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Case Study

How deep learning influences workflows and roles in virtual surgical planning

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Abstract

Background Deep learning (DL) has the potential to transform surgical practice, altering workflows and changing the roles of practitioners involved. However, studies have shown that introducing such change requires user acceptance. Following the development and presentation of a visual prototype for planning facial surgery interventions, the project aimed to understand the utility of DL, the implied workflow and role changes it would entail, and the potential barriers to its adoption in practice.

Method This paper presents a multi-year case study providing insights from developing and introducing a visual prototype. The prototype was co-developed by facial surgeons, DL experts, and business process engineers. The study uses project data involving semi-structured interviews, workgroup results, and feedback from an external practitioner audience exposed to the prototype regarding their views on adopting DL tools in practice.

Findings The surgeons attested a high utility to the application. However, the data also highlights a perceived need to remain in control, be able to intervene, and override surgical workflows in short intervals. Longer intervals without opportunities to intervene were seen with skepticism, suggesting that the practitioners' acceptance of DL requires a carefully designed workflow in which humans can still take control of events.

Conclusion Deep learning can improve and accelerate facial surgery intervention planning. Models from the business and management literature partially explain the acceptance of new technologies. Perceived ease of use seems less relevant than the perceived usefulness of new technology. Involving algorithms in clinical decision-making will change workflows and professional identities.

Keywords Facial surgery · Workflows · Decision-making · Technology acceptance · Change · Artificial intelligence · Deep learning

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1 Introduction

Artificial intelligence (AI) has recently gained remarkable momentum among practitioners and academics [13]. As an umbrella term for various intelligence applications, AI has a subset called Deep Learning (DL). It is based on multilayer artificial neural networks built on Machine Learning (ML) concepts [28]. As a general-purpose technology, DL is well suited to handle large data volumes or simultaneously process many variables. These capabilities are poised to substantially benefit medical research and clinical practice [32]. Experts foresee a significant impact on healthcare systems [54], although they anticipate no replacement of humans soon [46].

While DL capabilities continuously evolve, the implication for organization and roles still need to be fully understood. The emerging shift of human reasoning tasks to DL systems is a central aspect of this change. This shift opens up the possibility for new clinical workflows understood as a sequence of work steps, which may form the basis for clinical workflow innovations. Such innovations are poised to deliver new patient services but should go beyond simple automation [15]. However, these workflow changes will only be successful if physicians and healthcare organizations accept them. Studies among physicians indicate positive perceptions of DL [39], but these perceptions are not necessarily paralleled in daily clinical practice. Acceptance will likely remain a concern as DL will increasingly shift judgment and reasoning tasks from humans to DL systems [29].

With many current Virtual Surgical Planning (VSP) tools employing Computer-Aided Design and Manufacturing concepts (CAD/CAM) (Efanov et al. [20]), this study focuses on the development of a VSP tool for facial surgery interventions involving DL. The expected shift in judgment and reasoning tasks alters the decision model. It also involves changes to organizational and professional logic and impacts human behavior. This paper analyzes a multi-year development of a VSP prototype development for facial surgery (Cranio-maxillofacial, CMF) with high utilization of DL. It aims to illustrate how DL may change clinical workflows and professional roles in surgical planning. Furthermore, it illuminates the relationship between the perceived usefulness of DL and surgeons' behavioral intentions to use the system in clinical practice.

2 Literature

Introducing new computer-based technology to an organization may transform internal systems and change work patterns. These changes interact with the users' values and beliefs and may trigger emotional responses [49], which could affect the acceptance of new technologies like DL. Consequently, to ensure a smooth implementation of DL in the healthcare industry, understanding the factors contributing to physicians' acceptance of novel ideas is important [37]. The extended Technology Acceptance Model (TAM2) [57] describes factors affecting the acceptance of new technologies (see Fig. 1).

While TAM2 helps to explain antecedents of accepting new technologies, it does not explicitly focus on explaining Machine Learning models. Machine learning models are rarely translated into clinical practice. The prevailing research literature takes little account of this either [31]. And there is little academic evidence of clinical or economic impact.

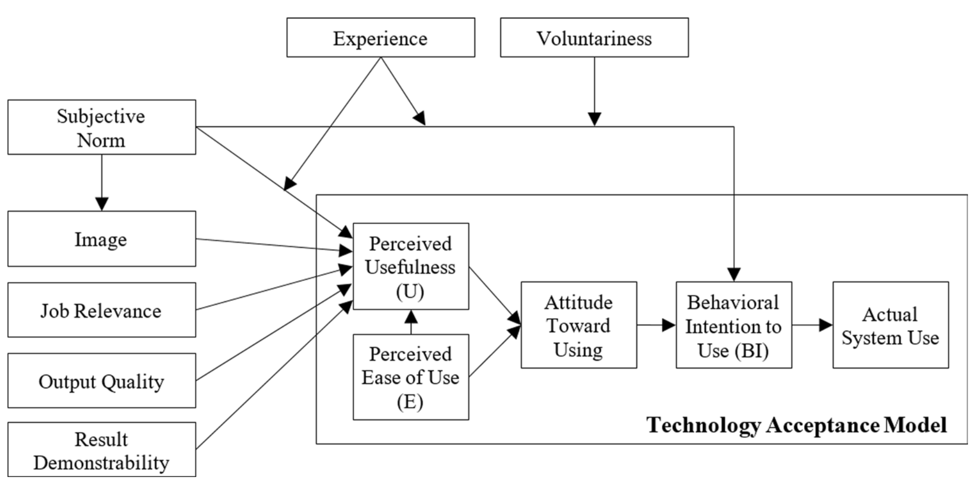

Fig. 1 Extended Technology Acceptance Model (TAM 2)

The translational path remains unclear [40]. In surgical planning, the response to new technologies may go beyond the antecedents of the already extended technology acceptance model TAM2 [57] as it may additionally involve identity work [38], evoked by such DL capabilities as classification, prediction, and decision-making [52] or deductive and inductive reasoning and inference extended by logical rule-based inference [11, 19]. These capabilities enable DL to take over human reasoning tasks like fracture reconstruction or defining fixation areas.

With perceived usefulness and ease of use identified as determinants of the attitude towards using DL in clinical reasoning, this paper highlights the role of both factors, their antecedents, and their consequences embedded in an eclectic developmental framework of the prototype (see Fig. 2). This structured approach allowed the project team to increase attention to detail continuously and helped the developers respond to the requirements highlighted by surgeons. This approach combined different knowledge levels and helped to achieve a common understanding among the parties involved.

As a first step, storyboarding [56] helps combine technological possibilities with user requirements understandable by technicians and medical professionals. More specifically, storyboarding allows developers to better understand clinical practice needs, develop ideas, and suggest possible human–machine interactions to surgeons using visual prototyping [27, 58].

Explaining the adoption of innovation, diffusion of innovation theory [50] suggests that for innovation to be adopted, participants in a social system first need to be aware of them. The decision to adopt the innovation and its initial and continued use and the pace in which this adoption takes place is affected by various factors. The management literature [43] suggests that the rate of adoption tends to be higher when the innovations "(1) have a relative advantage over existing methods, (2) are compatible with existing values, past experiences, and current needs, (3) are simple to understand, (4) can be tried out or played with by potential adopters, and (5) are observable, such that adopters can see the results for themselves" (p. 81). These aspects seem important in explaining the willingness to restructure surgical judgment and reasoning.

Despite user engagement, changes in surgeons' behavior following changes in organizational and professional logic might be subject to resistance. Resistance to Change (RTC) Theory [18] explains how people behave when facing innovations or changes. More recent work [45] expands this model, suggesting the following six sources: "(a) reluctance to lose control, (b) cognitive rigidity, (c) lack of psychological resilience, (d) intolerance to the adjustment period involved in change, (e) preference for low levels of stimulation and novelty, and (f) reluctance to give up old habits" (p. 680). In

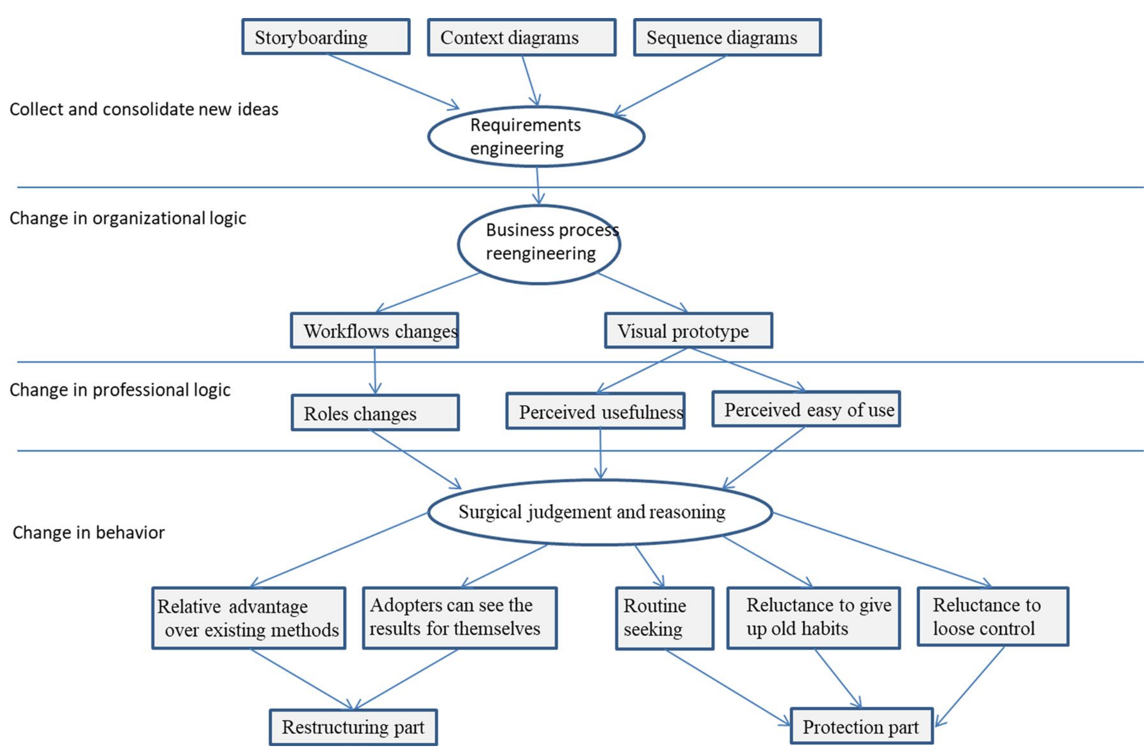

Fig. 2 Overview of the development process

this case study, routine seeking and the reluctance to lose control and give up old habits appeared particularly relevant in explaining practitioners' reservations towards DL tools.

3 Methodology

This case study applies an abductive research strategy. This strategy is considered beneficial for exploring new or emerging phenomena. As shown above, existing management theory can help explain the adoption of DL tools in clinical practice by combining existing works in an eclectic manner. In such a case, an abductive research strategy allows researchers to extend theories based on observations and then test them through further data collection and analysis, helping to build a more comprehensive understanding of the phenomenon, rather developing than testing assumptions [5]. The abductive research process helps to analyze and illustrate workflow changes, clinical judgment processes, and role adaptations following established recommendations for case study research [59] and building or expanding theory [21].

3.1 Case context and description

The case in this paper focuses on surgical intervention planning as a simulation of the subsequent surgery [22]. The case involves three surgical intervention scenarios: trauma, orthognathic, and plastic surgery.

Trauma: CMF reconstruction poses inherent and unique challenges due to the critical importance of restoring speech, swallowing, mastication, and symmetrical facial contour [63]. This scenario aimed to recreate the original situation virtually. This recreation helps surgeons to decide if a reconstruction of this part is possible or if a prosthesis (ex Orbita) is required. In the case of reconstruction, details on drilling holes and implant type have to be proposed by the system.

Orthognathic surgery, understood as the surgical treatment of deformities or malocclusion [12], represents a suitable field to evaluate DL for its potential because standard osteotomy lines are defined, and cephalometric data exist which describe surgically relevant points and lines in faces [55]. There are two possibilities for positioning the mandible and maxilla (upper and lower jaw) with or without splints. The splint-less procedure requires the DL system to ensure the correct tooth position (occlusion), achieved by the precise positioning of the maxilla and mandible and favored by the surgeons.

Plastic surgery is based on orthognathic surgery but places more emphasis on post-operative appearance. This focus requires tension tissue models and a more photorealistic representation of the patient's face and hair, both potential fields for DL systems. Hair visualization is crucial for patients to understand better how they will look after the intervention. Therefore, these requirements were adopted for the face scan.

Visual planning of the surgical intervention in orthognathic and plastic surgery requires facial scans, intraoral dental images, and CT scans or MRIs as a starting point. The system merges these three artifacts into a unified model via landmarks. The surgeon uses this integrated model for planning the procedure as well as for visualization to the patient. The project team used past patient intervention cases to validate the practicality of the solution and worked on different degrees of complexity of patient situations. This collaboration with surgeons, DL developers, and surgical domain experts from medical domain experts resulted in nine DL features shown in Table 1.

Table 1 DL feature list

DL feature	Aim of feature	Based on
Automated bone segmentation	Creating bone segments	Rules and SSM
Statistical shape model (SSM)	Serve as skull reference	CT or MRI scans
Automated landmark detection	Detecting landmarks	Rules and SSM
Automated cephalometric application to patient	Simulation of surgical intervention	Rules, SSM, intra-oral scan and DICOM data
Semi-automated occlusion detection	Support occlusion	Oral scan, upper and low jaw bone segments
Automated trauma parts reconstruct	Initial reconstruction of skull	3D parts recognition algorithm
3D-2D model synchronization	Allow past and future work style	Rendering engine, vectoring
Soft tissue modelling	Fade in–out soft tissue for s	Skin tension model
Simulate results in a post-op view	Visualize post-op face	Face scan and tension model

3.2 Data collection

The data collection is based on archived project data. Case data include critical decisions made during the two-year project and allow comparing the final result with previous workflows. To focus on the results that can be attributed to the DL rather than mere process optimizations, any process optimizations that were not achieved by DL were excluded. This approach ensured that the changes caused by DL can be described and traced. Sources of data collection were semi-structured interviews, workgroup results, and feedback from an external audience during the presentation of the prototype. Project members more closely involved were encouraged to participate in a real-life surgical intervention for direct observation.

3.2.1 Semi-structured interviews

During the project, two working groups were formed: group one consisted of eighteen active surgeons represented by two lead surgeons. The study is based on data from twenty in-depth interviews covering various surgical topics, including surgical examples. The interviews in this group aimed to understand their current workflows and gather their issues and ideas for future workflows in *Trauma, orthognathic and plastic surgery*. For this purpose, the interviews were thematically structured into three scenarios following the guidelines from Bai [7].

The second group consists of DL technicians from various medical fields who were queried to obtain technical possibilities and restrictions. To streamline the discussion, topics are defined within the scenarios. For trauma, the study focused on bone segmentation, detecting fracture lines, identifying fracture parts, and automatic fracture parts repositioning. For dysgnathia, the study focused on applying a standard osteotomy line, splintless surgery (Mandibular/Maxilla), and automatic occlusion detection [1]. A soft tissue tension model was required for plastic surgery and found externally. As a result, an accepted feature list was created, which helped to estimate effort and complexity.

3.2.2 Collect and consolidate workgroup results

As the workgroups continuously gained new insights and refined existing knowledge, a flexible approach was needed to consolidate and share this information. A neutral and illustrative method was required, as medical and technical experts worked together. Storyboarding was seen as a valuable approach for developing the DL prototype. The results of the various workgroups were captured by the business process engineers and continuously incorporated into the storyboards and sequence diagrams. These artifacts were refined until they became stable. Once declared final, they were signed off by the surgeons and handed over to the prototype developers.

3.2.3 Feedback from external audience

The results of this prototype were used to discuss its perception outside the case study team. The goal of the presentation was to determine the commercial feasibility of the prototype. Feedback to the presentation was sought to provide insight into what a commercialized solution should look like to be accepted by the market. For this purpose, two independent surgical institutions were selected: one institute for Orthognathic Surgery and one institute for Plastic Surgery. Both institutes have a long history, possess a vast experience in their field, and are potentially interested in such solutions. Seeking external feedback reduced the bias in development and got an outside perspective.

3.3 Data analysis

The perception of how useful a DL tool is for clinical practice overlaps with the notion of value. While perceived usefulness describes the degree to which individual practitioners believe that utilizing a DL tool would improve their job performance, the idea of value includes a wider set of stakeholders. In this project, the data is used to determine the value of DL for each DL feature for different stakeholders. The evaluation was conducted by the surgeons involved in the project. Qualitative Content Analysis [42] was applied for analysis with categories and rules illustrated below (Table 2).

To further validate the perceived usefulness, the prototype was shown to three external institutes for evaluation at the end of the development phase. The results were compared with the project team. This comparison allowed the evaluation

Table 2 Categories and rules

Category	Rules
Value for patients	- Reduce awkward and inconvenient patient duties - Better understanding of intervention - Show expected surgical intervention result before surgical intervention
Value for surgeons	- Reducing repetitive routing tasks - Reduce memory load - Enhanced support for manual task - Enabling visual intervention (2D/3D enabling)
Saving cost	- Reducing planning time - Reducing surgical intervention time - Reducing operating room time - Reducing material & devices
Increase quality	- Simulation of intervention variants - Compare pre- und post intervention
Reducing risk	- Reducing infection risk by shortening surgical intervention time - Visualization of post-operative results to patients

to be more broadly based. The external members were an institute for orthognathic surgery with three surgeons, a plastic surgery team of an internationally known surgeon in Zurich, and the development manager of a successful software developer for osteotomies in Germany.

To capture the changes in organizational logic, context diagram, storyboards, DL feature descriptions, and sequence diagrams were analyzed. Based on the process parts shifting from humans to DL, it was possible to infer how processes and roles are changing. Surgeons determined four process parts concerning patient role changes and nine concerning surgeons (see Table 3).

Table 3 Process parts and role impact

Process parts and roles changes	Description
Patient role changes	Orthognathic and plastic surgery only
Involvement in surgical decision	Patient and surgeon decide in shared decision model
Eliminating awkward procedures	A dental cast is necessary so that the position of the jaw and the position of the teeth can be matched. The procedures for this are uncomfortable for the patient and should be eliminated
Agreements on aesthetic outcomes	It should be possible to discuss the esthetic aspects with the patient. Since aesthetic aspects may be individual
Additional scans (facial & oral)	The unpleasant procedures of the patient should be replaced by an intraoral scan. Additionally, to provide a post-operative view, facial scans are necessary
Surgeons' role changes	For all surgical workflows
Application of cephalometric rules	The cephalometric data no longer have to be applied manually
Gender conversion proposal	The cephalometric data proposed for correction are applied to the existing facial structures
Automated face type definition (Western, Caucasian etc.)	Facial surgery is based on the existing facial type. This also sets the limits for a correction
Automated landmark detection	The landmarks and their recognition are the prerequisite for the connection of statistical shape model to patient
Automated bone segmentation	Bone segmentation is a prerequisite for cutting lines and fixation zones
Semi-automated occlusion determination	The mandible and maxilla (lower and upper jaw) must be optimally positioned for occlusion. These position needs to be determined bevor the surgical intervention
Cutting guide generation	The generation of cutting guides relieves surgeons from freehand cutting
Drilling guide generation	Calculating the drilling guides sets the holes so that after cutting the implant will pull the bony parts to the correct position
Intervention result visualization	Predicting how the face may look after the intervention helps the surgeon to discuss the intervention with the patient. However, a too detailed prediction is not possible

In a next step, this research focused on changes in organizational logic, professional logic, and human behavior employing three units of analysis.

(a) Surgical workflows were analyzed as a static observation at the beginning of the project as the initial situation and at the end of the project as the target situation. The difference quantified the need for organizational change.
(b) Role changes that would occur from the introduction of the prototype were analyzed. This aspect includes the responsibilities and override options in the prototype.
(c) Feedback and observation from surgical project members. This aspect was extended with feedback from project external surgeons to whom the prototype was presented.

The feature list included both technical capabilities and medical desires. Each of these artifacts was examined for feasibility, effort, and usefulness. Features were evaluated in the context of the overall workflow and concerning future technological developments such as augmented reality or additive manufacturing of drilling jigs, cutting guides, and implants.

3.3.1 Surgical workflow analysis

The application of DL features changed the original workflows. Particular emphasis was placed on analyzing surgeons' options to control and override the redesigned workflows. The new functions also formed a basis for new ways of working. Considerations of how artificial and human capabilities can be combined in new ways, offers greater potential value than simply automating existing processes [15]. The project team followed this guidance and created a DL-agent similar to a human agent. The introduction of DL features as an agent and the application of the agent concept made it possible to redesign the processes. Figure 3 shows a simplified process part of a trauma process.

The process analysis focused on which parts can be substituted by DL features and at which points human control and intervention are necessary in the process chain. The development of the DL features and their introduction as agents changed the process flow and offered different control and override concepts (see Fig. 4).

The process parts and control options changed the process and the role of surgeons but not their responsibilities. The responsibility remains with the surgeons. Therefore, the splitting of the process is paramount and will be analyzed in the case study. This analysis allowed the project team to understand the interaction between surgeons and DL-agents better. Particular emphasis was placed on the process control length. The newly developed DL features also offered new combinations and fully utilized the automation possibilities, as this was an aim of the project. Post-operative simulation may serve as an example.

3.3.2 Role impact analysis

Shifting workflow parts from human to DL agents changes the tasks in the surgical roles. In the cases of orthognathic and plastic surgery, the new function "post-operative simulation" introduces patients as a new, additional agent (see Fig. 5).

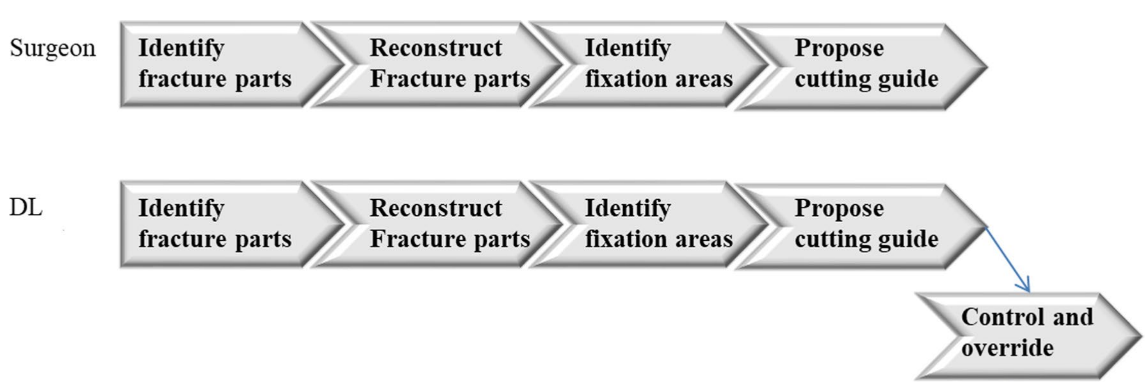

Fig. 3 Simplified trauma process

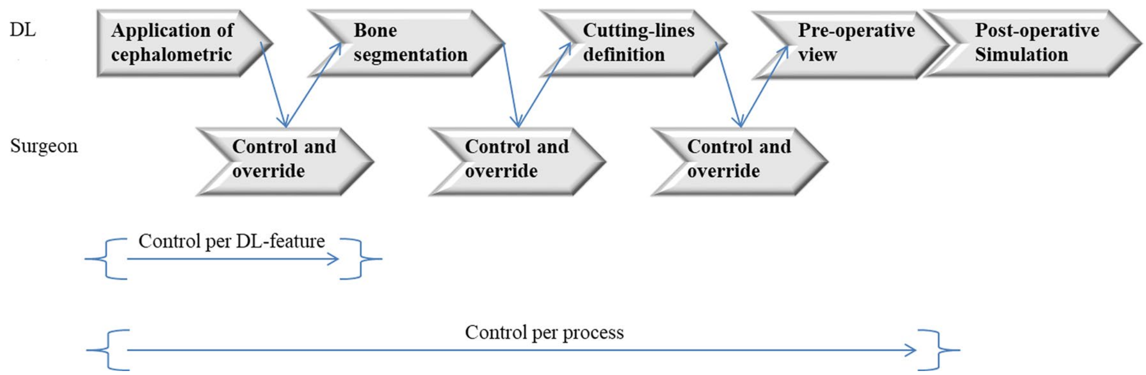

Fig. 4 Control intervals

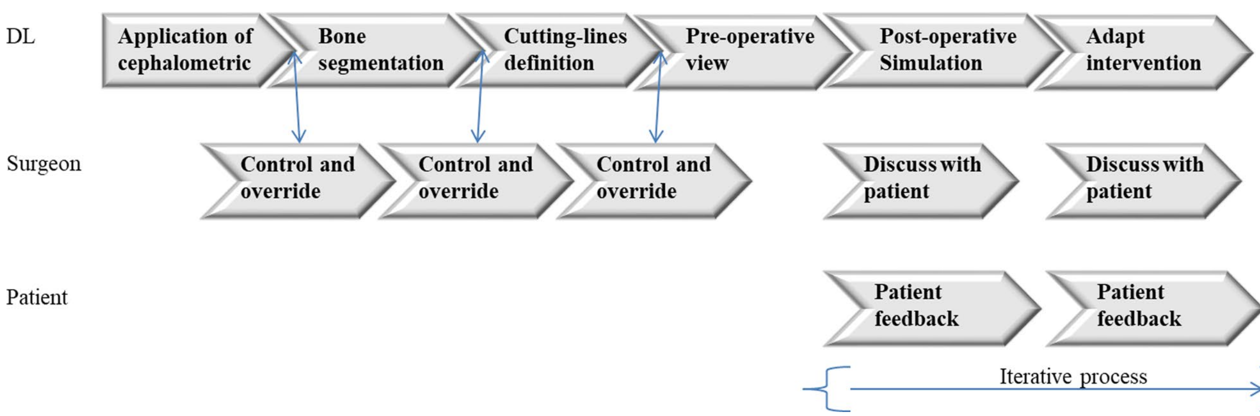

Fig. 5 Patient involvement

3.3.3 Analysis of behavioral intension to use

At the beginning of the project, the surgeons defined their ideas and requirements for the DL system. At the end of the project, the surgeons were asked whether they would use the DL system if it were fully developed based on the visual prototype. This step intended to learn more about the attitude changes during and DL acceptance at the end of the project. Furthermore, the analysis looked into the role of surgeons' degrees of control for DL. Insights on the actual intention to use DL may help innovators and transformational change managers understand potential resistance factors that impede the adoption of DL tools in clinical practice.

4 Results

4.1 Perceived usefulness of deep learning

Over a two-year period, DL developed the ability to address all feature requirements except for detecting nerves, for which the signal in CTs was too weak. The surgeons rated each DL feature on its value at the end of the project, assessing their value for patients, themselves, and other stakeholders (see Table 4). The group had to agree on a rating. The measurement of efficiency gains and cost reductions proved to be case-specific with considerable scatter but was positive in all the cases. The surgeons reported that efficiency gains and cost reductions were highest for the more complex cases. It also appeared that orthognathic and plastic surgery offered greater potential for time and cost savings than trauma surgery. In addition, DL provided the opportunity to engage the patient early by simulating the post-operative condition and involving them in the planning stage.

In the evaluation, the project team did not distinguish between the value of DL for planning and intervention. Therefore, cost reductions or quality increases may occur in one or both places.

Table 4 Value assessed by surgeons per DL feature

Categories per workflow	DL features								
	1	2	3	4	5	6	7	8	9
Trauma surgery									
Value for patients	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Value for surgeons	+ +	+	+	0	n.a	+ +	+ +	0	0
Saving costs	+	0	+	0	n.a	+ +	+ +	0	0
Increase quality	0	0	0	+	n.a	+ +	+	0	0
Reducing risks	+	0	0	+	n.a	+ +	+	0	0
Orthognathic surgery									
Value for patients	0	0	0	0	+ + +	n.a	0	+ +	+ +
Value for surgeons	+ +	+ +	+	+ +	+ +	n.a	+ +	+ +	+ +
Saving costs	+ +	+ +	+ +	+ +	+ +	n.a	+	+	+
Increase quality	0	0	0	0	0	n.a	+ +	+ +	+ +
Reducing risks	0	+	0	+	0	n.a	+	+	+
Plastic surgery									
Value for patients	0	0	0	0	+ + +	n.a	0	+ +	+ +
Value for surgeons	+ +	+ +	+	+ +	+ +	n.a	+ +	+ +	+ +
Saving costs	+ +	+ +	+ +	+ +	+ +	n.a	+	+	+
Increase quality	0	0	0	0	0	n.a	+ +	+ +	+ +
Reducing risks	0	+	0	+	0	n.a	+ +	+ +	+ +

Rating: 0 no value, + Minor value, + + value, + + + strong value, −n.a. not applicable

4.2 Service and process innovations

The DL features of the prototype open up new possibilities for patients and surgeons. *Service innovation for patients:* the prototype replaces the dental cast with an intraoral scan. The scan is more comfortable for the patient and takes less time. As a second service innovation, the prototype will allow patients to simulate the changes to their faces during surgery, providing additional information about the intervention. *Process innovations for surgeons*: for surgeons, the prototype provided four service innovations: first, it highlights the possibility of identifying implant fixation areas and setting drilling holes, eliminating the need to work with splints, thereby simplifying and shortening the intervention time. Second, it allows the automatic adjustment of the tooth surfaces of the upper and lower jaw (occlusion). Third, it provides the design and creation of drilling- and cutting guides and their production (additive manufacturing). Finally, it enables the production of individual implants or the pre-forming of standard implants based on 3D models.

4.3 Results in workflow changes as part of organizational change

Surgical workflow Trauma: identifying and visualizing the fractured bony parts helps the surgeon decide which parts to consider for reconstruction. Highlighting the parts in 3D reduces the demands on the surgeon's imagination based on the CT slices [61]. It also facilitates sharing with colleagues because the parts are adequately visible. In very complex cases with many fractions, multiple staggered procedures are required. In such cases, the fractions were printed in plastic (PA12), and the reconstruction was discussed with the surgical team when planning the surgical sequence. In addition, this proved a very efficient way to train trainee surgeons on real patient cases. In addition, the reconstruction function assists the surgeon in deciding whether reconstruction is even possible or whether a prosthesis is necessary. The repositioning function virtually brings trauma parts into their original position, creating a 3D model of the skull and allowing the surgeon to determine the drill holes and implant type for fixation [2]. These system functions can be run in a few seconds [60], significantly reducing planning time (CSF). It also facilitates the creation and virtual execution of different surgery variations, thus increasing the quality of treatment (CSF). Better planning reduces the intervention time and, in consequence, the operating room occupancy time, which reduces costs and infection risks for the patient (CSF).

Surgical workflow Orthognathic surgery: when treating deformities, the DL system shortens the surgeon's workload by automatically determining the cephalometric points and lines on the patient [1]. This process step provides a quick overview of the patient's deviations from a standard skull. The simple simulation of surgical procedures and the visual representation of the resulting post-operative situation make it easy to create variants quickly. This way, checking whether chewing and swallowing functions are preserved is also simpler. The patient may be involved in the process as their face may change. The visual representation makes it more convenient for the surgeon to explain the procedure and for the patient to understand it (CSF).

The cephalometric DL support significantly simplifies the planning of the intervention. Thus, the landmarks and lines and their deviation from standard skulls are visible. Landmarks can be modified similarly to a drawing tool. Particularly in the case of splintless procedures [35], the planning work is shortened because the denture impression and splint creation and placement during surgery are no longer required (CSF). Improved planning shortens intervention time and reduces operating room occupancy and infection risk (CSF). The shorter intervention time is particularly valuable as such interventions often take several hours. Switching between pre- and post-operative visualization allows the surgical procedure to be performed and virtually verified. This way, the best possible intervention is determined and trained in advance, streamlining the intervention in the operating room and shortening the intervention time. Unexpected situations or spontaneous decisions during intervention are reduced to a minimum (CSF).

Surgical workflow Plastic surgery is used in cases of facial injury, deformities, or aesthetic ideals emulation and may also use DL support [36]. Besides the bone changes, tissue behavior is very important. The post-operative visualization of the face after surgery is challenging for surgeons because the face is an essential part of the personality. The surgeon can modify the facial scan and discuss the post-operative situation with the patient using the post-operative simulation feature. This feature facilitates communication and reduces the risk of unwanted facial changes (CSF).

Process innovation: the prototype showed very good results in post-operative visualization. The surgeons described the alternation between pre- and post-operative visualization as realistic and helpful. The segmentation of the bone structures and the cutting of the segments was also considered a valuable process innovation. Own trials and learning by doing factors strongly affect the acceptance process innovation [44]. The 3-dimensional imagination in complex intervention cases and the ability to apply cephalometric correctly without VSP requires high concentration capabilities. The automatic application of the DL system and the generation of warnings in critical situations relieves the surgeons' workload [22]. It also reduces misinterpretations and thus increases the quality of the intervention.

The demonstration of splintless treatment led to process innovation in which the system carries out the occlusion. Further development with haptic feedback would also be possible here but has yet to be tested. Additional process innovations can result by automatically creating cutting and drilling guides. In virtual planning, the interventions can be developed and simulated until they appear satisfactory. Afterward, they are virtually executed, and the appropriate implants are virtually screwed in the post-operative situation. The system calculates how the drilling and cutting guides should be in the pre-operative phase. These cutting and drilling guides could then be printed out using additive manufacturing (3D printing). This method is particularly suitable for orthognathic and plastic surgery. Although it is somewhat more time-consuming in the planning phase, it shortens the operation time and thus reduces costs. The surgical process changes with the drilling done before the bone segments are cut, and the implant moves the bone pieces into the correct position. Another process innovation was the formation of intervention variants. Various surgical options can be simulated and assessed for their post-operative effects.

4.4 Individual role perception

The role of trauma surgeons is to get as close as possible to the original state before the trauma occurs and to ensure functionality. In orthognathic or facial plastic surgery, many outcomes are subjective evaluations based on the patient's or/and physician's judgment of a surgical result [4]. The developing team created a corresponding simulation to offer surgeons and patients the possibility of a post-operative representation. This simulation allowed the patient to be involved in the decisions and thus influenced the roles of both sides. The surgeons were invited to assess how their role and that of the patients would change because of the DL system. Table 5 shows the expected changes in roles grouped by DL features.

In addition to involving patients in decision-making, eliminating awkward processes was rated important. The dental casting into the modeling clay was the most frequently mentioned procedure, which was replaced by an intra-oral scan.

The new visualization capabilities indicate that surgeons will spend more time with patients; therefore, patient-friendly language is needed, explaining medical terms in a common language that patients can understand. As patients now see multiple options and participate in deciding which one should be applied, experienced surgeons encounter limits in

Table 5 Roles and DL feature matrix

Impact on roles	DL features								
	1	2	3	4	5	6	7	8	9
Patient role changes									
Involvement in surgical decision	n.a	n.a	n.a	n.a	+	n.a	n.a	+ +	+ +
Eliminating awkward procedures	n.a	n.a	n.a	n.a	+ + +	n.a	n.a	0	0
Agreements on aesthetic outcomes	n.a	n.a	n.a	n.a	+	n.a	n.a	+ +	+ +
Additional scans (facial & oral)	n.a	n.a	n.a	n.a	+ +	+ +	n.a	+ +	+ +
Surgical role changes									
Application of cephalometric rules	n.a	+ + +	+ + +	+ + +	0	n.a	n.a	n.a	n.a
Gender conversion proposal	n.a	+ +	+ + +	+ +	0	n.a	n.a	+ +	n.a
Face type definition (Western, Caucasian etc.)	n.a	+ + +	+ + +	+ +	0	n.a	n.a	+	n.a
Landmark detection	n.a	+ + +	+ + +	+ + +	0	n.a	+	n.a	n.a
Bone segmentation	+ + +	0	0	0	0	n.a	+	n.a	n.a
Occlusion determination	n.a	0	+ +	0	+ +	n.a	n.a	n.a	n.a
Cutting guide generation	n.a	0	0	0	+ +	n.a	+	n.a	n.a
Drilling guide generation	n.a	0	0	0	+ +	n.a	+	n.a	n.a
Intervention result visualization	n.a	0	0	0	0	n.a	0	+ +	+ + +

Rating: 0 no contribution, + Minor contribution, + + contribution, + + + strong contribution, n.a. not applicable

using their ideas for a face as a measure of quality. On the other hand, while using the prototype, it was noticeable that a high level of trust in the technology was required. The prototype showed that this was easier for tech-savvy surgeons. Therefore, it is desirable to familiarize surgeons with the artificially intelligent system by offering education and hands-on training before introducing an intelligent system [51].

Clinical judgement and reasoning: as DL capabilities improved, they could also take over clinical judgment and reasoning tasks. Therefore, the project team decided to model the DL features as an agent and to redesign the processes. Thus, not only was the core competence clinical judgement and reasoning of the surgeons extended with DL, but the processes were redesigned to include the capabilities of the DL features as a clinical judgement and reasoning agent. In this way, new workflows were created. Two process chains were presented to the surgeons as proposals for planning the surgical intervention. The first included a long and automated DL process chain for planning the procedure. In this one, a complete proposal was created, which could be modified by the surgeons as they wished within the rules.

The second process chain offered an assessment and override option after each DL features. In this way, each DL feature proposal could be overridden individually. The surgeons unanimously chose the second process chain. Since the responsibility of the intervention always remains with the surgeon, they want to have intervention points in the process where they can confirm or override the automated work in small process steps. For this purpose, the concept of "step-by-step" and "accept" or "change" for each step has been introduced.

4.5 Observed changes in behavior

Reluctance to lose control: the relationship between responsibility and control opened up a field of tension. The process changes had to provide the same control capabilities as the existing manual processes. The process parts performed by the DL system had to be verifiable by the surgeon. In addition, surgeons demanded an overwrite function, which the DL system had to consider in further process parts. Printing of model parts using additive manufacturing was introduced as an additional function for extensive or complex process steps. In particular, the printout of the mandible and maxilla with tooth position significantly reduced concerns about occlusal function. During the two-year development period, a change in attitude was noticeable. While the initial phase was dominated by enthusiasm about the system's capabilities, this enthusiasm changed over time with concerns about maintaining control. This change in perception suggests that this is a critical success factor in the diffusion of DL systems.

Reluctance to give up old habits: at the beginning of the project, creativity was the main focus, and enthusiasm was high. As time passed, the difference between the less experienced and the very experienced surgeons grew. While the less experienced surgeons wanted to keep innovation as high as possible and welcomed the value of the DL system, the experienced surgeons became increasingly skeptical about the need to shift work to the DL system. It became more and more evident that less experienced surgeons had to give up less and quickly reached a high level of quality with the DL system, while the experienced ones felt deprived of their years of experience and increasingly saw the DL system as a restriction in their professional creativity.

4.6 Final prototype evaluation

At the end of the project, the visual prototype was presented to the project team and external audiences. The aim was to get a more in-depth view of whether the prototype should proceed towards developing it as commercial product.

Project team (Group A): at the beginning of the project, the surgeons agreed on requirements that should be realized using DL. The development should maximize the utilization of DL. The automated step length should become as long as possible, while the degree of human intervention should be as low as possible. The main reason for this was to free the surgeons from repetitive tasks and use their experience mainly to adapt the work of the DL features. These fundamentals served as the basis for the evaluation.

External audience (Group B): an institute for orthognathic surgery with three surgeons saw the value of the SSM. However, they found that their experience was sufficient, and therefore, the usefulness of the SSM was marginal. They asked for more support from the system in creating surgical reports for the health insurance company and further administrative support, for example, in patient management.

External audience (Group C): represented a plastic surgery team of an internationally known surgeon in Zurich. The visual representation was immediately appealing, as post-op visualization is an ongoing issue. On the one hand, the surgeon wants to offer variation to patients, but at the same time, it is also important to show the limits of cosmetic surgery. Additionally, once finalized, this would help the patient get used to the "new" face over a longer period and, if necessary, to make changes before the intervention happened. Another field has been described in standard interventions such as cleft palate. For these, the initial cutting lines and possible plates could be transferred from the SSM to the patient situation, thus reducing planning time. Table 6 shows the internal and external evaluation.

The prototype ended up having smaller automated steps with more frequent checkpoints. Additionally, it turned out that the acceptance of a commercial solution increases when the principle of "propose and override" is applied consistently. These findings highlight the importance of automated step length and intervention point setting. This aspect seems crucial for accepting a commercial solution.

Comparing the prototype and the eventual commercial solution highlights some differences: Based on an assessment of potential customers, an existing solution was enhanced and further developed into a marketable solution. The difference between the prototype and the commercial solution provided insight into the extent to which facial

Table 6 Internal and external evaluation

Feature or function	A	B	C
Automated segmentation	+ +	+ +	+
Statistical shape model	+ + +	–	–
Automated landmark detection	+ + +	+ +	+
Automated Cephalometric	+ + +	+ +	+ +
Automated trauma reconstruct	+ +	n.a	n.a
3D-2D model synchronization	+ + +	+	+
Fade-in fade-out soft tissue	+ +	+ +	+ +
Simulation result in post op view	+ +	+ + +	+ + +
Process length			
Provide a surgical proposal "all-at-once"			
Provide a "step-by-step" model			
New features proposed by the external audience			
Generating surgical report	–	+ + +	+
Health insurance report generating	–	+ + +	–
Soft-tissue tension model	+	+ + +	+ + +
Patient hair and eye overlay in post-op view	+	+ + +	+ + +

Rating: – no interest, + interested, + + strong interest, + + + buy argument surgeons are willing to use new AI-based systems. Routine seeking and reluctance to lose control appear as relevant variables. Therefore, the commercial solution had to be brought closer to the accustomed process. In addition, manual, system-supported functions replaced the automated functions required in the prototype. This change mainly affected the statistical shape model, which was not incorporated in the commercial solution.

5 Discussion

Most experts expect DL's computing power and medical reasoning capabilities to continue to grow [62]. Additionally, artificial clinical judgement and reasoning are driven by two additional forces: The amount of available medical data and the acceptance by the physicians. As a result of these factors, the future increase in DL capabilities is expected to be able to perform entire work sections autonomously. Furthermore, the human DL systems interaction will increasingly be done in natural language [23], transforming the ease-of-use part of the TAM2 model toward an ask-respond concept and, therefore, to a human-like interaction model.

Due to the correlation between confidence in DL capabilities and physicians' need for control capabilities, new approaches must be found to convince medical DL adopters. Two approaches are considered helpful: First, the physicians see the scientific proof as evidence that the DL features provide correct results as a task of the DL provider. The second approach is the issuance of regulations by the regulator with a certification authority. The case study results indicate that DL could also be useful in other medical fields. While there is little doubt of the merit of DL for analyses [3], further research and large amounts of medical data are needed in diagnosis and treatment planning. Besides scientific databases, considerable hopes are associated with the introduction of Electronic Health Records (EHR) [6, 30]. As an alternative solution, probabilistic modeling can also achieve good results. It offers a unique advantage by closely mimicking the rationale behind clinical diagnoses [16].

5.1 Contribution to theory

The perceived usefulness element of the TAM2 theory seems relevant for understanding the acceptance of the DL features in clinical practice. The usefulness assessment showed a difference between more experienced and less experienced surgeons. The less experienced surgeons rated the utility higher than the very experienced ones. This observation points to the role that the variable "experience" plays in explaining the acceptance of DL systems. Compared to perceived usefulness, ease of use seemed less relevant in the prototype setting, since the DL features solved the tasks independently, while the surgeons were controlling and overwriting. Perceived ease of use reportedly influenced the acceptance and behavior of users only marginally when shifting reasoning tasks to DL systems. But, such shifting triggers some emotional work, especially for experienced and well-recognized medical professionals.

Perceptions of creative limitation occasionally emerged. However, this perception could result from enforcing clinical guidelines in some DL features. The requirement to use DL extensively for the prototype resulted in long workflow sections in which many tasks were executed autonomously by DL, creating a sense of loss of control over the work processes performed by DL. In addition, the identification with the workflow decreased, resulting in insecurity. These user perceptions support the role of the RTC variables "Reluctance to give up old habits" and "Reluctance to lose control" in explaining resistance to change. Providing scientific proof and a medical class certification may reduce this reluctance. Both eased the concerns of the two variables. Surgical domain experts whose reputation affects their attractiveness to clients may initially experience of loss of status when DL executes complex reasoning tasks. This reservation towards DL was mainly reported by the external audience. It was apparent that depending on the magnitude of change, some identity work was necessary. A positive correlation between the magnitude of change and the amount of perceived identity threat was observed.

Additionally, the role changes induced by the duration of DL work done between human interventions are relevant. A correlation between the length of the DL task and the disapproval of this level of automation was observed. Based on this observation, this length was so that the identity protection part increases and, at the same time, identity restructuring decreases [34]. Furthermore, the developers increased the human intervention possibilities in the DL system to foster the acceptance of the DL system.

The change in surgeons' attitudes at the beginning and end of the project was surprising. While enthusiasm and curiosity about DL capabilities were high initially, they decreased as the fulfillment of the DL features increased. The situation is similar for the intention to use the DL system at the beginning and the surveyed willingness to use it at the end of the project. The latter dropped unexpectedly. While the exact causes remain unclear, a possible interpretation is that the time gap between a vision regarding a vignette and the actual product with reasoning components triggers an attitude change.

Diffusion of innovation [50] describes the role of early adopters in accelerating the application of new systems. Surgeons interested in and familiar with new technologies tend to be advocates for DL systems. They were curious about DL in general and were eager to explore it in real life in the prototype. In addition, younger surgeons with less professional experience showed more interest, with more cautious attitudes observed among older surgeons. This observation is consistent with existing research [41].

After decades-long calls for its adoption, shared decision-making (SDM) remains uncommon in routine care [8]. Especially involving patients seems complicated as patients often do not wish to participate in decision-making or do not feel competent to make "good" decisions [14]. The experience with the prototype showed that with appropriate adaptation at the patient level and elaborating a value for the patient, there is more interest in participating in such decisions. Since SDM is not yet widely used, an extension combining it with DL included within the SDM domain is recommended. The prototype experience is in line with other research showing higher participation by patients when physicians and the DL system are involved in decision- making [53].

5.2 Practical contribution

The case study suggests that DL could simplify or take over a significant part of the surgical work in planning. The automation of existing processes creates value, and the possibility of recombining parts of the process by applying DL capabilities can help create more efficient workflows [15]. Therefore, it is recommended that practitioners start with understanding the capabilities of the DL components and see them as analog to participants contributing to their surgical work. Development teams can model their capabilities into new workflows using storyboards. This approach could lower resistance towards DL and might soften the thinking in previous workflows and allows new things to emerge. DL feature implementers are encouraged to counteract a possible loss of status and control among highly experienced domain experts by providing sufficient override and control possibilities.

5.3 Future of using DL in clinical decision-making

Participants in the case study rated the involvement of the patients in the pre-operation stage as positive. The involvement of patients supports the surgeons in explaining the possibilities and limitations of the intervention and draws nearer to a shared decision. This experience from facial surgery could be extended to other areas. Emerging examples are disease diagnosis and the development of treatment plans. Such work consists of a judgement and a decision part, referred to as "clinical judgement and reasoning" in the literature [33]. Clinical judgment and reasoning trends toward patient involvement in diagnosis and treatment plans but needs a shared model. New clinical judgement models are helpful for this. Since the various medical disciplines differ in the way they make decisions, the decision models must be able to take this into account and reflect it. A well-known model is the Shared Decision Model (SDM), which involves the patient in decision-making processes. An SDM can be easily adapted to different disciplines [10]. It is equally easy to incorporate artificial decision-making into the model by adding an (artificial) participant. Existing research indicates that this leads to higher patient acceptance of treatment recommendations [53] Another model is the Multi-Criteria Decision Model (MCDM) used in aviation [25], which now attracts interest in medicine. DL can make a valuable contribution here by creating criteria from large amounts of data, comparable disease processes, or stored medical research models. Looking a little further into the future, a kind of "service design" in healthcare is emerging [24]. Analysis, diagnosis, and treatment will then be developed as a service and adapted to the patient's situation. One approach to this is the Metro Map model [17]. Artificial decision-making can be well integrated into this procedure. The most value of a service design involving DL is likely in complex contexts such as cancer treatment or personalized medicine.

5.4 Future of roles

The case study indicates that some of the work carried out by humans will be transferred to machines over time and that the role of physicians will therefore need to adapt. The shift from human tasks to systems seems to be evident [48]. This demands advanced IT Knowledge and trust in artificial intelligence. The latter can be influenced by providing explainability and causality functions [26]. However, this is challenging. The results are based on parameters, thresholds, and mathematical models that human participants do not easily understand. Nevertheless, DL experts predict a convergence of human and artificial clinical decision- making [9]. Pinnock et al. [47] argue that there is an urgently need to consider how to incorporate AI into teaching clinical reasoning.

Incorporating patient-specific situations and circumstances, which is already taking place, will be accelerated by integrating artificial intelligence into clinical judgment. This convergence is the basis for personalized and evidence-based medicine and therefore requires patient-centered thinking. As a result, standard procedures or disease-specific patterns will become more patient-specific and need to be applied more flexibly. Interaction and communication with the patient will become more salient. This was evident in the case study for orthognathic and plastic surgery.

5.5 Limitation of this case study

Each medical discipline is different regarding the use of DL. However, the case study results should still provide a basis for interpretation relevant for applications in other medical disciplines. In this context, it was important to avoid analyzing surgery-specific constructs but focus on more commonly known and used constructs.

6 Conclusion

Deep Learning has the potential to improve health systems. This paper aimed to illustrate how DL may change clinical workflows and professional roles in surgical planning. The potential of DL was demonstrated in a case study on facial surgery. Depending on the type of facial surgery, the critical success factors vary. The level of perceived usefulness varies from case to case and is higher for complex cases. The application of DL enables service innovation but should focus on more than merely optimizing existing processes but rather on redesigning them based on DL capabilities. It opens new avenues for surgical interventions with patient involvement in decision-making, improving quality and reducing costs. However, such redesign requires adaptation of organizational structures and surgical roles. Practical prototypes and trials with real patient cases are helpful in ensuring the acceptance of new or redesigned systems. In these systems, surgeons' responsibilities and control options must be well structured, or they may refuse to take responsibility for the entire workflow.

Author contributions BH was in the steering committee of the project. In this role, he contributed the project management expertise and supervised the business process engineering. Prof. Dr. KL, contributed his expertise in the fields of medicine and artificial intelligence. Prof. Dr. MK contributed his management and business administration expertise. BH, KL, and MK contributed to the interpretation of the results. BH took the lead in writing the manuscript. All authors contributed to the article and approved the submitted version.

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Code availability No.

Declarations

Ethics approval and consent to participate The project set-up phase followed the hospitals standards and ethical considerations path necessary for this type of project. All project parts passed these checks.

Consent for publication All data used (DICOM Data Sets) where anonymized and provided by the hospital followed the hospital guidelines.

Competing interests Although the author was part of the project management, no decisions were influenced by this. The authors declare that they have no competing interests.

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