Healthcare 3D Printing Service Innovation: Resources and Capabilities for Value Co-Creation

Atanu Chaudhuri*

Durham University Business School, UK

Aalborg University, Denmark

E-mail: atanu.chaudhuri@durham.ac.uk

Hussein Naseraldin

ORT Braude College of Engineering, Israel

E-mail: nhussein@braude.ac.il

Gopalakrishnan Narayanamurthy

University of Liverpool Management School, UK

E-mail: G.Narayanamurthy@liverpool.ac.uk

*Corresponding Author

Accepted for Publication in

Technovation

Healthcare 3D Printing Service Innovation: Resources and Capabilities for Value Co-Creation

Abstract:

Healthcare 3D printing (3DP) is in nascent stage and some service providers are facilitating its adoption across hospitals in the world. There is limited research on healthcare 3DP services, the business models of such service providers, the value they provide to the surgeons and the hospitals and the co-creation process needed to deliver such service innovation. The objective of this research is to identify the value proposition, value creation, value capture and value provided to users by the healthcare 3DP service providers and to identify the resources and capabilities needed by the healthcare 3DP service providers and the clinical team to co-create value. Interviews are conducted with seven healthcare 3DP service providers, three surgeons, and a healthcare 3DP design expert along with secondary data collected from the service providers to answer the research questions. The results show that healthcare 3DP service providers utilise their exploitative capabilities while the surgeons used both explorative and exploitative capabilities to engage in the co-creation process and to create perceived value for patients. The findings also show that integrated healthcare 3DP service providers by providing knowledge, expertise, insights and training to the surgical teams are better suited to improve the absorptive capacity of hospitals to adopt 3D Printing than specialised implant developers.

Keywords: healthcare, 3D printing, service innovation, co-creation, resources, ambidextrous capabilities, absorptive capacity

Healthcare 3D Printing Service Innovation: Resources and Capabilities for Value Co-Creation

Introduction

Digital technologies are expected to improve the quality of care and operational efficiency by facilitating clinical and administrative tasks associated with assessment, evaluation, and precision of medical treatment (Kraus et al., 2021). Healthcare 4.0, based on Industry 4.0 paradigm, is triggering and facilitating transition from traditional to e-health (Aceto et al., 2020; Lepore et al., 2022). 3D Printing (3DP) is one such key digital technology. 3DP application are increasingly being adopted by firms for developing customised products. But the focus of the academic research in areas like technology management and innovation has primarily been on industrial and consumer applications. 3DP service providers play critical roles in facilitating the adoption of this technology (Rogers et al., 2016; Chaudhuri et al., 2019 and Holzmann et al., 2020). Analysis of service providers' role and their business models have also been restricted to consumer and industrial applications. For example, Rogers et al. (2016) considered four types of 3DP service providers: consumer 3DP services, enterprise 3DP services, 3DP equipment and material producers, and 3DP equipment and material distributors. Chaudhuri et al. (2019) analysed the role of industrial 3DP service providers by studying three such service providers and industrial users of such services. Holzmann et al. (2020) classified the 3DP service providers as follows: a single technology specialist, a multiple technology champion, a local service provider, and all-rounders. However, application areas were unclear. Healthcare is among the sectors that are immensely impacted by 3DP. 3DP is facilitating service innovation through pre-surgical planning and simulation, design and development of customised surgical guides and implants (Ramola et al., 2019), thereby significantly changing the way the surgical procedures are planned and conducted. Such 3DP enabled service innovation in healthcare is different from industrial and consumer 3DP services for multiple reasons and hence need to be studied separately. First, anatomical models, surgical guides, and implants – all must be designed based on a specific patient's anatomy and clinical conditions and must be produced on-demand within a short lead-time. For industrial applications, 3DP services can be for prototyping or for spare parts, which may not require customised design. Second, design of patient-specific surgical guides and implants requires active involvement of the surgeon, working collaboratively with the service providers and to a lesser extent for developing the anatomical model. Industrial 3DP service providers can design parts or products with higher degree of design freedom based on performance requirements and specifications and requires lesser involvement of the customer. In the consumer 3DP services, customers can customise the designs according to their needs (Rogers et al., 2016).

Third, healthcare 3DP service providers can also setup point-of-care 3DP facility inside the hospital. Industrial 3DP service providers need not provide such services within customers' premises. Fourth, use of patient-specific anatomical models, surgical guides, and implants have impacts both on hospital efficiency, such as surgical time reduction, and on clinical outcomes, such as reduced recovery time, reduced blood loss, reduced anaesthesia usage etc. (Chaudhuri et al., 2020). In contrast, industrial 3DP applications for prototypes and spare parts provide different benefits such as reduction in lead-time, inventory levels, and material, while 3D printed industrial tools provide productivity enhancement and product performance improvement in terms of durability and reduced energy consumption.

Kraus et al. (2021) conducted a review on digital transformation in the healthcare sector. Interestingly, the review did not include 3DP in the healthcare. Research on the innovation, impact, and value that 3DP can bring to the healthcare service sector is invaluable yet, studies on healthcare service innovation using 3DP in business and innovation management literature is at a very nascent stage. Thus, the business models of such service providers, the value they provide to the surgeons and the hospitals, and the co-creation process needed to deliver such service innovation need to be studied.

Hence, the objective of this research are as follows:

1) To identify the value proposition, value creation, value capture, and value provided to users by the healthcare 3DP service providers
2) To identify the resources and capabilities needed by the healthcare 3DP service providers and the clinical team to co-create value.

To fulfil the objectives of the study, we investigate business model designs of seven healthcare 3DP service providers by conducting interviews with the service providers, hospital administrators, and surgeons as well as by analysing secondary material.

We contribute to the co-creation literature by 1) identifying the resources and capabilities needed by the healthcare 3DP service providers and the surgical team to engage in the co-creation process and 2) by demonstrating that exploitative capabilities of healthcare 3DP service providers and both explorative and exploitative capabilities of users, i.e., surgeons, are needed for the partners to engage in co-creation process, thereby creating value. To the best of our knowledge, this research is one of the earliest studies on the business models of healthcare 3DP service providers and how they provide value to the patients, surgeons, and hospitals.

The paper is structured as follows: in Section 2 we review the relevant literature, followed by a discussion of the methodology in Section 3 and in Section 4 we present the findings. In sections 5 and 6 we present the discussion and the conclusions.

2. Literature Review

Several strands of research are of interest. We first review business models in the healthcare. Then we embark on digitalization in the healthcare sector with emphasis on value creation. Then we shed light on the potential gaps therein.

2.1 Business models for digital healthcare

A business model represents a specific combination of resources, which generate value for both customers and the organization through transactions (DaSilva and Trkman, 2014) and expresses the firm's understanding of customer expectations (Baden- Fuller and Haefliger, 2013). Business models can enable firms to attract stakeholders by articulating a compelling story (Doganova and Eyquem-Renault, 2009). But, to deliver value to the customers, firms must understand the expectations of the market and discover what offerings are needed (Teece, 2010). Business models in the service context should be based on the understanding of service provider and the client's value-creation logic. A basic assumption of a business model is that the creation and implementation of any service requires a set of value activities to be performed by the partners, thereby forming a value-creating system.

Digitalization has expanded the scope of resources that are accessible to firms and, thus allows them to design novel configuration of resources which, in turn, enables value creation with different partners including their customers (Amit & Zott, 2012; Prahalad & Ramaswamy, 2004). Digital transformation enables experimentation and implementation of novel digital business models, for creating and capturing value (Teece, 2010). Business models can be categorized as digital if digital technologies trigger fundamental changes in these value dimensions (Veit et al., 2014). A digital business model can indeed improve transaction efficiency and enhance cost advantages (Schiavone et al., 2021). Hence, there is a potential to capture value by integrating service offerings and digital technologies (Frank et al., 2019).

In the context of 3DP, Rogers et al. (2016) identified three types of digital services, namely, generative, facilitative, and selective services. Generative services focus on the generation of 3D printable models and include, for instance, scanning and construction services. Facilitative services emphasize 3DP of objects without generating the model itself. Selective services aim to generate huge databases of 3D printable models from which customers can choose. Rayna et al. (2015) derived a taxonomy of online 3DP platforms and concluded that these platforms facilitate the transition of customers into more active prosumers. Growth of 3DP service industry can result in existing business models and the development of new business models (Holzmann et al., 2017). But 3DP services for healthcare can create unique value beyond transaction cost efficiency and cost advantages. Coupling technological advances with appropriate business models can be a prerequisite to improve the healthcare system (Hwang and Christensen, 2008). Healthcare services deploying 3DP can be considered as processes' value-adding businesses. These businesses transform inputs of resources, such as people, equipment, raw materials, energy, and capital, into outputs of greater value. In the context of healthcare 3DP services, though design and development of anatomical models, surgical guides, and implants will be customised for each patient, service providers can generate efficiency and cost effectiveness for hospitals and patients by focusing on process excellence. Other benefits accrue due to patient-specific on-demand nature of the services and patients' clinical outcomes, which can be achieved.

2.2 Value co-creation and digitalization for healthcare service innovation

Amit and Han (2017) suggest that the digitization of businesses requires firms to conceive of and design their resource configurations based on a systems view and from the perspective of value-creation. Indeed, customers play a key role in the realization of value out of the value potential embodied in a service provider's value proposition. This directs attention from the provider's competences to understanding the customers' resources and capabilities, and thus leads to an understanding of the collaboration between the customer and the service provider (Möller et al., 2008). A healthcare system, in general and the use of 3DP therein, in particular, should focus on the "*systemic interplay of actors in an interrelated system of reciprocal service provision*" (Vargo & Lusch, 2011, p. 183).

In a traditional healthcare system, patients passively receive care from service providers, including for example, clinicians, nurses, and allied health professionals. However, patients are increasingly viewed as active contributors to their healthcare outcomes, and there is a growing evidence that supports the benefit of a patient-centred approach to health solutions (Porter & Lee, 2013). Hence research on co-creation for healthcare service delivery has been studied from the point-of-view of the focal dyad of patient and physician (Osei-Frimpong et al., 2015). Balta et al. (2021) studied the role of digital technologies in influencing the interactions between the stakeholders involved in the occupational health service. The patient-centred approach involves healthcare being designed around the specific needs of a patient. Benefits of such an approach include improved health outcomes and cost efficiencies.

Use of 3DP in healthcare is motivated by the need to develop customised solutions for patients either when no other options are available or to improve clinical outcomes. Radical service innovations create discontinuities within usual patterns of behaviour and can challenge existing ways of doing business in the industry (Perks et al., 2012). 3DP is creating such service innovation in healthcare by radically altering how surgeries are planned and conducted. Firms introducing radical innovations need to continuously adapt and refine the original radical concept, in its early stages, to achieve their competitive position (Perks et al., 2012). Ramaswamy and Ozcan (2018) define co-creation as an enactment of interactional creation across interactive system-environments (afforded by interactive platforms), entailing agencing engagements and structuring organizations. An agencial assemblage emphasizes both an "ensemble" and a "process". It is an "ensemble" in terms of an arrangement of parts that work together, as well as a "process" as in terms of how those parts come together. In this context, an interactive platform includes artefacts such as physical and digitalized models, processes include digitized and more conventional processes of interactions, interfaces include physical and digitalized means by which an entity interacts with another entity. Persons include individuals in their roles such as customers, employees, partners, and any other stakeholders (Ramaswamy and Ozcan, 2018).

Development of a surgical or treatment plan and conducting the surgery using 3DP involves 3DP service providers, and the surgical team, who must work together to co-create the solution, which involves development of artefacts such as the anatomical model, customised surgical guides, implants, and surgical simulators etc. Creation of such "ensembles" involves a multi-stage process starting from the service provider understanding the clinical needs from the surgeon till the usage of the anatomical model, surgical guides, and implants during the surgery.

2.3 *Gaps from the literature*

There is lack of research addressing the phenomenon of business model designs in the advent of a novel technology-based industry (Holzman et al., 2020). Moreover, limited research on business models of 3DP service providers are mainly focussing on industrial and consumer applications (Rogers et al., 2016; Holzmann et al., 2020). The business models and value created by healthcare 3DP service providers have not been explored yet and hence comparing the approaches taken by different types of healthcare 3DP service providers in creating value is expected to contribute to this underexplored topic. Value co-creation literature in healthcare has focused on the relationship between healthcare service providers and receivers, i.e., patients. In the context of use of digital technology like 3DP for service innovation in healthcare, roles played by service providers and the surgical team are critical, which have not been addressed in the literature. Research on co-creation for healthcare service delivery has focused on the role of patients and physicians (Osei-Frimpong et al., 2015) and not between technology and healthcare service providers. Investigating the interaction between 3DP technology service providers and the surgical team is expected to reveal nuances that needs to be taken into account for establishing a successful collaboration and sustainable business model.

2.4 Theoretical foundation

Resource-Based View (RBV) explains how resources help a company to create value for customers. When resources are accumulated by a firm in a specific way, they are harder to imitate or substitute (Barney, 1991). Such resources can be tangible, such as infrastructure, or intangible, such as “know-how”. RBV identifies the characteristics of the resources such as value, rarity, non-imitability, non-substitutability, and non-transferability (Barney, 1991). Resources are valuable when they enable a firm to implement strategies to improve efficiency and effectiveness and are rare when they are not possessed by many competing or potentially competing firms.

Capabilities are created when the resources have been integrated and are usually acquired through the development, learning, and exchange of knowledge of the staff. Knowledge is considered one of the fundamental resources of value co-creation (Vargo and Lusch, 2004). Knowledge allows dynamic organisational learning in organisations while relational capability can augment the resources of alliance partners to create, extend or modify their resource bases (Teece, 2000). Knowledge transfer in healthcare ecosystems is composed of four main components: healthcare ecosystem’s players’ categories; knowledge flows among different categories of players along the exploration and exploitation stages of innovation development; players’ motivations for open innovation; and players’ positions in the innovation process (Secundo et al., 2019). Søberg and Chaudhuri (2018) also demonstrated the benefits of utilizing prototypes in relation to technical knowledge creation as it allows working with knowledge in a tacit form, which is particularly relevant related to technical knowledge creation. Firms that are able to build capabilities by combining resources in unique ways, and partnering with firms that have complementary assets (Dyer and Singh, 1998), can access bundles of resources with which to successfully compete against rivals (Hervas-Oliver and Sempere-Ripoll, 2015). Transforming an innovation into a commercially viable product or service requires that the know-how inherent in the innovation can be utilized in conjunction with complementary assets

(Paradkar et al., 2015). Such complementary assets include manufacturing facilities, marketing and distribution networks, after-sales servicing, and specialized components (Paradkar et al., 2015). Access to resources and capabilities from other actors are requisite in value creation and hence value is always inherently co-created (Vargo and Lusch, 2004). Value in exchange is what is promised by a service provider and expected by a customer at the time of purchase while value in use is dependent on suppliers', customers' as well as other third parties' resources and capabilities. These organisations thus become co-creators of value (Eggert et al., 2018). Integration of resources (knowledge and skills) plays a critical role in such co-creation (Osei-Frimpong et al., 2015). Distinct from a firm-based perspective, the system-based view explicitly considers the value propositions for all value-creation participants, rather than only those for the customers when designing a system (Amit & Zott, 2015). Such a system-based view draws on the ecosystem perspective by recognizing the important role of complementary resource providers in a focal firm's ecosystem in determining its value creation or innovation outcome (Adner & Kapoor, 2010).In the context of healthcare, value can be co-created from the interactions between technology and healthcare service providers and between healthcare service providers and patients. Service Science considers service systems "as dynamic value co-creation configurations of resources (people, technology, organizations, and shared information)" (Maglio and Spohrer, 2008: p. 19). Patients, providers, professionals, technology, and information are significant resources that constitute the healthcare service system and co-create value (Vargo et al., 2008) and hence need to be integrated (Frow et al., 2016).

Thus, using the above theoretical foundations, we analyse how healthcare 3DP service providers create value, engage in co-creation with the surgeons, and the resources and capabilities needed by them and by the healthcare service providers, i.e., hospitals and the clinical team for such co-creation.

3. Methodology

3.1 Data collection and the sample

We used the multiple-case study method to answer our research questions. The case-study approach is appropriate for our investigation as it is suitable for early, exploratory investigations in which the phenomenon (i.e. 3DP applications in surgeries) is not well understood (Voss et al., 2002) and with limited research (Yin, 2014). Multiple case study design is preferred over a single case study design as it can provide more opportunities to gather different perspectives and conduct comparative analysis (Dyer and Wilkins, 1991).

We compiled a list of 18 healthcare 3DP service providers (excluding those providing 3D bio-printing services) by searching news articles from Factiva, industry reports and 3DP related websites. The criteria we chose to select these 18 out of the total of 42 was that these companies should already be delivering services for hospitals. Thus, these should not be early stage companies which have not yet delivered services for hospitals. Thus, we decided to exclude 3Dbio printing companies as they were specialised only in bioprinting and are yet to deliver services on a commercial scale. We reached out to the leadership team and executives of the chosen 18 companies by sending emails and contacting via LinkedIn. Finally, seven companies agreed to be interviewed. We used a combination of secondary data and interviews with healthcare 3DP service providers and surgeons to collect information about value proposition, value creation, and value capture by the service providers and value co-creation by the service providers and surgeons. Semi-structured in-depth interviews were conducted with the key informants in the service providers. A total of 12 interviews were conducted with service providers, five interviews with surgeons and one professor with expertise in design of 3D printed surgical guides and implants. The details of the interviews conducted, and additional data collected are provided in Table 1. In line with practices followed by Dicuonzo et al. (2022) and Dal Mas et al. (2021), we show the set of semi-structured interview questions for 3DP service providers and surgeons along with references in Table 2.

To supplement the interviews, additional material was collected from the companies' websites, LinkedIn posts, and other material such as presentations requested from the companies, which also included quotes from surgeons working with the service providers. A comprehensive case document was created consisting of the transcripts of the interviews conducted by the researchers and the secondary information collected. The case documents were sent to the interviewees for validation. If needed, further clarifying questions were asked, which were responded by the key informants over email or through additional interviews. The manuscript was also sent to the interviewees and their feedback was sought over email or over a short interview, where possible.

We employed qualitative content analysis to ensure systematic categorization of collected information on value propositions, value creation and capture, resources, capabilities, and value co-creation (Mayring, 2004).

“Insert Table 1 here”

“Insert Table 2”

3.2 Coding

The first step in our data analysis involved an in-depth analysis of raw data (e.g., the case document including interview transcripts and the collected additional material). The components of business model consisting of value proposition, value creation, and value capture were used as the framework that guided our data analysis but also provided freedom for interpretation and inductive categorization.

To start the coding, we categorised the case documents based on the components of the business model. In the next step, we coded the common words, phrases, terms and inductively extracted variables from the data and aggregated them to appropriate business model subcomponents of value propositions, value creation, value capture by the service providers, resources and capabilities and co-creation. The coding was done using NVivo and the relationships between resources, capabilities, value creation and co-creation were identified for the different types of service providers. The findings of the study, the propositions developed, and the frameworks are also validated with the interviewees.

A binary coding system was followed by assigning the value 1 if a specification was present in a firm's business model and the value 0 if it was absent (Holzmann et al., 2020). Two of the authors independently coded the interview documents and archival material. Wherever minor differences were observed in coding, the other authors collectively discussed those, and conclusions were reached. We ensured internal consistency of the data coding process by calculating the inter-rater agreement. Inter-rater agreement of 87.5% indicated substantial agreement between the two raters. Wherever there was a disagreement, those were discussed with the third author and final agreement was reached. This process resulted in a total of 48 variables in total including the resources and capabilities. We inductively found 14 variables associated with the value proposition, 10 for value creation, and 5 for value capture.

4. Findings

We discuss the elements of value proposition and value creation, which are mentioned by at least 50%, i.e, 4 out of 7 service providers. The value capture elements differed between the service providers. Hence, we include all of those for analysis. We also mention the values which are extracted by the users and surgeons and compare those with the value propositions by the service providers. Table 3 shows the most common value propositions as well as those which are less common and mentioned by only a few service providers.

"Insert Table 3 here"

4.1 Value Proposition by service providers

Designing value propositions require understanding of the customer segment and their needs, their pains and challenges which help in creating services, which help alleviating the 'pains' and 'create gains' (Osterwalder et al., 2014).

The patient related benefits proposed by the service providers include shorter patient recovery time and other clinical benefits such as reduced blood loss and reduced anaesthesia usage.

Shorter patient recovery time

As the surgery is pre-planned with minimum uncertainties and the cutting guides and /or implants are custom designed, there are limited chances for post-surgical complications. This is evidenced from the quote by Lucid Implants COO.

> *"With 3D printed implants, patient recovery is faster (7 to 10 days) whereas in conventional cases, recovery may take up to 70 days. Also, second surgery (due to no extra donor side morbidity) is not needed."*- Co-founder of Lucid Implants

Other clinical benefits

Other patient benefits include reduced blood loss, reduced time under anaesthesia (Anatomiz3D), fewer complications, reduced tissue damage (Synergy3DMed)

The benefits to surgeons include precise and faster surgical planning, access to knowledge, expertise and insights, catering to the needs and requirements of surgeons and providing customised solutions.

Precise and faster surgical planning

Use of 3D printed anatomical model results in faster and more precise patient specific treatment planning. Such planning and practicing help the medical team feel prepared and confident. Due to the simplified planning experience, the surgeons can have control of the procedure.

> *"The ability to use 3D printed anatomical models for rapid assessment for trauma cases has traditionally been limited by the capabilities of 3D hardware to manufacture the required models within the desired turnaround times. We have recently provided a number of 3D models for use in trauma assessment. The time taken from receiving of the image data to finished product has been within the time frames necessary for the surgeons to make rapid assessments."*- Co-founder of 3DLifePrints

Access to knowledge, expertise, and insights

The service providers also bring together experiences of using 3DP for hundreds of surgeries across specialties and bring knowledge expertise and insights. Thus, they also help the surgical team understand the possibilities and limits of 3DP and help in the design of the guides and the implants.

> *"We did more than 800 or 900 operations, so I have a lot of experience and knowledge in 16 different specialties."*- CEO and founder of Synergy3DMed

"The company's expertise, knowhow, understanding of clinical and 3DP- i.e anatomical, clinical design and 3DP perspectives is a key value proposition."- Co-founder of Anatomiz3D

Catering to the needs and requirements of surgeons and providing customised solutions

The service providers must be able to understand the requirements of the surgeons and their exact needs and translate those into feasible designs of the guides and implants. It is important that the service providers can understand the clinical language without the need for the surgeons to explain to them the requirements in details as their time is limited.

"Our strength lies in designing as per the surgeon's requirements and patient's needs, no matter what anatomy, no matter what technology, no matter what product".- Co-founder of Anatomiz3D

The value propositions for hospitals include cost effectiveness, reduced surgery time and better operating theatre utilisation and supporting certification and validation requirements and faster delivery time.

Cost effectiveness

For public health systems saving operating costs is key for the hospitals. For private healthcare systems where patients pay out-of-pocket or are subsidised to a certain extent, use of 3DP can be viable if the patients are able to bear the costs.

"*Our solutions help surgeons choose the appropriately sized medical devices, thereby saving costs*." 3DLifeprints co-founder

Reduced surgery time and better operation theatre utilisation

Significant reduction in surgery time (usually in terms of a few hours) can help in planning more surgeries and thus improve operation theatre utilisation. It is important to recognise that a few minutes saved will not unnecessarily result in better operation theatre utilisation and it will also depend on the scheduling and sequencing of the surgeries.

"We reduced the overall surgery time by 1.5 hours based on 120 cases done till date."- Co-founder of Lucid Implants

Supporting certification and meeting regulatory requirement

The service providers which can support the entire workflow including ensuring all certification and quality standards and help meet all regulatory requirements can provide better value to the hospitals.

"Business proposition for us is to manage the workflow under the right regulation. For anatomical models, it is not a problem. But when you're talking about medical devices and patient specific instrument in the operation room, this is in a different league."- CEO and Founder of Synergy3DMed

Faster delivery lead-time

For certain cases, meeting fast delivery lead-times is critical as it may be a question of life and death for the patient.

"One patient had a car accident at 10 pm. The hospital sent the CT scan to us by 10: 30 pm. We directly printed the skull of the patient and the print was complete by 6 am which was then used by the surgeons to plan the surgery. This was possible because we have our printers inside the hospital."- Founder of Bone3D

4.2 Value creation

The integrated healthcare 3DP service providers create value through multiple activities such as managing the integrated workflow, providing anatomical models with specific or multiple materials, design, and production of 3D printed implants, facilitating printing within hospitals, or providing printing support. Table 4 shows the value creation by service providers.

"Insert Table 4 here"

Integrated workflow

The entire process from communicating the need, placing the order along with converting the 2D images to 3D files, iterating and finalising the designs is a complex workflow, which needs to be managed seamlessly and automatically, wherever possible.

"Complex workflow in the legacy process for taking 2D images and converting into 3D files has been the biggest barrier and we are removing that using our automated process."- Founder of Axial3D

"A process to manage all the workflow under the right regulation is a key element."- CEO and Founder of Synergy3DMed

"In-house digital platform gives clinicians the ability to request new devices, view progress of segmentation, review, approve and provide feedback for each case"- Co-founder of 3DLifeprints

Providing anatomical models with specific or multiple materials

The service providers create value by providing anatomical models made with the most suitable materials and multiple materials to distinguish between bones, veins, arteries etc.

"We reproduce anatomy parts, with or without pathology, using different materials in order to represent both hard and soft tissues, and to make the simulation experience realistic in terms of sensation."- Founder of Bone3D

Design and production of 3D printed implants

Design and production of polymer and metallic 3D printed implants to suit the needs of the patients and surgeons is a key value creating activity for the service providers.

> *"Our ISO 13485 facility empowers us to design and 3D Print customized implants in Medical Grade Titanium, as per patient's anatomical needs and surpass the limitations of pre-fabricated implants in terms of design, form and fit."*- Co-founder of Anatomiz3D

Facilitating printing within hospitals or providing printing support

Setting up printing facilities within the hospital or a nearby facility or providing on-demand printing support can be very valuable to meet short lead-times and facilitate better communication with the surgical team.

> *"We believe one of the best ways to benefit from 3DP is via an in-housed 3D LifePrints managed service. We offer a variety of cost-effective packages to meet the budgets of hospitals, where we provide on-site state-of-the-art 3D printers, highly qualified bio-medical engineers, clinicians, 3D experts and medical software systems"*- Co-founder of 3DLifePrints.
>
> *"With our Point of Care Centres we help establish an entire process flow for hospital 3DP labs, along with providing back-end support for end to end solutions."* – Co-founder of Anatomiz3D
>
> *"For the hospitals which do not have in-house printer as they cannot afford to hire an engineer or invest in the equipment, we provide printers with one of our partners and software so that they do not have to invest heavily in software licences upfront."* – Founder of Axial3D
>
> *"For large hospitals, the factory is inside, or we can rent facilities nearby. For smaller hospitals which do not have the demand, like in islands, there can be one facility which caters to all the hospitals. Some part of the process is done outside the hospital and rest is in the hospital"*- Founder of Bone3D.

The above analysis also shows that some service providers are trying to differentiate themselves with other competitors by providing additional value creating activities. These include simulation and outcome analysis, deployment of systems remotely using cloud platform, providing an ordering catalogue/system, providing teaching and learning tools, delivering services across different modes and even analysing the total cost of ownership from the patient's perspective. For example, 3DLifePrint provides on-site simulation facility by which clinicians can identify and fit appropriate implant types and sizes, giving the hospital notice of which implants will be needed on the day of surgery. It also provides paediatric intravenous trainer and simulator. Lucid Implants provides end-to-end virtual simulation along with outcome analysis. They conduct Finite Element Analysis of the implant to simulate how the implant performs when the patient is sleeping, eating etc. Bone3D uses multi-material 3D printers to print biomechanically correct surgical simulators with good mechanical properties so that the surgeon can have the real sense while practising the surgery. Axial3D's processes are on a cloud platform. Thus, they can deploy solutions remotely and can scale relatively easily. Anatomiz3D has developed an education models kit with 130 cases for teaching in super-specialization. Lucid implants conducts a Total Cost of Ownership analysis so that surgeons can explain and demonstrate to patients the cost of using 3D printed solutions with respect to conventional options.

4.3 Value capture by service providers

The service providers captured value using different revenue models i.e., contract from setting up of Point-of-Care centres in hospitals, monthly or annual fee from hospitals, pricing for long term adoption of 3DP, solution price based on the individual project and model-as-a-service. It is interesting to note that though many of the services offered by the service providers are similar, they captured value using different means. Table 5 shows the value capture by the service providers.

Contract from setting up of Point of Care centre in hospitals

> *"For local hospitals, we have labs inside the hospital and production is either inside the hospital or at our central facility. For distant hospitals either everything is done using our portal or we can go and deliver"*- CEO and founder of Synergy3DMed

Monthly fee from hospitals

> *"Hospitals only pay for the monthly fee. If the hospital does not have space, we can take up place next to the hospital and can deliver from there. That works only when we have long term partnership i.e. at least 3 years. If they want more or less, we can change. Where demand from individual hospitals is not there, we put a common facility which hospitals can share. These hospitals also share the monthly fee and that comes out very economical for the hospitals."*- Founder of Bone3D

Pricing for long term adoption of 3DP

> *"This was like buying a ticket to come in, I gave them all the knowledge and become their partner over there. They need to pay in advance for 50 cases and this money goes to the company to qualify a designer for the team, to prepare the marketing materials for them and to be available, whenever needed"*- CEO and founder of Synergy3DMed.

Solution price based on project/part

> *"Solution price is based on the project. It can include only anatomical model or involve all the way till implant design and production"*- Co-founder of Lucid Implants

Model as a Service

"Our revenue comes from Model- as- a- service where hospitals pay for what they are using with zero upfront investment required for the hospital"- Axial3D.

"Insert Table 5 here"

4.4 Comparison between service providers

The service providers were clustered based on their coding similarity using Jaccard's coefficient in Nvivo and broadly two clusters were identified. Cluster 1 consisted of integrated healthcare 3D printing service providers (3DLifePrints, Anatomiz3D, Axial3D, Bone3D and Synergy3DMed) while cluster 2 includes specialised 3D Printed implant developer (Kanfit3D and Lucid Implants). Our analysis shows that the unique value propositions of the integrated service providers are providing other clinical benefits such reduced blood loss, reduced anaesthesia usage and providing access to knowledge, expertise and insights, improved training of surgeons for complex surgeries and improved communication with patients while the unique value proposition of implant developers was improved reputation for hospitals. The unique value created by the integrated service providers include deployment of systems using cloud platform, delivery of services across different modes and providing teaching and learning tools while an implant developer created value by analysing total cost of ownership from the patients' point of view. The two types of service providers also differed in terms of value capture. While the integrated service providers, captured value either through monthly or annual fee from hospitals or from contracts for setting up point-of-care facilities in hospitals, the implant developers primarily captured value by pricing solutions based on individual project or part.

Many technology service providers tend to be specialised while others provide a broad range of services to become a one-stop shop for potential customers. Healthcare 3D Printing industry is no exception in that. But it is interesting to observe that implant providers are not just a sub-set of the integrated service providers and do provide unique value propositions and create unique value.

4.5 The co-creation process

The co-creation process as shown in Figure 1 involves multiple activities.

The process starts with the surgeons sending a request to the service provider using an online platform or an inquiry form. If needed, the service provider and the surgical team can have an initial discussion, based on the request to understand the requirements better and to explain the possibilities and limits of using 3DP. Once this clarity is achieved, the service provider proceeds with segmentation in which Computed Tomography (CT) and Magnetic Resonance imaging (MRI) files are merged using the Digital Imaging and Communications in Medicine

(DICOM) files shared by the hospital. Image segmentation is a process of partitioning the image into sets of pixels. Segmentation helps in identifying and visualizing the affected area. Based on the inputs of the surgeon, a semi-transparent anatomical model is then 3D printed in colour showing the size and the exact location of the affected anatomy. Surgeons plan the surgery using the measurements from the anatomical model and decide how to cut it, which determines the specifications of the surgical guides and jigs, which will be used for the surgery. The service provider then designs the guides and implants and after discussion with the surgical team, conducts a few iterations, if needed and finalises the designs. Those guides and implants are then custom printed for the surgery. On some occasions, the service provider may provide options to the clinical team to conduct a simulated surgery using the designed cutting guides and implants and be fully prepared for the surgery. This will also help understand the risks and complications, expected during the surgery, and adjust the surgical plan, if needed. The surgeons conduct the surgery with the anatomical model, surgical guides, and implants with minimal surprises.

Merging of CT and MRI files and accurate segmentation of the section helps create a customized and accurate anatomical model of the affected area of the patient. The semi-transparent anatomical model showing the exact location and length of portion to be cut leads to surgical precision. The pre-planning of the surgery using the anatomical model, which can also be used in the operation theatre, if needed and the use of patient specific surgical guide facilitate precise cutting. This in turn help in reducing surgery time and cost. Precise cutting avoids keeping bigger margins of safety and hence unnecessary bone loss and blood loss are avoided.

"Insert Figure 1 here"

4.6 Resources and capabilities supporting the co-creation process

The common resources, which all types of service providers have, are skilled manpower, in-house 3DP facility, quality management system, and library of complex cases. Table 6 shows the resources and capabilities needed by the service providers.

4.6.1 Resources required by the healthcare 3DP service providers

Skilled manpower

Skilled manpower with strong engineering design expertise and understanding of clinical knowledge are key resources which service providers need.

"Our highly experienced team of industrial designers, biologists and engineers has

access to the latest technology and can quickly turn the concepts into reality." – CEO and founder of Synergy3DMed

In-house 3DP facility

An in-house 3DP facility along with skilled manpower and quality management system to ensure that the printed guides and implants meet all regulatory requirements are indispensable resources, which service providers will need.

> *"Once everything is finalised, we proceed for final fabrication at our facility, which is a clean room, and ISO 13485 certified."*- Co-founder of Lucid Implants

> *"We have state of the art, validated production technologies such as 3D metal printing, combined with the more 'traditional' manufacturing services such as machining, finishing, and clean packaging."*- Co-founder of Kanfit3D

Quality management system

The service providers must be certified with the appropriate quality management for design, development and manufacturing of the surgical guides and implants.

> *"... the management system of the company has been certified according to the standard ISO 13485-2106 and 9001:2015 Certification. The ISO 13485 and the ISO 9001 certified management system covers the development, production and quality management of Kanfit3D.*- Co-founder at Kanfit3D.

Library of complex cases

> *"Considering our experience with over 700 live cases, we have a library of complex cases across specialisations that serve as great teaching and training tools."- Anatomiz3D*

The resources which hospitals and surgeons should have include Picture archiving and communications system (PACS) system to share data via data sharing agreement and knowledge of which information to share with the service provider

The key capabilities of service providers include understanding of both engineering design and medical needs, understanding of the entire workflow, ability to use the design and use the printing software, ability to build a network involving surgeons, and thorough understanding of the materials and manufacturing processes. Understanding of how the solution can be integrated in hospitals was observed by the service providers, which also helped in setting up point-of-care facilities in the hospital.

Library of complex cases is a unique resource possessed by integrated healthcare 3DP service providers.

4.6.2 Capabilities needed by the healthcare 3DP service providers

Understanding of both the engineering design and the medical need

The engineers from the service providers have limited time to understand the requirements from the surgeons and translate those requirements into a feasible surgical guide or implant design.

Understanding of the materials and manufacturing processes

It is an imperative that the engineers and designers from the service providers are thoroughly conversant with all the 3D printable materials and the 3DP process as they will have to choose the right material and the right technology to meet the requirements and optimise the manufacturing process parameters to achieve the desired quality of the surgical guides and more importantly for the implants.

Understanding of the entire workflow

It is not enough to have only design capabilities; the service providers must understand the entire workflow and how the 3DP solution can be integrated within the hospital considering the needs of the multiple stakeholders as well as the different IT systems the hospitals may have.

Ability to build a network involving surgeons

Networking with surgeons to understand their pain points, their expectations and updating them about the possibilities of 3DP is key for the service providers to develop confidence and trust in surgeons. This may eventually lead to the first set of use cases where the surgeons may be willing to explore 3DP as a viable option.

"need to get the connections and understand the market very well.""- Co-founder of Kanfit3D

It is important to note that most of the resources and capabilities, which the service providers currently have are not rare (except proprietary software for design and communication) and can also be imitated by others. Hence, these are unlikely to create unique competitive advantage for them in the long run.

"Insert Table 6 here"

4.6.3 Resources needed by the surgical team

The resources which hospitals and surgeons should have include Picture Archiving And Communications system (PACS) to share data and data sharing agreement, knowledge of which information to share with the service provider and clinical knowledge (shown in Table 7).

PACS to share data and data sharing agreement

Picture Archiving And Communications system (PACS) helps in image transmission from the site of image acquisition to multiple physically disparate locations. Hence, it is a pre-requisite for the hospital to share CT and MRI images to the service provider. PACS along with the data sharing agreement will be needed for the service provider to initiate the co-creation process.

Knowledge of which information to share with the service provider

Surgeons should know which information to share with the engineers so that they can segment and develop the anatomical model and design the surgical guides and implants, if needed. Sharing too little information will result in infeasible designs and multiple iterations while sharing too much information may also confuse the engineers.

The capabilities demonstrated by the surgeons include ability to plan with minimal printing, understanding of which information to share with the service provider and ability to segment and design. For using the specific instruments and equipment, the surgeons also demonstrated additional capabilities such as willingness to practice the surgeries and focus on continuous upgradation of skills.

4.6.4 Capabilities needed by the surgical team

Ability to explore alternatives when other solutions do not exist

The surgeons should be willing to explore 3DP as an option to improve clinical outcomes and particularly for cases where no other options exist or the available approaches may not be suitable.

Ability to segment and design

Though the surgeons may not need to segment and design themselves, knowing how to segment and use the software to design always helps particularly if the hospital is keen to invest in 3DP within the hospital. Not only it builds confidence in the clinical team, but it also enhances their understanding of the technical and technological process performed by the 3DP service provider.

Ability to rehearse the surgery using the model/simulators

Excellence is achieved by practice. Indeed, the fact that surgeons can rehearse the operation using the jigs and implants utilizing the anatomical model in hand not only increases their confidence but also shorten the average expected future duration, primarily because of repetition and the learning curve effect.

Ability to communicate effectively within the team

Effective communication within the surgical team during the pre-surgical planning, while finalising the design and during surgery is critical for the success of the entire co-creation process and in achieving the desired outcomes. This is congruent with the findings of Cobianchi et al., 2021, who stated that clinical teams need to employ knowledge translation mechanisms and tools to transfer and share information effectively, by relying on non-technical skills such as leadership, teamwork, and communication.

Ability to conduct surgical planning

Surgeons should be able to utilise their surgical planning skills, which are enhanced by 3DP.

> *"We have been doing surgical planning all these years using CT and MRI files and by using our own judgment and experience. We surely know how to plan for surgeries but use of 3DP for anatomical models and simulators make our job easier and we can discuss specific details with our team members."*- surgeon at KGMU.

"Insert Table 7 here"

Table 8 below shows the resources, capabilities, and value creating activities needed to support the specific activities in the co-creation process.

"Insert Table 8 here"

"Insert Table 9 here"

We depict the resources and capabilities needed for co-creation in Figure 2 below. It shows how the healthcare 3DP service providers combine their resources and capabilities to engage in value creating activities. Similarly, the surgical team uses their resources and capabilities and by utilising the value creating activities performed by the service providers, they engage in the co-creation process, which in turn deliver value for the patients (as perceived and experienced by the surgical team).

"Insert Figure 2 here"

5. Discussion

Our findings help in understanding how the 3DP service providers and the surgical team in hospitals could utilise their respective resources to develop capabilities (Vargo and Lusch, 2004; Teece, 2000) and how such interactions between the 3DP service provider and the surgical team can co-create value (Ramaswamy and Ozcan, 2018). But, the findings also point out that nature of the capabilities varied between the 3DP service provider and the surgical team. Hence, we analyse those capabilities to develop propositions in section 5.1 below.

5.1 Proposition development

March (1991) defined the exploration of knowledge as experimenting with new alternatives, where results are uncertain, often negative, and far away in future. On the other hand, exploitation involves refining and extension of existing skills and technological paradigms, which can result in predictable outcomes. These concepts were later enhanced by Levinthal and March (1993, p. 105), who defined exploration as “the search for knowledge of ‘facts’ that can become known”, whereas exploitation was understood as “the use and development of well-known ‘facts’. García-Muiña and Navas-López (2007) showed that technological activities oriented to knowledge exploration processes have more potential to improve firm performance than those technological capabilities focused on the mere maintenance of a certain competitive advantage.

Prototypes or physical artefacts can facilitate transfer of tacit knowledge and hence facilitate nurturing of novel ideas as opposed to incremental ones (Søberg and Chaudhuri, 2018). In the context of this research, anatomical models played such a role in facilitating exploration through discussion between members of the surgical team and thus enabled transfer of tacit knowledge.

Our findings show that healthcare 3DP service providers are exploiting their resources to develop exploitative capabilities for value creation, thereby supporting the co-creation process. This can possibly be explained by the fact that all the service providers included in this research already have few years of experience in using 3DP for multiple surgical procedures and they are exploiting the resources and capabilities they have built since inception. It can be true that a new start-up developing innovative healthcare 3D printed services will have to demonstrate more explorative capabilities than exploitative. It is also worth noting that exploitative and explorative orientations require different structures and resources (Dominguez Gonzalez & Massaroli de Melo, 2018) and many firms that attempts to pursue both fail in the process (Solis-Molina et al., 2018). Hence, it may be true that healthcare 3DP service providers included in our study preferred to be conservative and exploit their capabilities in the early phases of adoption of their services.

The surgical team, on the other hand, demonstrated both explorative and exploitative capabilities to engage in the co-creation process. The outcomes can only be obtained from using 3DP in surgeries if the surgical team was willing to experiment, try new options, and learn new skills. Without the role of the users, it will not be possible for the service providers alone to utilise their resources and capabilities to derive the outcomes. This further emphasises the criticality of the co-creation process and the need of the service provider to build a network and maintain relationship with surgeons, who will be willing to engage with them in the co-creation process. This is in-line with findings of Paradkar et al. (2015), who concluded that alliances with partners are an important asset and leveraging available resources to attract alliance partners can provide firms access to necessary complementary resources. In the context of our study, such partners are in the surgical team in hospitals. Hence, creating such a network with surgeons to understand their current and future needs can be considered as proactive market orientation (Möller et al., 2008), which can be achieved by working closely with lead users (Narver et al., 2004), e.g., surgeons willing to experiment. As surgeons engage in the co-creation process over multiple surgical procedures, they become more confident of which information to share, how to plan better with the anatomical model, and how to conduct the surgeries. Indeed, relationship building, communication and customer knowledge improvement has been identified by Ballantye and Varey (2006) as the activities that need to be considered to enable exchanges and value in use.

The relevant proposition is as follows:

> ***P1****: Exploitative capabilities of healthcare 3DP service providers and ambidextrous (both explorative and exploitative capabilities) of the surgical team help in the co-creation process of using 3DP in surgeries*

Our analysis of commonality and differences between the integrated healthcare 3DP service providers and implant developers also lead to interesting insights. The set of unique differentiators for integrated healthcare 3DP service providers with respect to implant developers lie in their value propositions in terms of providing knowledge, expertise and insights, improved training for surgeons and improved communication with patients which are supported by providing teaching and learning tools for the surgeons. Thus, apart from developing anatomical model, surgical tools and implants, the integrated healthcare 3DP service providers facilitate valuable knowledge, expertise and training to the surgical teams, which translates into improved communication with patients. This results in higher absorptive capacity for the surgical team to adopt 3D printing. An implant developer working on individual surgical cases and designing and developing implants may not have opportunity to pass on valuable knowledge on a continuous basis which can facilitate 3DP adoption by hospitals unless they work on a significant number of surgical cases.

Higher levels of absorptive capacity can result in generating benefits from ambidextrous capabilities of the surgical team as higher levels of absorptive capacity allow a firm to fully capture the benefits resulting from ambidexterity in technology sourcing (Rothaermel and Alexandre, 2009). External sources may also help organisations not only to explore new knowledge but also to have the capability to transform and exploit it. External sources affect the entire learning process of absorptive capacity: exploration learning, transformation learning and exploitation learning (Ferreras-Méndez et al., 2016).

This leads to our proposition 2

> ***P2:*** *By providing knowledge, expertise, insights, and training to the surgical teams, integrated healthcare 3DP service providers are better suited to improve the absorptive capacity of hospitals to adopt 3D printing than specialised implant developers.*

5.2 Contribution to literature

There are recent calls to conduct business model research that is more time-sensitive and contextualized (Foss and Saebi, 2017). While Holzman et al. (2020) analysed business models of a larger sample of 3DP service providers, it is unclear whether their sample included any healthcare 3DP service providers. As explained before, healthcare 3DP service providers needed to be studied separately compared to industry or consumer oriented 3DP service providers. Hence, ours is possibly the first study on business models of healthcare 3DP service providers. Moreover, in the context of healthcare 3DP, it was important for us to study the co-creation process and the resources and capabilities needed to generate value through the co-creation process. We add to the body of co-creation literature (Ramaswamy and Ozcan, 2018) by demonstrating that exploitative capabilities of healthcare 3DP service providers and both explorative and exploitative capabilities of users, i.e, surgeons are needed for the partners to engage in the co-creation process, thereby creating value. We also identify how different types of healthcare 3DP service providers differ in terms of their role in adoption of 3DP by hospitals.

5.3 Managerial implications

Our findings help hospital administrators and surgeons to understand the value they can obtain by using the services of healthcare 3DP service providers and the resources and the capabilities they will need to engage in the co-creation process to create value. The findings help the service providers to identify the resources and capabilities they will need to create value. There is also a need for the service providers to clearly demonstrate the value they provide by collecting relevant data from the hospitals during the co-creation process and from the procedures.

The results bring to spotlight that the service providers have limited differentiation with their competitors as most hospitals are in the initial phases of adoption of 3D printing, providing enough opportunities for the service providers to grow their businesses using their existing offerings. As the markets mature and hospitals adopt the technologies, increasingly more hospitals will have in-house investments and will also like to develop internal capabilities. However, as discussed earlier, finding the balanced point such that expensive time is not devoted on activities that could have been performed by cheaper assets remains to be explored. Due to its relative novelty, adoption of 3DP should be viewed as a complex phenomenon that may not only be driven by its perceived value, the pressure to gain legitimacy, or fostering reputation. A rational analysis of the true benefits of the technology to the hospital and its patient population should always remain the main concern (Ukobitz and Faullant, 2021). Hence, service providers need to develop dynamic capabilities to further develop innovative services which will help them to differentiate themselves from competitors and create performance driven unique business models with the hospitals. There are also opportunities for service providers with differentiated innovative services, focussing on the process of surgical planning and rehearsal for complex surgeries with close-to-reality multi-material models so that the actual surgery can be simulated with high precision.

6. Conclusion

Our findings show that as hospitals are in the early phases in adoption of 3DP for surgeries, 3DP service providers are utilising their exploitative capabilities while the surgical team are demonstrating both explorative and exploitative capabilities to engage in the co-creation process and create value.

Ours is possibly the earliest study on business models of healthcare 3DP service providers. We also contribute to the co-creation literature 1) by identifying the resources and capabilities needed both by the service providers and the surgical team, 2) how exploitative capabilities of healthcare 3DP service providers and both explorative and exploitative capabilities of users, i.e., are needed for the co-creation process to create value and 3) by highlighting the role of knowledge transfer for service providers in improving the absorptive capacity of the surgical team.

6.1 Opportunities for future research

As more hospitals adopt 3DP and also improve their maturity in adoption over a large number of different types of surgical procedures, healthcare 3DP service providers need to not only choose the right combination of resources and the most efficient transactions, they must be able to renew their distinctiveness as competition threatens, through the constant development and nurturing of dynamic capabilities (Ferreira et al., 2020) and improve organisational agility (Teece et al., 2016) as they face uncertainty related to regulation and hospital's desire to develop capabilities in-house. They must be able to redefine their business model in accordance with the strategy and the contingencies they face (DaSilva and Trkman, 2014). Hence, future research should explore how such dynamic capabilities can be developed and their impact on the competitive advantage and performance of healthcare 3DP service providers. Such studies can include service providers in different stages of growth and varying experience so that the role of dynamic capabilities and ambidexterity can be studied considering those contingencies. Moreover, such dynamic capabilities can be observed at individual (entrepreneur, design engineers), firm level and at the network level (Rothaermel and Hess, 2007) with a network of clinical teams in hospitals.

It is important to note that in this study, we did not have opportunity to interact with patients or patients' family members. Hence, the value derived by patients was only captured from the perspective and recounting of surgeons. Future studies should attempt to interact with patients or patients' family members directly to capture the value they got when undergoing surgeries, which used 3D printed anatomical models, surgical guides and/or implants.

As more innovative healthcare 3DP service providers including specialised medical device and equipment manufacturers and 3D bio-printing service providers enter the market, there are opportunities to conduct detailed evaluation of different business models of healthcare 3DP service providers like Holzman et al. (2020). There are also opportunities for in-depth study of the co-creation process involving service providers and surgeons like that conducted by Perks et al. (2012) for radical service innovation in the auto insurance industry. Such studies should analyse customer co-creation based on four dimensions of communication – frequency, direction, modality, and content (Gustafsson et al., 2012). Moreover, design in the context of service innovation is less understood (Candi, 2016). Hence, studies on co-creation in healthcare 3DP service innovation should also consider role of design excellence both for the physical models, surgical guides, and implants as well as designing the entire experience for the surgeons and the patients.

Some 3DP service providers offer services across different manufacturing industries along with healthcare. It will be worthwhile to understand the role of resources and capabilities needed for co-creation and how they are orchestrated to create value for customers across industries. Further research can examine the extent to which the experience of working across industries for 3DP applications facilitate generation and transfer of new knowledge between designers and engineers, and what impact does it have on deliverables to customers from different industries. Research can also help understand how accessing broader scope of services from a single service provider compared to obtaining specialised services from multiple service providers might impact performance outcomes for hospitals and patients.

Organisations can engage in deep learning, drawing on knowledge from one or few organisations or broad learning from multiple organisations (Ferreras-Méndez et al., 2016). In our research, we did not have opportunity to analyse extent of knowledge sharing between service providers and hospitals considering the hospital's stage of absorptive capacity accumulation. When an organisation's objective is to retain newly assimilated knowledge and use it for later application, Ferreras-Méndez et al., 2016 found that organisations should develop sustained collaborations with external sources rather than relationships with a broad number of collaborators. But, at the exploratory stage of learning, it will be beneficial to engage with multiple external collaborators. It will be worthwhile to test the impact of broader collaboration with multiple specialised healthcare 3DP service providers at exploratory phase and deeper collaboration with integrated healthcare 3DP service providers at transformative phase on hospital efficiency and clinical outcomes as hospitals embark and continue their journey to adopt 3D printing, especially because the regulations regarding adopting 3DP in healthcare are still under development.

It is also worthwhile to note that the relationship between the surgeons and the 3DP service providers may motivate the surgeons or young physicians working with them to claim in-depth familiarity with the process and perform the tasks themselves. In that case, an important issue that rises is: will continued collaboration between surgical teams and 3DP service providers be the most effective way of utilizing the time of an expensive asset like the physician. This issue can be investigated further through future research.

The COVID 19 pandemic has put the healthcare systems across the world under severe stress and lot of patients faced long delays in undergoing surgeries because of lack of availability of beds, the medical devices or implants, and excess workload for the surgical team (CoBianchi et al., 2020a). It is an imperative for healthcare and surgical systems to overcome the COVID-19 crisis stronger than before, being inspired by an anti-fragile perspective as outlined by Cobianchi et al. (2020b). 3D Printing can be part of the antifragile capabilities which hospitals can develop in collaboration with healthcare 3D printing service providers to minimise delays in surgeries. Such role of 3D printing in surgeries to improve resilience of healthcare systems should be explored in future research.

References

Aceto, G., Persico, V. and Pescapé, A., 2020. Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0. *Journal of Industrial Information Integration*, 18, p.100129.

Adner, R. and Kapoor, R., 2010. Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, 31(3), pp.306-333.

Amit, R. and Han, X., 2017. Value creation through novel resource configurations in a digitally enabled world. *Strategic Entrepreneurship Journal*, 11(3), pp.228-242.

Amit, R. and Zott, C., 2015. Crafting business architecture: The antecedents of business model design. *Strategic Entrepreneurship Journal*, 9(4), pp.331-350.

Amit, R. and Zott, C., 2012. Creating value through business model innovation, *Sloan Management Review*,

Baden-Fuller, C., Haefliger, S., 2013. Business Models and Technological Innovation. *Long Range Planning*, 46, 419–426.

Ballantyne, D. and Varey, R.J., 2006. Creating value-in-use through marketing interaction: the exchange logic of relating, communicating and knowing. *Marketing theory*, 6(3), pp.335-348.

Balta, M., Valsecchi, R., Papadopoulos, T. and Bourne, D.J., 2021. Digitalization and co-creation of healthcare value: A case study in Occupational Health. *Technological Forecasting and Social Change*, 168, p.120785

Barney, J., 1991. Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), pp.99-120.

Candi, M., 2016. Contributions of design emphasis, design resources and design excellence to market performance in technology-based service innovation. *Technovation*, 55, pp.33-41.

Chaudhuri, A., Rogers, H., Soberg, P. and Pawar, K.S., 2019. The role of service providers in 3DP adoption. *Industrial Management & Data Systems*.

Chaudhuri, A., Naseraldin, H., Søberg, P.V., Kroll, E. and Librus, M., 2020. Should hospitals invest in customised on-demand 3DP for surgeries*?, International Journal of Operations & Production Management.*

Cobianchi, L., Dal Mas, F., Massaro, M., Fugazzola, P., Coccolini, F., Kluger, Y., Leppäniemi, A., Moore, E.E., Sartelli, M., Angelos, P. and Catena, F., 2021. Team dynamics in emergency surgery teams: results from a first international survey. *World Journal of Emergency Surgery*, 16(1), pp.1-13.

Cobianchi, L., Pugliese, L., Peloso, A., Dal Mas, F., & Angelos, P. , 2020a. To a new normal: surgery and COVID-19 during the transition phase. *Annals of surgery*, 272(2), e49.

Cobianchi, L., Dal Mas, F., Peloso, A., Pugliese, L., Massaro, M., Bagnoli, C. and Angelos, P., 2020b. Planning the full recovery phase: an antifragile perspective on surgery after COVID-19. *Annals of Surgery*, 272(6), p.e296.

Dal Mas, F., Tucker, W., Massaro, M. and Bagnoli, C., 2022. Corporate social responsibility in the retail business: A case study. *Corporate Social Responsibility and Environmental Management*, 29(1), pp.223-232.

DaSilva, C.M. and Trkman, P., 2014. Business model: What it is and what it is not. *Long Range Planning*, 47(6), pp.379-389.

Dicuonzo, G., Donofrio, F., Fusco, A. and Shini, M., 2022. Healthcare system: Moving forward with artificial intelligence. *Technovation*, p.102510.

Dominguez Gonzalez, R. V., & Massaroli de Melo, T. (2018). The effects of organization context on knowledge exploration and exploitation. *Journal of Business Research*, 90, 215–225.

Dyer, J.H. and Singh, H., 1998. The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review*, 23(4), pp.660-679.

Doganova, L. and Eyquem-Renault, M., 2009. What do business models do?: Innovation devices in technology entrepreneurship. *Research Policy*, 38(10), pp.1559-1570.

Dyer Jr, W.G. and Wilkins, A.L., 1991. Better stories, not better constructs, to generate better theory: A rejoinder to Eisenhardt. *Academy of Management Review*, 16(3), pp.613-619.

Eggert, A., Ulaga, W., Frow, P. and Payne, A., 2018. Conceptualizing and communicating value in business markets: From value in exchange to value in use. *Industrial Marketing Management*, 69, pp.80-90.

Ferreira, J., Coelho, A. and Moutinho, L., 2020. Dynamic capabilities, creativity and innovation capability and their impact on competitive advantage and firm performance: The moderating role of entrepreneurial orientation. *Technovation*, 92, p.102061

Ferreras-Méndez, J.L., Fernández-Mesa, A. and Alegre, J., 2016. The relationship between knowledge search strategies and absorptive capacity: A deeper look. *Technovation*, 54, pp.48-61.

Foss, N.J. and Saebi, T., 2017. Fifteen years of research on business model innovation: How far have we come, and where should we go?. *Journal of Management*, 43(1), pp.200-227.

Frank, A.G., Mendes, G.H.S., Ayala, N.F. and Ghezzi, A., 2019. Servitization and industry 4.0 convergence in the digital transformation of product firms: a business model innovation Perspective. *Technological Forecasting and Social Change*, 141, 341-351.

Frow, P., McColl-Kennedy, J.R. and Payne, A., 2016. Co-creation practices: Their role in shaping a health care ecosystem. *Industrial Marketing Management*, 56, pp.24-39.

García-Muiña, F.E. and Navas-López, J.E., 2007. Explaining and measuring success in new business: The effect of technological capabilities on firm results. *Technovation*, 27(1-2), pp.30-46.

Goldstein, S.M., Johnston, R., Duffy, J. and Rao, J., 2002. The service concept: the missing link in service design research?. *Journal of Operations Management*, 20(2), pp.121-134.

Gustafsson, A., Kristensson, P. and Witell, L., 2012. Customer co-creation in service innovation: a matter of communication? *Journal of Service Management,* 23(3), 311-327.

Holzmann, P., Breitenecker, R.J., Schwarz, E.J. and Gregori, P., 2020. Business model design for novel technologies in nascent industries: An investigation of 3DP service providers. *Technological Forecasting and Social Change*, 159, p.120-193.

Holzmann, P., Breitenecker, R.J., Soomro, A.A., Schwarz, E.J., 2017. User entrepreneur business models in 3DP. *Journal of Manufacturing Technology Management*, 28, 75-94.

Hervas-Oliver, J.L. and Sempere-Ripoll, F., 2015. Disentangling the influence of technological process and product innovations. *Journal of Business Research,* 68(1), pp.109-118.

Hwang, J. and Christensen, C.M., 2008. Disruptive innovation in health care delivery: a framework for business-model innovation. *Health affairs*, 27(5), pp.1329-1335.

Kraus, S., Schiavone, F., Pluzhnikova, A. and Invernizzi, A.C., 2021. Digital transformation in healthcare: Analyzing the current state-of-research. *Journal of Business Research*, 123, pp.557-567.

Lepore, D., Dolui, K., Tomashchuk, O., Shim, H., Puri, C., Li, Y., Chen, N. and Spigarelli, F., 2022. Interdisciplinary research unlocking innovative solutions in healthcare. *Technovation*, p.102511.

Levinthal, D.A. and March, J.G., 1993. The myopia of learning. *Strategic Management Journal*, 14(S2), pp.95-112.

March, J.G., 1991. Exploration and exploitation in organizational learning. *Organization science*, 2(1), pp.71-87.

Maglio, P.P. and Spohrer, J., 2008. Fundamentals of service science. *Journal of the Academy of Marketing Science*, 36(1), pp.18-20.

Mayring, P., 2004. Qualitative content analysis. A companion to qualitative research, 1(2), pp.159-176.

Möller, K., Rajala, R. and Westerlund, M., 2008. Service innovation myopia? A new recipe for client-provider value creation. *California management review*, 50(3), pp.31-48.

Narver, J.C., Slater, S.F. and MacLachlan, D.L., 2004. Responsive and proactive market orientation and new-product success. *Journal of Product Innovation Management*, 21(5), pp.334-347.

Osei-Frimpong, K., Wilson, A. and Owusu-Frimpong, N., 2015. Service experiences and dyadic value co-creation in healthcare service delivery: a CIT approach. *Journal of Service Theory and Practice*, 25(4), pp. 443-462.

Osterwalder, A. Pigneur, Y., Bernarda, G., Smith, A. and Papadakos, T. (2014), Value proposition design, Strategyzer series, Wiley, New Jersey.

Paradkar, A., Knight, J. and Hansen, P., 2015. Innovation in start-ups: Ideas filling the void or ideas devoid of resources and capabilities? *Technovation*, 41, pp.1-10.

Parasuraman, A., Berry, L.L. and Zeithaml, V.A., 1991. Understanding customer expectations of service. *Sloan Management Review,* 32(3), pp.39-48.

Perks, H., Gruber, T. and Edvardsson, B., 2012. Co‐creation in radical service innovation: a systematic analysis of microlevel processes. *Journal of Product Innovation management*, 29(6), pp.935-951.

Porter, M.E. and Lee, T.H., 2013. The strategy that will fix health care. *Harvard Business Review*, 91(12), pp.24-24.

Prahalad, C. K., & Ramaswamy, V. 2004. Co-creating unique value with customers. *Strategy and Leadership,* 32(3), 4-9.

Ramaswamy, V. and Ozcan, K., 2018. What is co-creation? An interactional creation framework and its implications for value creation. *Journal of Business Research*, 84(4), 196–205.

Ramola, M., Yadav, V. and Jain, R., 2019. On the adoption of additive manufacturing in healthcare: a literature review. *Journal of Manufacturing Technology Management*, 30(1), 48-69.

Rayna, T., Striukova, L., Darlington, J., 2015. Co-creation and user innovation: the role of online 3DP platforms. *Journal of Engineering and Technology Management*. 37, 90-102.

Rogers, H., Baricz, N. and Pawar, K.S., 2016. 3D Printing services: classification, supply chain implications and research agenda. *International Journal of Physical Distribution & Logistics Management*, 46(10), pp. 886-907.

Rothaermel, F.T. and Hess, A.M., 2007. Building dynamic capabilities: Innovation driven by individual-, firm-, and network-level effects. *Organization science,* 18(6), pp.898-921.

Rothaermel, F.T. and Alexandre, M.T., 2009. Ambidexterity in technology sourcing: The moderating role of absorptive capacity. *Organization science*, 20(4), pp.759-780.

Schiavone, F., Mancini, D., Leone, D. and Lavorato, D., 2021. Digital business models and ridesharing for value co-creation in healthcare: A multi-stakeholder ecosystem analysis. *Technological Forecasting and Social Change*, 166, p.120647

Secundo, G., Toma, A., Schiuma, G. and Passiante, G. , 2019. Knowledge transfer in open innovation: A classification framework for healthcare ecosystems. *Business Process Management Journal*, 25(1), pp. 144–163.

Søberg, P.V. and Chaudhuri, A., 2018. Technical knowledge creation: Enabling tacit knowledge use. *Knowledge and Process Management*, 25(2), pp.88-96.

Solis-Molina, M., Hernandez-Espallardo, M., & Rodriguez-Orejuela, A. (2018). Performance implications of organizational ambidexterity versus specialization in exploitation or exploration: The role of absorptive capacity. *Journal of Business Research*, 91, 181–194.

Teece, D.J., 2000. Strategies for managing knowledge assets: the role of firm structure and industrial context. *Long Range Planning*, 33(1), pp.35-54.

Teece, D., Peteraf, M. and Leih, S., 2016. Dynamic capabilities and organizational agility: Risk, uncertainty, and strategy in the innovation economy. *California Management Review*, 58(4), pp.13-35.

Teece, D.J., 2010. Business models, business strategy and innovation. *Long Range Planning* 43, 172–194.

Ukobitz, D.V. and Faullant, R., 2021. The relative impact of isomorphic pressures on the adoption of radical technology: Evidence from 3D printing. *Technovation*, p.102418.

Vargo, S.L. and Lusch, R.F., 2004. The four service marketing myths: remnants of a goods-based, manufacturing model. Journal of Service Research, 6(4), pp.324-335.

Vargo, S.L. and Lusch, R.F., 2011. It's all B2B… and beyond: Toward a systems perspective of the market. *Industrial Marketing Management*, 40(2), pp.181-187.

Vargo, S.L., Maglio, P.P. and Akaka, M.A., 2008. On value and value co-creation: A service systems and service logic perspective. *European Management Journal*, 26(3), pp.145-152.

Veit, D., Clemons, E., Benlian, A., Buxmann, P., Hess, T., Kundisch, D., Leimeister, J.M., Loos, P. and Spann, M., 2014. Business models. *Business & Information Systems Engineering*, 6(1), pp.45-53.

Voss, C., Tsikriktsis, N. and Frohlich, M., 2002. Case research in operations Management. *International Journal of Operations & Production Management*, 22(2), pp. 195-219

Yin, Robert K., 2014. Case Study Research Design and Methods (5th ed.). Thousand Oaks, CA.

Table 1: Interviews conducted and additional data collected

Organisation	**Country**	**Designation of persons interviewed**	**Number of interviews (duration in minutes)**	**Additional data collected**
3DLifePrints	United Kingdom	Co-founder	1(42)	Material from website, presentation by co-founder in a webinar
Anatomiz3D	India	Co-founder	2 (55, 46)	Material from website, presentation by co-founder in an industry conference, LinkedIn posts
Axial3D	United Kingdom	Founder	2 (47, 36)	Material and case studies from website, news articles, LinkedIn posts
Bone3D	France	Founder	2 (39, 22)	
Kanfit3D	Israel	Co-founder	2(51, 46)	Material from website, LinkedIn post
Lucid Implants	India	Co-founder	1 (56)	Material from website
Synergy3DMed	Israel	CEO and founder	2(63 ,54)	Material from website, LinkedIn post, presentation by the CEO and founder in a conference
Cardiff Metropolitan University	United Kingdom	Professor of Healthcare applications of Design	1 (29)	Academic papers

King George Medical University (KGMU)	India	Professor- Oral and Maxillofacial surgery	1 (24)	Material about research project conducted by the Professor
All India Institute of Medical Sciences (AIIMS)	India	Surgeon, who completed Phd on 3DP applications	1 (33)	
Galilee Medical Center	Israel	Head of Galilee College of Dental Sciences- Prof and Chair of Oral and Maxillofacial surgery	2 (35, 23)	LinkedIn posts

Table 2: Interview questions

Area of investigation	Interview questions for service providers	Reference
Value Proposition	What are the key value propositions of your company?	Osterwalder et al., 2014; Holzmann et al., 2020
	How do you communicate value to the doctors and the hospital administrators?	Eggert et al., 2018
Value creation	How did you identify the value creation opportunities?	Osterwalder et al., 2014; Holzmann et al., 2020
	How did your organisation design the service delivery process to create value for customers?	Goldstein et al., 2002
Co-creation	With examples, can you explain how designers in your company co-create value with surgeons? What information do they need from surgeons and what information do they provide to them? How does this collaborative process work? Are there any challenges associated with it?	Möller et al., 2008; Rayna et al., 2015; Ramaswamy and Ozcan, 2018; Balta et al., 2021
Resources and Capabilities	What resources does your organisation need to co-create value with customers?	Vargo et al., 2008
	What capabilities were needed by your organisation to create value?	Vargo and Lusch, 2004
Value capture	What are the revenue models you follow for the services you provide?	Osterwalder et al., 2014; Holzmann et al., 2020
Area of investigation	**Interview questions for surgeons**	**Reference**
Background	What are the main applications you use 3D Printing for?	No specific reference
Customer Expectations	What are your expectations from 3D printing service providers?	Parasuraman et al., 1991
Co-creation	How do you collaborate with service providers? To what extent do you need to provide them inputs? How does this collaborative process work? Are there any challenges associated with it?	Möller et al., 2008; Rayna et al., 2015; Ramaswamy and Ozcan, 2018; Balta et al., 2021
Value in use	What value do you think the 3D printing service provide to the surgical team and patients?	Eggert et al., 2018; Holzmann et al., 2020

Table 3: Value proposition by the service providers

Categories	**Value proposition by service providers**	**% of service providers interviewed considering it**
Patient benefits	Shorter patient recovery time*	**100**
	Other clinical benefits such reduced blood loss, reduced anaesthesia usage	43
Benefits to surgeons/hospitals	Precise and faster surgical planning*	**100**
	Catering to the needs and requirements of surgeons and providing customised solutions*	**100**
	Reduced surgery time and better operation theatre utilisation*	**100**
	Faster delivery lead time*	**71**
	Access to knowledge, expertise, and insights*	**57**
	Supporting certification and meeting regulatory requirements*	**57**
	Cost effectiveness*	**57**
	Improved communication with patients*	**43**
	Improved training of surgeons for complex surgeries*	**43**
	Providing opportunities to innovate	14
	Improved tactile feedback for surgeons	14
Other miscellaneous benefits to hospitals	Providing revenue generating opportunity for hospitals	14
	Improved reputation for hospitals	29
	Legal liability protection for hospitals	29

**Included in the analysis as demonstrated by higher percentage of service providers*

Table 4: Value creation by the service providers

Value creation by integrated healthcare 3DP service providers	**Percentage of service providers interviewed creating this value**
Integrated workflow	86*
Providing anatomical models with specific or multiple materials	86*
Design and production of 3D printed implants	86*
Facilitating printing within hospitals or providing printing support	71*
Simulation and outcome analysis	43
Deployment of systems remotely using cloud platform	43
Providing an ordering catalogue/system	29
Providing teaching and learning tools	29
Delivering services across different modes	29
Analysing Total Cost of ownership from patient's perspective	14

**Included in the analysis as demonstrated by higher percentage of service providers*

Table 5: Value capture by the service providers

Value capture by service providers	**Percentage of service providers interviewed capturing value by this means**
Contract from setting up of Point of Care centre in hospitals	43
Solution cost based on project /part	29
Monthly or annual fee from hospitals	14
Pricing for long term adoption of 3DP	14
Model-as-a-service	14

Table 6: Resources and capabilities needed by the service providers and their characteristics

Resources of service providers	**Value**	**Rarity**	**Substitutability**	**Imitability**
Skilled manpower	**High**	**Low**	**Low**	**High**
Quality Management System	**High**	**Low**	**Low**	**High**
Proprietary software for design and communication	**High**	**High**	**Medium**	**Medium**
Library of complex cases	**Medium**	**Medium**	**Medium**	**High**
in-house 3DP facility	**Value**	**Low**	**Medium**	**High**
Capabilities of service providers				
Understanding of both engineering design and medical needs	**High**	**Medium**	**Low**	**High**
Understanding of the entire workflow	**High**	**Low**	**Low**	**High**
Understanding of materials and manufacturing process	**High**	**Low**	**Low**	**High**
Ability to use the design software	**Medium**	**Low**	**Low**	**High**
Ability to build a network involving surgeons	**High**	**Medium**	**Low**	**Medium**

Table 7: Resource and capabilities needed by the hospitals and surgeons and their characteristics

Resources at hospitals	**Value**	**Rarity**	**Substitutability**	**Imitability**
PACS system to share data and data sharing agreement	**High**	**Low**	**Low**	**High**
Knowledge of which information to share with the service providers	**Medium**	**Low**	**Low**	**High**
Clinical knowledge	**High**	**Low**	**Low**	**High**
Capabilities of surgical team				
Ability to communicate effectively within the surgical team	**High**	**Low**	**Low**	**High**
Ability to conduct surgical planning	**High**	**Low**	**Low**	**High**
Ability to explore alternatives when other solutions do not exist	**High**	**Low**	**Low**	**High**
Ability to segment and design, if needed	**Medium**	**High**	**High**	**Medium**
Ability to rehearse the surgery using the model/simulators	**High**	**Medium**	**Medium**	**Medium**

Table 8: Resources, capabilities, and value creating activities for the co-creation process

Co-creation process	**Service provider resources**	**Hospital/surgical team resources**	**Service provider capabilities**	**Surgical team capabilities**	**Service provider value-creating activities**
The service provider understanding requirements from surgeons	Understanding of clinical needs	1.PACS system to share data with data sharing agreement 2.Knowledge of which information to share	Ability to explain limitations and possibilities of 3DP	Surgeon's ability to explore alternatives	Providing an ordering catalogue/system
Segmentation and development of the anatomical model	1.Skilled manpower 2.Software for design and communication 3. Library of complex cases		Ability to segment and design	Ability to segment and design, if needed	Providing anatomical models with specific or multiple materials
Surgical planning using the anatomical model				1.Ability to plan with minimal printing, if needed 2.Communicate effectively within the team	Providing anatomical models with specific or multiple materials
Surgical team setting up requirements for surgical				Surgical planning	

guides and implants					
Service provider coming up with initial design of guides and implants	1.Skilled manpower 2.Software for design and communication 3.Library of complex cases		Understanding both engineering design and clinical needs		
Surgeon providing feedback to the service provider				Communicate effectively within the team	
Design of guides and implants		Knowledge of which information to share	Understanding of materials and manufacturing process		Design and production of 3D printed implants
Practising the surgery and conducting simulation				Ability to rehearse the surgery using the model/simulators	Simulation and outcome analysis
Joint analysis of risks and complications			Understanding both engineering design and clinical needs	Communicate effectively within the team	Simulation and outcome analysis
3DP of the guides and implants	1.In-house 3DP facility 2.Quality management system		Understanding the entire workflow		Facilitating printing within hospitals or providing printing support

Using the anatomical model, guides and implants during the surgery	Quality management system			Communicate effectively within the team	

Table 9: Types of capabilities of service providers and surgical team with supporting evidence (representative quotes)

Type of capabilities	**Individual capability dimensions**	**Examples of evidence from data to support these assertions**
Exploitative: 3DP service providers	Understanding of both engineering design and medical needs	*"All people in Bone3D have attended engineering school and have also encountered medical school at least once in their lives. So when they are interacting with surgeons, they understand what he or she is talking about without asking too many questions."*- Founder of Bone3D
	Understanding of the entire workflow	*"It also requires understanding how this can be well integrated in a hospital, involving a number of stakeholders, such as hospital management, radiologists, clinicians, IT, Billing,"*- Co-founder of Anatomiz3D
	Understanding of materials and manufacturing process	*"Understanding how the manufacturing process works is important. Design engineer should also have knowledge of materials and the equipment, which works best for the application.* - co-founder at Kanfit3D
	Ability to use the design software	"*Our team needs to have expertise in reading DICOM data, understand what is a soft tissue , how a hard bone, thin bone looks like and must be able to use the segmentation tools"*- Co-founder of Anatomiz 3D
	Ability to build a network involving surgeons	*"need to get the connections and understand the market very well.*"- Co-founder of Kanfit3D
Exploitative: surgical team	Ability to communicate effectively within the surgical team	"*We surely have to communicate within the surgical team so that everybody is clear what we are doing and why. Now we can have much detailed conversation before the surgery and avoid surprises at the operating table. This is also a good way to train trainees and juniors*.- Surgeon at Galilee Medical Centre
	Ability to conduct surgical planning	*"We have been doing surgical planning all these years using CT and MRI files and by using our own judgment and experience. We surely know how to plan for surgeries but use of 3DP for anatomical models and simulators make our job easier and we can discuss specific details with our team members."*- surgeon at KGMU
Explorative: surgical team	Ability to explore alternatives when	*"This patient was initially rejected for surgery considering the complications associated with a*

	other solutions do not exist	*procedure of this level. But the surgical team had heard of 3DP and reached out to us to provide the infant with a last chance of survival*."- Co-founder of Anatomiz 3D, validated with other secondary material which referenced the surgeons
	Ability to rehearse the surgeries using the models/simulators	*"We did not have options to rehearse surgeries before. Hence, we had to learn how to do it. Once you get used to it, it gives you lot of confidence and make your life much easier."*- Surgeon at Galilee Medical Centre
	Ability to segment and design, if needed	*"I was involved in the whole process. I didn't design but I changed the design and finalised it. I gave inputs on where the stresses will be there, where the forces will be acting, which will suit the patient's need, where should I be able to place the screw etc. Everyone's role is important. The engineer should surely be involved. But, I did the design myself initially and learnt CAD myself."*- Maxillofacial surgeon in India

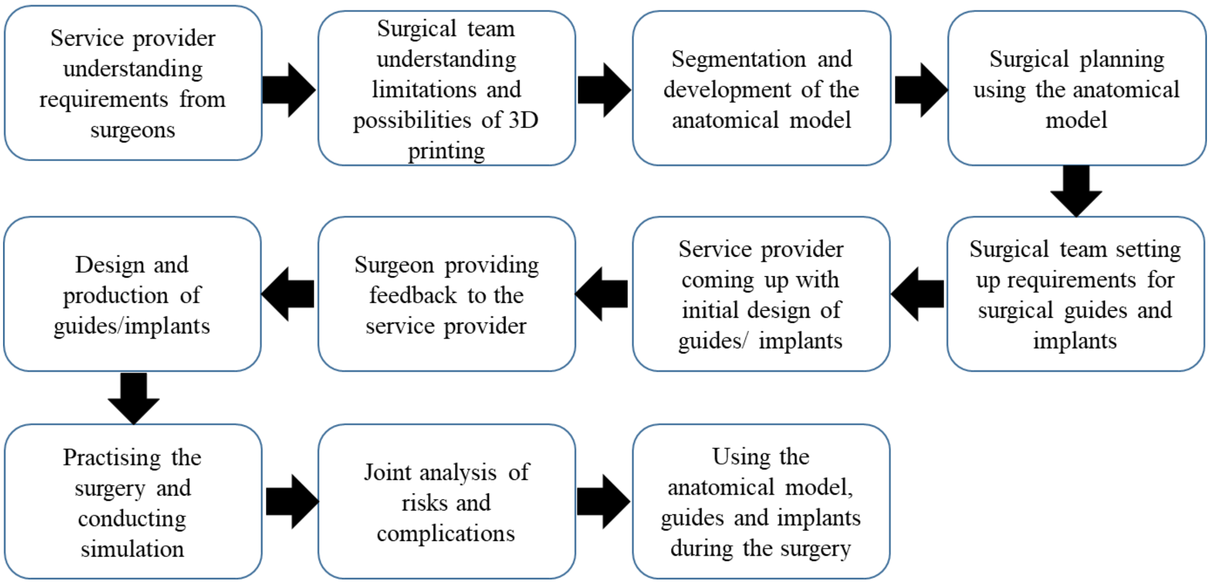

Figure 1: The co-creation process for surgical applications of 3D printing

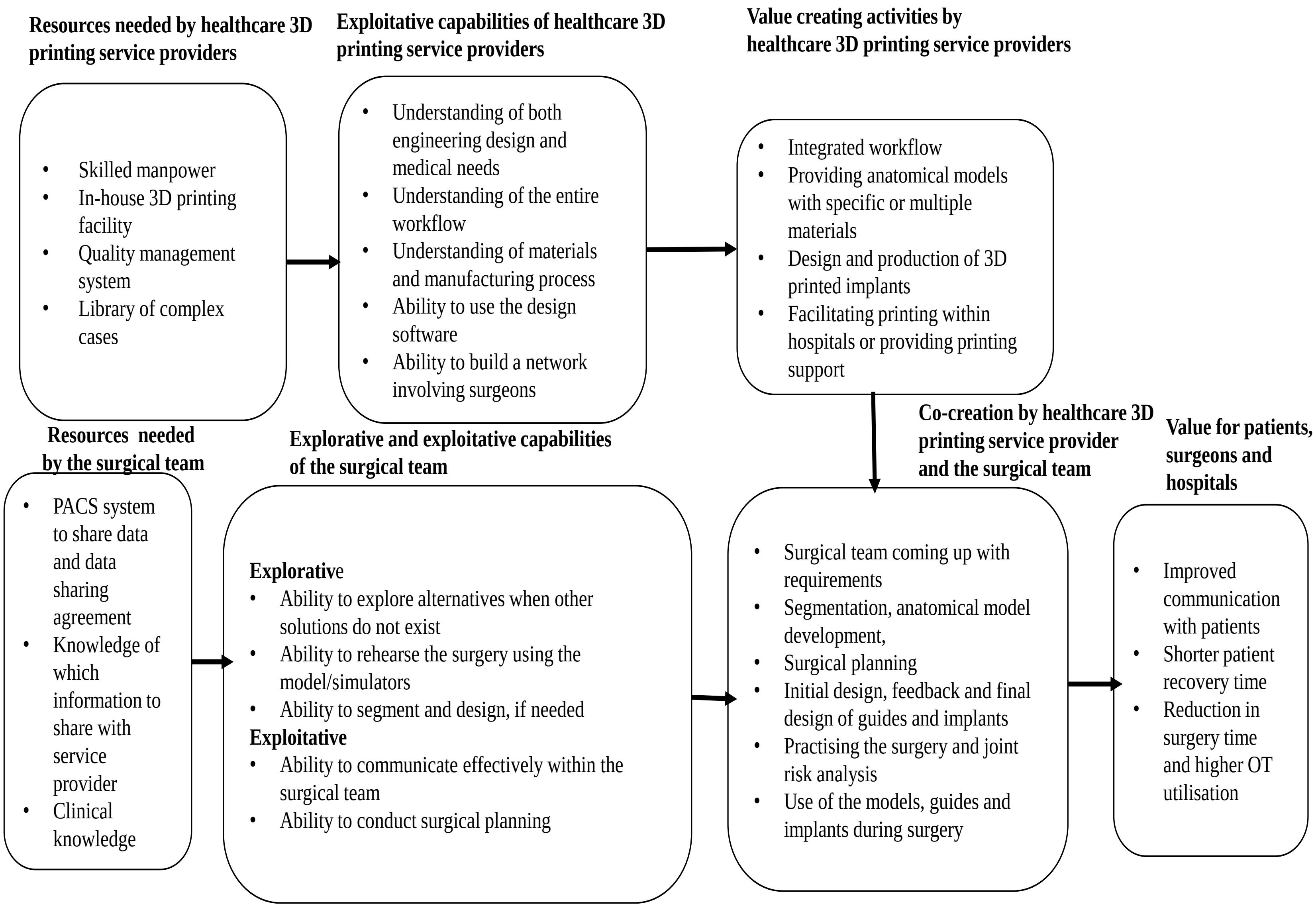

Figure 2 - Resources and capabilities needed for co-creation.