congruence with the published results from the Netherlands (M. Jacobs, 2017). Improving workflows can be a low-risk, high-yield opportunity for many centers lacking the funds for large investments. A curriculum with core and adjunct tools for MPs is currently under development through the Medical Physics Leadership Academy Working Group (J. Johnson, personal communication, MPLAW Retreat, May 2019). The lack of statistically significant differences in other categories is a positive finding for the industry, as it implies that once centers break through the barrier of purchasing innovative technologies, there are no major differences in utilizing them.

Urbanicity and Innovation

In Research Question 1b it was demonstrated that urban centers have a higher innovation scores in patient positioning (*MD* = 0.31, 95% CI [0.011,0.612], $t(203) = 2.043$, $p = 0.042$, $d = 0.293$) and patient treatment (*MD* = 0.62, 95% CI [0.23,1.00], $t(203) = 3.145$, $p = 0.002$, $d = 0.457$). Thus, the results of this study are in congruence with similar studies performed in the United States (Charlton et al., 2015). The quantitative assessment did not reveal large differences for total innovation, which was an unexpected result. This is possibly due either to the low power of the study or the RUCA classification that was used in this study; greater granularity may be necessary. The results were plotted on a map of the United States for qualitative analysis, as shown in Figure 3. The population was superimposed with innovation score (darker green, higher population). Additionally, all RO the centers that are currently operational in the United States are superimposed as black squares (IAEA DIRAC database, 2018). The heatmap represents centers that are more innovative (red) versus less innovative (blue). The most innovative centers are in close proximity and in areas with high population density. Conversely, areas with low population density have the lowest innovation score. This qualitative assessment does support the claim that urban centers provide more innovative treatments, despite the absence of large effect sizes and statistical significance.

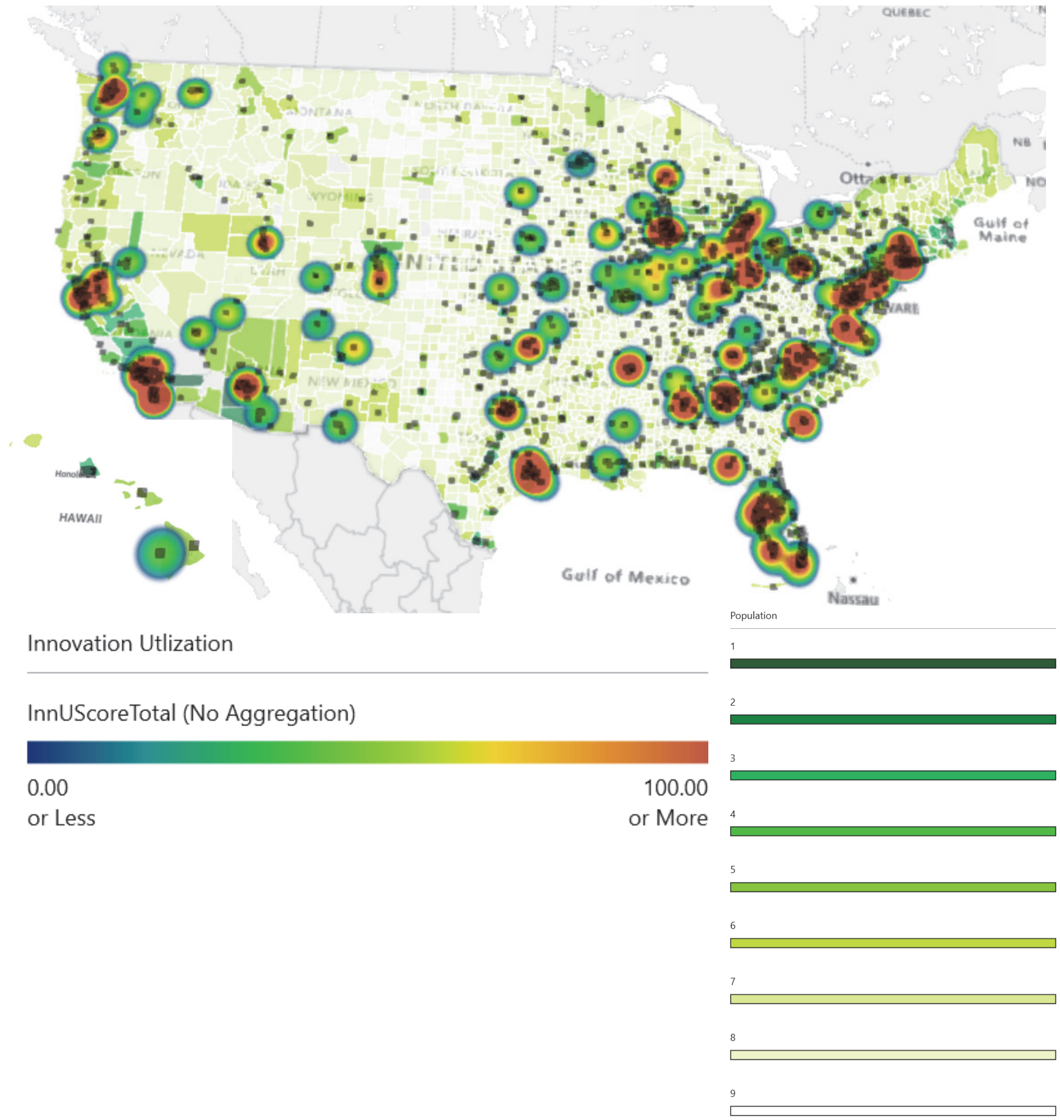

Figure 3. Map of the United States with innovation utilization score. Hawaii is not to scale. No data were received for Alaska. Map layers include population density as shades of green and RO centers as squares.

While differences in patient treatment are relatively easy to explain due to purchasing decision and competition in urban centers, the differences in patient positioning may not be so obvious. Patient positioning is typically decided at the time of simulation and is the primary responsibility of the radiation therapists. Historically there is great variation in MPs involvement in patient positioning and setup reproducibility, with some MPs being very involved, and some MPs being absent in the simulation process (Clements et al., 2018). The introduction of mandatory MP residencies is closing this gap. The increase in hypo-fractionated treatments has also changed this dynamic, as discussed in the 2014 AAPM summer school on "safely and accurately delivering high precision, hypo-fractionated treatments" and AAPM reports (Halvorsen et al., 2017). However, there may be discordance of information flowing to the American Society of Radiologic Technologists. Another possible explanation is that in urban centers, patients "shop around" for their treatment, with higher socioeconomic status patients often requesting or demanding certain types of treatment (Martin, Thomas, Harden, & Burnet, 2015; Roubou & Alexopoulou, 2015). Frequent examples from personal experience include prone breast treatments or large full-body immobilization.

Education and Innovation

In Research Question 2, it was demonstrated that the mean innovation utilization score for MPs with a Master's degree is higher than the mean innovation utilization score for Doctoral degree (*MD* = 5.06, 95% CI[0.18,9.94],

$t(188) = 2.046$, $p = 0.042$, $d = 0.278$). Out of the 118 respondents with a Master's degree, 41.5% were employed by a center with a university affiliation, and 58.5% of respondents were employed by a center without a university affiliation. Out of the 72 respondents with a Doctoral degree, 58.3% were employed by a center with a university affiliation, and 41.7% of respondents were employed by a center without a university affiliation. The survey did not ask participants the topic of their doctoral degree. It is possible that MPs with doctoral degrees in medical physics are employed in university hospitals with higher innovation scores, while MPs with doctoral degrees in other fields are employed in non-university hospitals with lower innovation scores. This discrepancy does not exist for Master's degree, as the Master's degree must be in Medical Physics to qualify for certification. Even though the results are statistically significant, education is likely to have a more complicated relationship with innovation. It is possible that Masters level physicists are more motivated and competitive, but this requires further study. This may partially explain the poor model fit in Research Question 2.

Appreciation and Motivation in Innovation

In Research Question 2, it was demonstrated that there is a small positive correlation between innovation utilization and participant appreciation ($r_s = 0.224$, $p = 0.002$) and motivation ($r_s = 0.215$, $p = 0.003$). Even though the correlations were small, the results are in congruence with prior published studies in general and in the health care setting (Wisdom et al., 2014). It is important to note that this is the first time these parameters have been measured for MPs, and results are in agreement with studies done on other health care professionals (Strömgren, Eriksson, Bergman, & Dellve, 2016). Appreciation and motivation are often considered “soft skills” that may be shunned by MPs in leadership positions (Gutierrez, Halvorsen, & Rong, 2017). This common misconception is declining since the introduction of the Medical Physics Leadership Academy and the 2016 summer school (J. Johnson, personal communication, July 14, 2019). The results of this study will serve to strengthen the base of evidence supporting intra-personal skills and clinical performance.

Barriers to Innovation Utilization

Four categories were found to have statistically significant barriers: patient treatment, treatment planning, quality assurance, and workflow. Statistically significant barriers were also detected for innovation utilization total. There were no statistically significant barriers detected for patient positioning, possibly due to lack of statistical power. Training and support was not a statistically significant barrier for any of the categories investigated. This result is in agreement with the AAPM TG 100 report listing training as the least effective tool of a quality management program (Huq et al., 2016).

In the patient treatment category, lack of interest is a statistically significant but with small effect size barrier in patient treatment innovation utilization (r_s = 0.199, p<0.05). It is noted that the patient treatment category involved very advanced techniques, see Appendix D for details. This lack of interest can be further explained in the context of university affiliation and urbanicity. Interestingly, university centers in metropolitan areas had even higher correlation coefficients for lack of interest in patient treatment innovation utilization (results not shown). This finding may be an indicator of complacency due to market domination (Martin et al., 2015; Roubou & Alexopoulou, 2015).

In the treatment planning category, five out of the seven barriers were found to be statistically significant: lack of evidence ($r_s = 0.203$, $p<0.05$), complexity ($r_s = 0.175$, $p<0.05$), lack of time and staffing ($r_s = 0.237$, $p<0.01$), lack of inter-operability ($r_s = 0.203$, $p<0.05$), and lack of reimbursement ($r_s = 0.269$, $p<0.01$). This is an alarming result; even though the coefficients are small, there are multiple barriers. The highest coefficient, reimbursement, is the obvious first choice for discussion. The treatment planning Current Procedural Terminology (CPT) codes have been steadily decreasing, stagnant or bundled in (“Reimbursement-American Society for Radiation Oncology (ASTRO)”, n.d.). In health care in general, it has been well demonstrated that financial incentives increase innovation utilization (Darzi & Parston, 2013). This conlusion is congruent with the second-highest coefficient, lack of time and staffing resources. In the absence of reimbursement, faced with low staffing support, the barrier to innovation is significant. Facilities with mixed vendor products may face high inter-operability issues, which are unfortunately unsolvable at the clinic level. There is a growing number of publications on evidence for treatment planning innovations and their effect on productivity and outcomes (Gintz et al., 2016;

Wang, Dong, Liu, & Xing, 2017), however, the results of this study show that critical mass has not yet been reached. The complexity of treatment planning innovations continues to be discouraging to users. These results may be of particular interest to treatment planning vendors and to AAPM workgroups writing recommendations for treatment planning.

In the quality assurance category, lack of time and staffing is a small negative statistically significant barrier in quality assurance innovation utilization (r_s = -0.178, $p<0.05$). The negative relationship means that lower staffing levels are correlated to higher innovation in quality assurance. This result can be explained in the context of daily clinical work. It is reasonable to assume that MPs have been forced into using innovations in quality assurance to compensate for reduced staffing levels. For example, the first category indicator, portal dosimetry, may take some initial time to set up, but the time gains for performing device-less quality assurance for every patient multiple times per week is a significant efficiency gain in the clinic. A similar concept applies to other indicators in the quality assurance category (Eckhause et al., 2015; Thompson et al., 2018). While it is positive that MPs are using quality assurance innovations, the instigating factor may be convenience. This is in contrast with treatment planning findings: when there is reduced staffing or time for treatment planning, MPs do not use the innovations to gain time (for example with automatic planning or automatic contouring) but instead do not use these innovations. This may be due to the significant resource investment needed to create some of these downstream benefits, and the involvement of other groups, such as dosimetrists and radiation oncologists, who may not be positive towards these innovations either (Georg & Thwaites, 2017). In contrast, physicists operate independently in tasks in the quality assurance category.

In the workflow category, lack of inter-operability is a small statistically significant barrier in workflow innovation utilization (r_s = 0.218, $p < 0.05$). In the context of workflow, inter-operability is not to be interpreted in a technical context, but more as the compatibility of heterogeneous business processes. In this frame of reference, MPs are encountering barriers in workflow innovations when the innovations are perceived to be incompatible with existing policies and procedures or standards of practice. This result is in agreement with prior results in the Netherlands (M. Jacobs et al., 2017). It is possible that MPs have so far been reluctant to get involved in process improvement and business development planning. As previously discussed, these avenues are now being explored by the AAPM and the Leadership Academy.

In total innovation utilization, there are multiple small statistically significant barriers, such as lack of evidence (r_s = 0.161, $p < 0.05$), lack of interest (r_s = 0.264, $p<0.01$), lack of inter-operability (r_s = 0.214, $p < 0.01$), and lack of reimbursement (r_s = 0.176, $p<0.05$). The coefficients are small, yet statistically significant. MPs face non-supportive organizational cultures in their clinics. This is a key finding of this study. Clinics as organizational entities have selected to reject innovations and maintain status quo, possibly due to the incorrect association of innovations as a compromise to safety, the cornerstone of modern RO.

Limitations of the Study

The presented study has limitations. Due to the study design, there was a possible selection bias. The study may not have reached some MPs, especially those who practice in rural areas. Since there are no known proportions of MPs per ZIP code, the effect of this limitation is impossible to calculate. Comparison with known proportions of university versus non-university centers showed a reasonable degree of agreement, which implies that selection bias was not a significant source of bias in this study. Another possible source of bias mentioned in Chapter 1, information bias, could also have influenced the results. Unfortunately, there is no way to assess the magnitude of this effect either. Both of selection bias and information bias are inherent to the study design.

Additionally, as mentioned in Chapter 4, there was a high level of internal consistency, as determined by Cronbach's alpha of 0.963. This statistic in combination with the face and content validity of the expert panel review leads to the conclusion that the constructs have high reliability. However, there were many assumptions made in the operationalization of constructs. It is possible that not all predictive parameters were included in the model, or operationalized appropriately. This would partially explain the poor fit of the predictive model. Additionally, the operationalization of constructs may not be transferable outside the United States, thus results should be applied with caution outside of the United States.

Furthermore, there are statistical limitations. The effect sizes used to calculate a priori power were hypothetical and chosen conservatively. Post hoc analysis for university status reveals that based on the detected sample effect size, the power of the study was 0.72. This may be slightly smaller than the intended 0.8, yet still within reason. Conversely, the power for the RUCA continuum ranged from 0.52 to 0.88, depending on the model selected. This is because of the selected RUCA continuum and the low response rates from areas closer to the rural end of the spectrum. It is uncertain if the effect sizes measured in this study are true population effect sizes or sample effect sizes, thus results should be interpreted with caution until effect sizes are confirmed by future studies.

Lastly, this was a cross-sectional study, thus the study design does not allow the investigation of temporal relationships and possible causality between the dependent and independent variables. Causal effects are typically demonstrated by experimental study designs (Salazar et al., 2015). However, the results are congruent with theoretical causal structures used in population health (Darzi & Parston, 2013).

Recommendations

It is recommended that this study can be repeated in the future under the aegis of the AAPM, possibly by a task group or workgroup. If so, the questionnaire or survey should be designed to limit selection and information bias, the two biggest limitations of this study. This could be achieved by addressing the study to the department chair, manager, or chief physicist. Changing the unit of measurement to the RO department, instead of the individual MPs could also serve to minimize the aforementioned sources of bias. Even without AAPM support, the results of this study should be validated by other researchers. It would be particularly interesting to perform similar studies outside the United States, assess generalizability and compare effect sizes.

Additionally, it is recommended that there is further theoretical exploration on appreciation and motivation in health care leadership theory. There is rich literature on emotional intelligence, organizational culture, and employee motivation, but the connection to appreciation is not obvious. Very little has been written about appreciation in the work environment. The Society for Human Resource Management, (2012) claims that even though 51% of supervisors claim they recognize good performance, only 17% of the same organization's employees feel recognized. The term "appreciative leadership" is often used in popular management literature. Scholarly work does address appreciative behaviors relating to praise and recognition, using verbiages such as support, respect, constructive feedback, social reinforcement, and appreciation (Stocker, Jacobshagen, Krings, Pfister, & Semmer, 2014). A possible expansion to the path-goal theory of leadership (House, 1996), as it applies to healthcare, may be necessary to fill this gap.

Another important aspect for further research is the transferability to Radiation Therapy Technologists and Radiation Oncologists. These professionals, along with MPs are in the front lines of daily clinical practice. The American Society for Radiologic Technologists (ASRT) would be an obvious choice for collaboration and dissemination of these findings. Similarly, collaborating with Radiation Oncologists and ASTRO would be the logical route to further the presented research and delve into qualitative and quantitative aspects of organizational culture. MPs do not practice in isolation. It is possible that a better predictive model could be derived using inter-team and intra-team dynamics (Reiter-Palmon, 2017). Removing the barriers to innovation utilization in the clinic must be a collaborative team effort.

Implications

Instrument Development and Benchmarking

During the literature review stage of this study, there was an evident relationship between the ninth essential public health service to "evaluate effectiveness, accessibility, and quality of personal and population-based health services" and innovation accessibility in RO. There was no available data or an instrument to effectively measure innovation in RO. This gap in itself is a barrier to improving the equity of delivery of appropriate treatment to all cancer patients. The need for a metric of innovation utilization was previously an abstract concept discussed only in theory. This study has now delivered an instrument to quantify innovation in RO. This quantitative instrument, along with qualitative work done by others, will be used to improve innovation utilization in RO. The data collected in this study can serve as a benchmark of the state of innovation today, with plans on how to improve it in the future.

Social Change Implications

Inequalities in health are parallel to inequalities in health care (Frenk, 2013). To improve public health further in the 21st century, there needs to be an inclusion of factors outside of traditionally-defined health care (DeSalvo, 2017). Disparities in access to advanced care have an impact on cancer survival. This statement may be considered contradictory by some, but it is well supported by recent literature (Nardi et al., 2016; Pfister et al., 2015; Wolfson, Sun, Wyatt, Hurria, & Bhatia, 2015). There are is an abundance of differences between centers that may have a causal effect on improved cancer survival. Innovation is only one of these parameters. This study did not attempt to show causal effects, as this can only be demonstrated by clinical trials (B. L. Jacobs et al., 2017). What this study did demonstrate, however, is that there are indeed differences in innovation accessibility in RO in the United States. The connection between innovation and improved cancer survival has been made by many authors; innovation-based care models are under discussion in reimbursement health care reform (Alvarnas, Majkowski, & Levine, 2015; Nardi et al., 2016). Thus, using the results of this study to further how innovation is measured in RO in the United States, and assess how the measured barriers can be minimized is a positive social change. Public health is expanding beyond government agency programs to a broader cross-sectoral practice (DeSalvo, 2017). RO as a community is in a position to further engage public health aspects that have a collective impact on population health.

Conclusion

In this study, innovation in RO in the United States was measured for the first time, through the development of a new survey instrument. Rural centers and centers with no academic affiliation are trailing behind in innovation implementation. Motivation and appreciation were shown to be statistically significant personal factors influencing innovation utilization, but no predictive model was possible. Barriers in RO innovation implementation were also assessed, with treatment planning showing the most statistically significant barriers.

RO practitioners follow an ethos of "as low as reasonably achievable" every day, making every attempt possible to reduce dose to patients. We do this almost subconsciously, as it has been engrained in our training as common sense. Getting MPs to view embracing innovation as part of their culture will only be possible if innovation is not considered to be competing with safety. The complementary relationship between safety and innovation is being discussed in many other health care fields. If every MPs practiced using "as innovative as reasonably achievable" as their mantra, similar to "as low as reasonably achievable", patients would benefit immensely. This is a worthy end goal to be striving towards. This study provides a small but promising step in this direction.

Although the exact number of lives saved or extended because of innovations in daily practices in RO may never be known, it is certainly worth it to try to make every treatment as innovative as reasonably achievable.

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Appendix A: Survey

Diffusion of Innovation in Radiation Oncology Survey

Organization Description

First, tell us a few things about the organization you practice in.

1. Does the Radiation Oncology practice you are responding for has a university or university hospital affiliation?

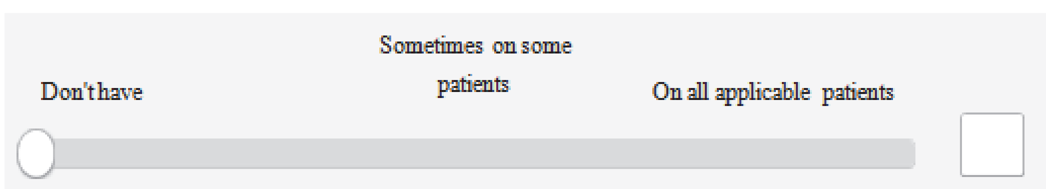
- ◯ Yes, there is a university or university hospital affiliation.
- ◯ No, there is no university or university hospital affiliation.

2.In what ZIP code is the practice located? (enter 5-digit ZIP code; for example, 22314). Answers will be used strictly for geocoding purposes.

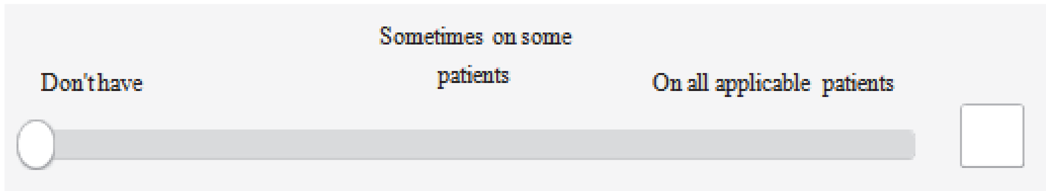
Organization products and technologies used for patient positioning and monitoring

Are any of the following products and technologies used in your department? If yes, to what degree are they used? Use the slider to respond. What barriers do you face for each category?

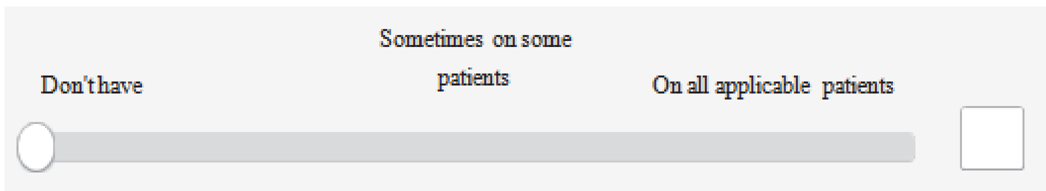
Category: Patient positioning and monitoring.



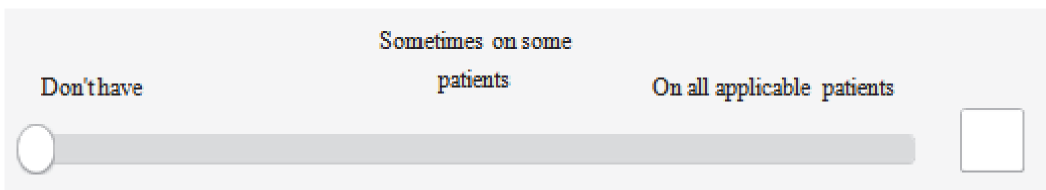
3.Surface guidance



4.Respiratory Gating

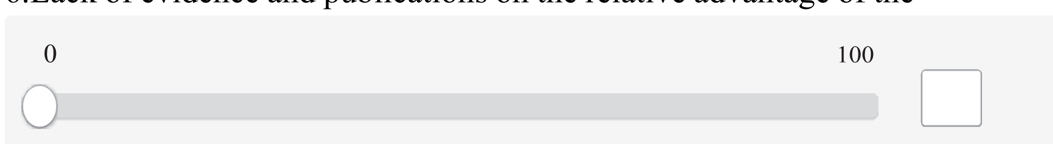


5.Breath Hold

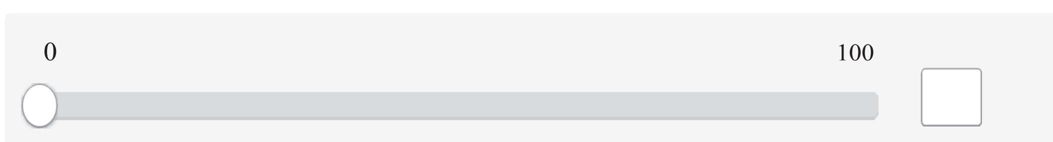


What barriers do you face in the implementation of innovation on patient positioning and monitoring techniques?

6.Lack of evidence and publications on the relative advantage of the



7.Complexity of the innovation



8.Lack of time to implement, staffing constraints, and emphasis on clinical productivity

0 100

9.Lack of training and support

0 100

10.Lack of interest from others, no supporting organizational culture

0 100

11.Lack of inter-operability with existing technology and practices

0 100

12.Lack of reimbursement

0 100

Organization products and technologies used for patient treatment

Are any of the following products and technologies used in your department? If yes, to what degree are they used? Use the slider to respond. What barriers do you face for each category?

Category: Patient Treatment

13.Stereotactic Body Radiosurgery

Don't have | Sometimes on some patients | On all applicable patients

Don't have | Sometimes on some patients | On all applicable patients

14.Stereotactic Cranial Radiosurgery

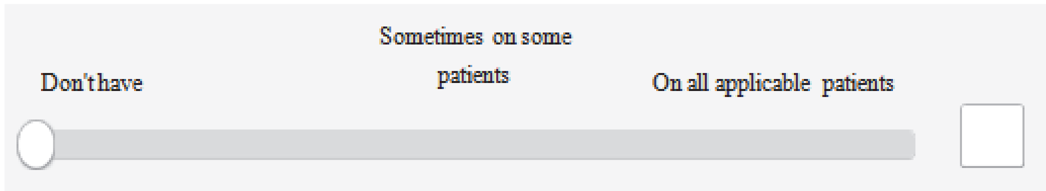
Don't have | Sometimes on some patients | On all applicable patients

Don't have | Sometimes on some patients | On all applicable patients

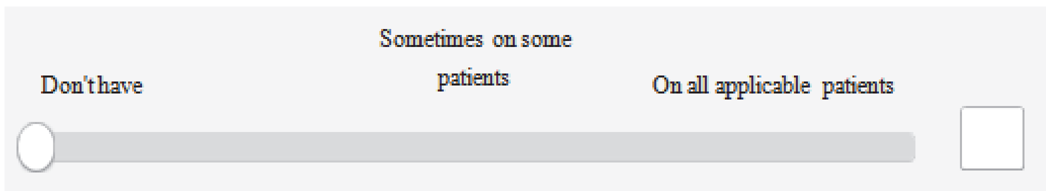
15.Robotic Therapy

Don't have | Sometimes on some patients | On all applicable patients

16.Intra-Operative Radiation Therapy

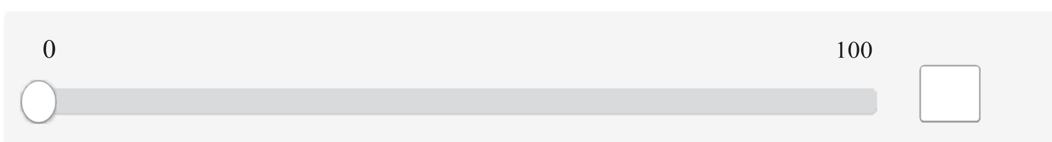


17.Flattening Filter Free beams

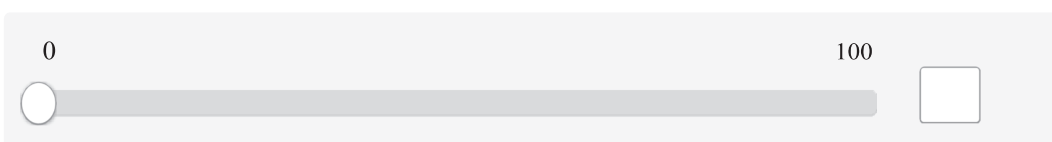


What barriers do you face in the implementation of innovation on patient treatment techniques?

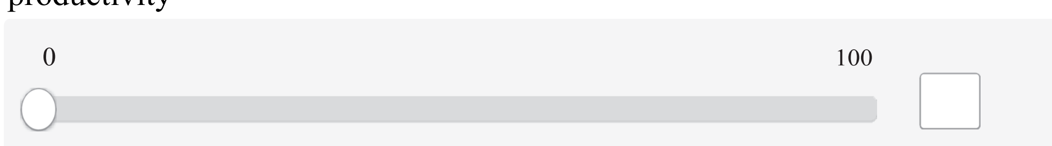
18.Lack of evidence and publications on the relative advantage of the innovation



19.Complexity of the innovation



20.Lack of time to implement, staffing constraints, and emphasis on clinical productivity



21.Lack of training and support

0 100

22.Lack of interest from others, no supporting organizational culture

0 100

23.Lack of inter-operability with existing technology and practices

0 100

24.Lack of reimbursement

0 100

Organization products and technologies used for treatment planning

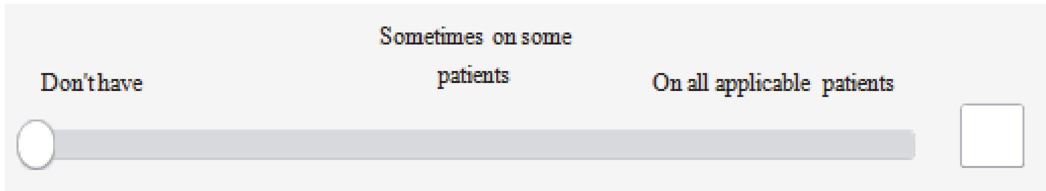
Are any of the following products and technologies used in your department? If yes, to what degree are they used? Use the slider to respond. What barriers do you face for each category?

Category: Treatment planning

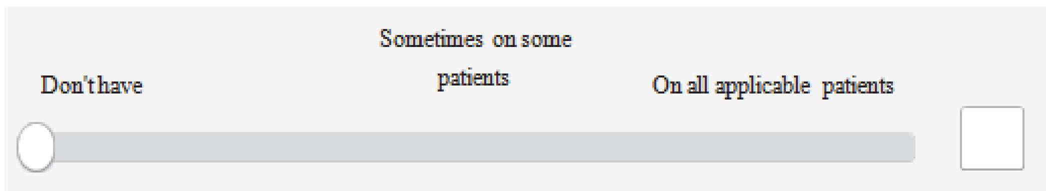
25.Automatic/knowledge-based contouring

Don't have | Sometimes on some patients | On all applicable patients

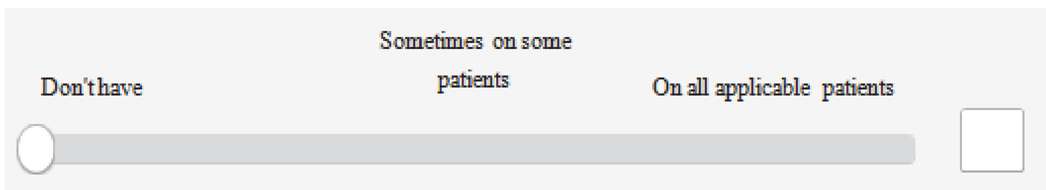
26.Deformable Image Registration



27.Automatic/knowledge-based planning

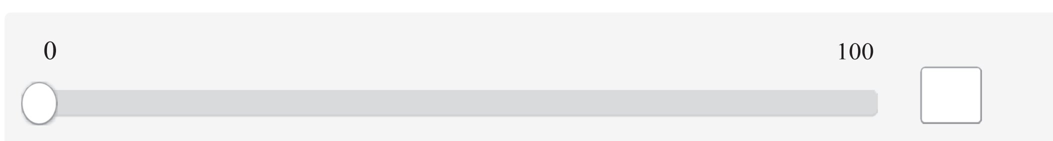


28.Adaptive planning

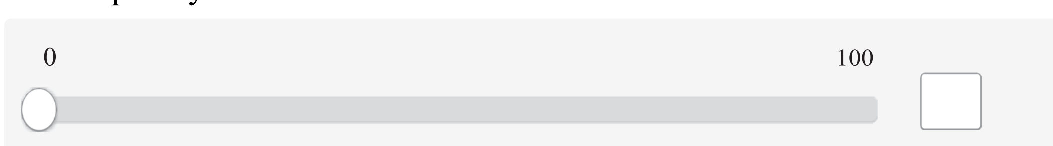


What barriers do you face in the implementation of innovation on treatment planning?

29.Lack of evidence and publications on the relative advantage of the innovation



30.Complexity of the innovation



31.Lack of time to implement, staffing constraints, and emphasis on clinical productivity

0 100

32.Lack of training and support

0 100

33.Lack of interest from others, no supporting organizational culture

0 100

34.Lack of inter-operability with existing technology and practices

0 100

35.Lack of reimbursement

0 100

Organization products and technologies used for quality assurance

Are any of the following products and technologies used in your department? If yes, to what degree are they used? Use the slider to respond. What barriers do you face for each category?

Category: Quality Assurance

36.Portal Dosimetry for linear accelerator QA

Don't have | Sometimes | Use all thetime

37.QA trending and statistical process control

Don't have | Sometimes | Use all thetime

38.Automated machine QA

Don't have | Sometimes | Use all thetime

39.Automated plan checks

Don't have | Sometimes | Use all thetime

What barriers do you face in the implementation of innovation on quality assurance?

40.Lack of evidence and publications on the relative advantage of the innovation

0 | 100

41.Complexity of the innovation

0 100

42.Lack of time to implement, staffing constraints, and emphasis on clinical productivity

0 100

43.Lack of training and support

0 100

44.Lack of interest from others, no supporting organizational culture

0 100

45.Lack of inter-operability with existing technology and practices

0 100

46.Lack of reimbursement

0 100

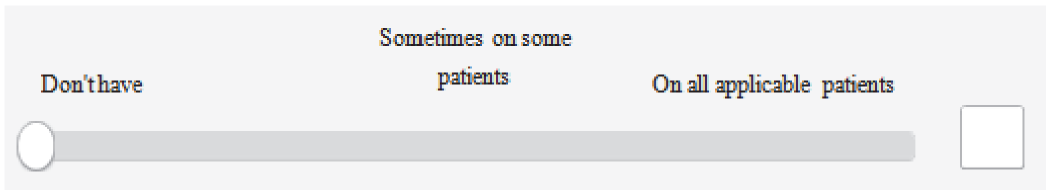
Organization products and technologies used for workflow

Are any of the following products and technologies used in your department?

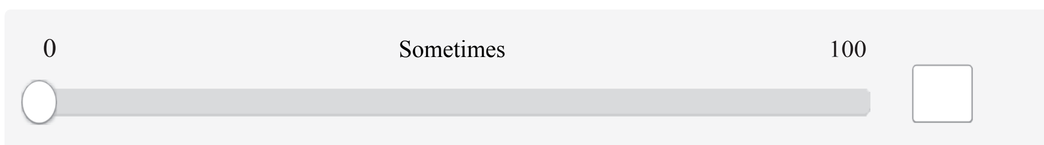
If yes, to what degree are they used? Use the slider to respond. What barriers do you face for each category?

Category: Workflow

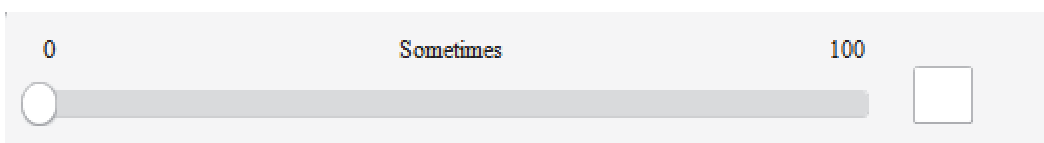
47.Does your clinic participate in clinical trials



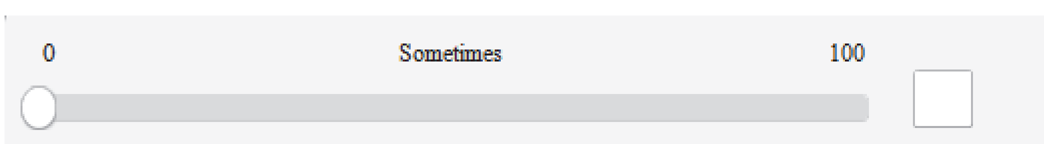
48.Does your clinic develop new practices for organizing procedures (for example re-designing workflows to be lean, quality management etc)



49.Does your clinic develop new methods for organizing work responsibilities and decision making (for example new training systems etc)



50.Does your clinic develop new methods of organizing external relationships with other organizations or public institutions (for example alliances for first use of an innovation, partnerships, outsourcing or sub- contracting innovations)



What barriers do you face in the implementation of innovation on workflow?

51.Lack of evidence and publications on the relative advantage of the innovation

0 100

52.Complexity of the innovation

0 100

53.Lack of time to implement, staffing constraints, and emphasis on clinical productivity

0 100

54.Lack of training and support

0 100

55.Lack of interest from others, no supporting organizational culture

0 100

56.Lack of inter-operability with existing technology and practices

0 100

57. Lack of reimbursement

0 100

58. What is your gender?

- ☐ Male
- ☐ Female
- ☐ Other (please specify)

59. Please enter your age

60. What is the highest degree you have received?

- ○ Master's degree
- ○ Doctoral degree
- ○ Other (please specify)

61. Have you completed a Medical Physics Residency?

- ○ No, I began my practice before the residency mandate.
- ○ No, I was not accepted in one
- ○ Yes, I successfully completed a Medical Physics Residency

62. Are you certified by the American Board of Radiology?

- ○ Yes, I am a diplomate of the American Board of Radiology
- ○ Not yet, I have only passed Part I
- ○ Not yet, I have only passed Part II

- ◯ No, I do not hold any certification
- ◯ No, but I hold a different certification

63.How many national meetings have you attended in the past 10 years? Please enter a number. A full list of AAPM and ASTRO meetings is shown below.

AAPM Annual 2009 in Anaheim, California

AAPM Annual 2010 in Philadelphia, Philadelphia

AAPM Annual 2011 in Vancouver, BC

AAPM Annual 2012 in Charlotte, North Carolina

AAPM Annual 2013 in Indianapolis, Indiana

AAPM Annual 2014 in Austin, Texas

AAPM Annual 2015 in Anaheim, California

AAPM Annual 2016 in Washington, District of Columbia

AAPM Annual 2017 in Denver, Colorado

AAPM Annual 2018 in Nashville, Tennessee

AAPM Spring Clinical 2009 in Virginia Beach, Virginia

AAPM Spring Clinical 2010 in San Antonio, Texas

AAPM Spring Clinical 2011 in Chattanooga, Tennessee

AAPM Spring Clinical 2012 in Dallas, Texas

AAPM Spring Clinical 2013 in Phoenix, Arizona

AAPM Spring Clinical 2014 in Denver, Colorado

AAPM Spring Clinical 2015 in Denver, Colorado

AAPM Spring Clinical 2016 in Salt Lake City, UT

AAPM Spring Clinical 2017 in New Orleans, Louisiana

AAPM Spring Clinical 2018 on Las Vegas, Nevada

ASTRO Annual 2009 in Chicago, Illinois

ASTRO Annual 2010 in San Diego, California

ASTRO Annual 2011 in Miami, Florida

ASTRO Annual 2012 in Boston, Massachusetts

ASTRO Annual 2013 in Atlanta, Georgia

ASTRO Annual 2014 in San Francisco, California

ASTRO Annual 2015 in San Antonio, Texas ASTRO Annual 2016 in Boston, Massachusetts ASTRO Annual 2017 in San Diego, California ASTRO Annual 2018 in San Diego, California ASTRO Annual 2018 in San Antonio, Texas

AAPM Spring Clinical Meeting 2019 in Orlando, Florida

64. Who do you report to?

- ○ Another Physicist (e.g. Chief Physicist / Physics Director/ Physics Chair)
- ○ A Radiation Oncologist (e.g. Program Director / Department Chair)
- ○ An Administrator (e.g. Manager / Director)
- ○ A Vice President
- ○ Other (please specify)

65.How many Physicists practice in the same location, including yourself?

- I am the only one
- 2-3
- 3-5
- 5-10
- >10
- Don't know

66.Have you ever volunteered in AAPM committees or leadership?

- Yes
- No

67.Do you feel appreciated at work?

0 100

68.Do you feel motivated at work?

0 100

69.Please share any final thoughts you may have on innovation in Radiation Oncology

70.If you would like to receive a $10 Amazon gift card, please enter your email.

If not, please click next.

Appendix B: Invitation Emails

Invitation E-email Sent April 27, 2019

Email Title:

Take the Diffusion of Innovation in Radiation Oncology Survey and receive a $10 Amazon gift card.

Email Body:

What innovative techniques are available in Radiation Oncology across the country and how much are they actually used in daily clinical work? Medical Physicists practicing in the United States are invited to participate in a 5-10 minute research study to find diffusion patterns and explore barriers in using innovative techniques in Radiation Oncology.

Please share this survey link with any Medical Physicists practicing in Radiation Therapy in the United States you may know.

https://www.surveymonkey.com/r/DiffusionOfInnovationSurvey

This study will remain open until 5/24/2019 11:59 pm EST. You will receive two additional reminders. If you choose to participate and enter your email at the end, you will receive a $10 Amazon gift card, or skip that step to remain completely anonymous. Anonymized aggregate data will be used to conduct a quantitative cross-sectional analysis to assess how innovation may vary depending on individual and organizational factors.

Thank you in advance for taking the time to participate in this research study.

First Reminder E-email Sent May 11, 2019

Email title:

First reminder: Take the Diffusion of Innovation in Radiation Oncology Survey and receive a $10 Amazon gift card.

Email Body

What innovative techniques are available in Radiation Therapy across the country and how much are they actually used in daily clinical work? Medical Physicists practicing in the United States are invited to participate in a 5-10 minute research study to find diffusion patterns and explore barriers in using innovative techniques in Radiation Oncology.

Please share this survey link with any Medical Physicists practicing in Radiation Therapy in the United States you may know.

https://www.surveymonkey.com/r/DiffusionOfInnovationSurvey

This survey will remain open until 5/24/2019 11:59pm EST. You will receive one additional reminder. If you choose to participate and enter your email at the end, you will receive a $10 Amazon gift card, or skip that step to remain completely anonymous. Anonymized aggregate data will be used to conduct a quantitative cross-sectional analysis to assess how innovation may vary depending on individual and organizational factors.

Thank you in advance for taking the time to participate in this research study.

Final Reminder Email Sent May 22, 2019

Email title:

Second and final reminder: Take the Diffusion of Innovation in Radiation Oncology Survey and win a $10 Amazon gift card.

Email Body:

What innovative techniques are available in Radiation Therapy across the country and how much are they actually used in daily clinical work? Medical Physicists practicing in the United States are invited to participate in a 5-10 minute research study to find diffusion patterns and explore barriers in using innovative techniques in Radiation Oncology.

Please share this survey link with any Medical Physicists practicing in Radiation Therapy you may know.

https://www.surveymonkey.com/r/DiffusionOfInnovationSurvey

This survey will remain open until 5/24/2019 11:59pm EST. This is the final reminder. If you choose to participate and enter your email at the end, you will receive a $10 Amazon gift card, or skip that step to remain completely anonymous. Anonymized aggregate data will be used to conduct a quantitative cross-sectional analysis to assess how innovation may vary depending on individual and organizational factors.

Thank you in advance for taking the time to participate in this research study.

Appendix C: 2013 Rural-Urban Continuum Codes

	Code	Description
Metropolitan	1	Counties in metro areas of 1 million population or more
	2	Counties in metro areas of 250,000 to 1 million population
	3	Counties in metro areas of fewer than 250,000 population
Non metropolitan	4	Urban population of 20,000 or more, adjacent to a metro area
	5	Urban population of 20,000 or more, not adjacent to a metro area
	6	Urban population of 2,500 to 19,999, adjacent to a metro area
	7	Urban population of 2,500 to 19,999, not adjacent to a metro area
	8	Rural or less than 2,500 urban population, adjacent to a metro area
	9	Rural or less than 2,500 urban population, not adjacent to a metro area

Appendix D: Indicators Used for Innovation Score Determination

Category	Indicator
Patient positioning	Surface guided radiation therapy Respiratory gating Breath hold
Patient treatment	Stereotactic body radiosurgery Stereotactic cranial radiosurgery Robotic radiosurgery Intra-operative radiation therapy Flattening free beams
Treatment planning	Automatic contouring Deformable image registration Automatic planning Adaptive planning
Quality assurance	Portal dosimetry Trending Automatic QA Automatic plan checks
Workflow	Clinical trials New procedures New responsibilities New external relations