Standardizing Corneal Transplantation Records with openEHR: Case Study

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Abstract

Background: Corneal transplantation, also known as Keratoplasty, is a widely performed surgical procedure that aims to restore vision in patients with corneal damage. The success of corneal transplantation relies on the accurate and timely management of patient information, which can be enhanced with Electronic Health Records (EHRs). However, conventional EHRs are often fragmented and lack standardization, leading to difficulties in information access and sharing, increased medical errors, and decreased patient safety. In the wake of these problems, there is a growing demand for standardized EHRs that can ensure the accuracy and consistency of patient data across healthcare organizations.

Objective: This paper proposes the use of openEHR structures for standardizing corneal transplantation records. The main objective of this research is to improve the quality and interoperability of EHRs in corneal transplantation, making it easier for healthcare providers to capture, share, and analyze clinical information.

Methods: A series of sequential steps were carried out in this study for implementing standardized clinical records using openEHR specifications. These specifications furnish a methodical approach that ascertains the development of high-quality clinical records. In broad terms, the methodology followed encompasses the conduction of meetings with healthcare professionals and the modeling of archetypes, templates, forms, decision rules and work plans.

Results: This research resulted in a tailored solution that streamlines healthcare delivery and meets the needs of medical professionals involved in the corneal transplantation process, while seamlessly aligning with contemporary clinical practices. The proposed solution culminated in the successful integration within a Portuguese hospital of three key components of openEHR specifications: forms, Decision Logic Modules (DLMs), and Work Plans (WPs). A statistical analysis of data collected from May 1st, 2022 to March 31st, 2023 allowed to perceive the usage of the new technologies within the corneal transplantation workflow. Despite the completion rate being only 64%, which can be explained by external factors such as patient health and availability of donor organs, there was an overall improvement in terms of task control and follow-up of the patients' clinical process.

Conclusions: This study shows that the adoption of openEHR structures represents a significant step forward in the standardization and optimization of corneal transplantation records. It offers a detailed demonstration of how to implement openEHR specifications and highlights the different advantages of standardizing EHRs in the field of corneal transplantation. Furthermore, it serves as a valuable reference for researchers and practitioners who are interested in advancing and improving the exploitation of EHRs in healthcare.

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Keywords: Eletronic Health Record; Corneal Transplantation; Keratoplasty; openEHR; Data Representation; Data Exchange; Templates; Archetypes; Forms.

Introduction

The eye is a highly evolved and complex sensory organ possessed by a wide range of species, enabling organisms to perceive and interpret visual information from their surroundings. Vision is one of the most valuable senses for humans and plays a critical role in every facet of an individual’s life [1]. The sense of vision is the result of an intricate interaction between the eyes, the brain, and the nervous system [2].

Visual impairment occurs when a pathological condition disrupts the visual system and one or more of its associated functions [1]. Blindness is a major public health issue, particularly in developing and underdeveloped countries where access to healthcare and resources is scarce [3,4]. The loss of sight can severely impact an individual's daily life, hindering their ability to perform routine tasks, interact with others, and preserve their independence [5]. On many occasions, blindness can also lead to social isolation, depression, and decreased quality of life [1,5].

In 2019, the World Health Organization (WHO) estimated, in the world report on vision, that there were approximately 2.2 billion people worldwide with vision impairment or blindness [1]. The prevalence of visual disability is alarming and a source of growing global concern.

The apprehension surrounding blindness is not only rooted in the physical limitations it imposes, but also in its social and economic consequences [3]. From an economic point of view, the loss of sight can cause reduced workforce participation, decreased productivity, and increased health expenses [5]. Consequently, the loss of income and the higher healthcare costs can drain governments with additional financial pressures, exacerbating poverty and slowing economic growth [1]. Hence, the impacts of blindness are far-reaching, affecting not only the individual, but also their families, communities, and society as a whole.

Without more assertive measures, the escalating demand for eye care services worldwide is projected to persist and intensify in the next few decades, posing a meaningful challenge to the healthcare industry and requiring innovative solutions to meet the increasing pressure for quality eye care services [6,7].

The eye is a complex organ composed of several structures that work together in the perception of the world in all its lights, colors, shapes, and movements [2]. One of the most vital structures of the visual system is the cornea, which is the clear outermost layer located at the front of the eye [8]. A transparent cornea acts as a clear window to allow light to enter the eye and reach the retina, a layer of neural tissue at the back of the eye where light is converted into electrical signals and transmitted to the brain for interpretation as visual information [2]. For an individual to have clear vision, the cornea must be transparent and free of any obstructions, such as scars or opacities, in order to allow light to cross the eye and access the retina [8,9].

The main causes of visual impairment are cataract, glaucoma, macular degeneration, detached retina, diabetic retinopathy, and retrolental fibroplasia [3,7,10,11]. Some of these eye conditions, such as cataract, diabetic retinopathy, and retrolental fibroplasia, can negatively impact the clarity of the cornea and lead to vision impairment [2,9]. According to the WHO, corneal opacities are the fourth leading cause of blindness on a global scale [9].

In many cases, visual rehabilitation is possible with corneal transplantation [4,8]. Corneal blindness can be effectively reversed with a healthy donor cornea transplant. Because the cornea lacks blood vessels, the risk of graft rejection is significantly reduced, making corneal transplantation one of the most successful forms of organ transplantation in the human body [8]. Corneal transplantation, also known as Keratoplasty, is a surgical procedure that replaces a damaged or diseased cornea with a healthy one to restore vision and improve the quality of life of patients [4].

The success of corneal transplantation heavily relies on the accurate and timely management of patient data, including preoperative evaluation, surgical planning, and postoperative care. Electronic Health Records (EHRs) have evolved as indispensable means for handling clinical information, providing a centralized repository for patient records, and facilitating communication between healthcare providers [12,13]. The appropriate use of EHRs can substantially bolster the positive outcomes of corneal transplant surgeries, culminating in improved patient results and a more seamless and efficient care journey. By minimizing errors and inconsistencies in patient data management, EHRs can further diminish the likelihood of unfavorable events, ultimately improving the success of corneal transplants.

Despite its widespread use, traditional EHRs are prone to lack of standardization and consistency [12]. As a consequence, inconsistency and fragmentation plague the management and documentation of corneal transplantation records, causing difficulties in accessing and sharing information, increased medical errors, and decreased patient safety. Furthermore, the lack of standardization and organization creates an obstacle for healthcare professionals to access complete and accurate information about patients who are due to undergo or have undergone corneal transplantation, resulting in inefficiencies and suboptimal patient care.

To address these issues, there is a growing need for standardized EHRs that can ensure the accuracy and consistency of patient data across healthcare organizations and locations [14, 15] to ultimately improve the management and documentation processes for corneal transplantation records.

One promising approach for standardizing EHRs is the use of openEHR structures [16,17]. openEHR is an open-source standard that provides a set of specifications and tools to support the creation of interoperable data structures and the long-term management of health data [18]. A foundational paradigm on which openEHR framework is based is the two-level modeling, separating domain semantics from software. Under the model-driven approach, a stable reference information model constitutes the first level of modeling, while formal definitions of clinical content in the form of archetypes and templates constitute the second. Overall, the adaptability, flexibility, and scalability of openEHR's modular methodology provide a powerful solution to the challenges facing the healthcare industry, and it is an ideal approach for healthcare systems of all sizes [16-19].

Hence, this study seeks to explore the implementation of openEHR structures as a means of standardizing records in the field of corneal transplantation. Additionally, this manuscript expounds upon the potential benefits that may arise from the use of openEHR specifications for standardizing corneal transplantation records, including improved data consistency and completeness, increased data accessibility and sharing, alongside the mitigation of errors and inefficiencies in data management. The paper will also delve into the challenges and limitations of implementing openEHR in the context of corneal transplantation.

Through the evaluation of the potential benefits and hurdles of using openEHR specifications, this study provides an informative resource and a valuable reference for researchers and practitioners interested in improving the use of EHRs in healthcare, extending beyond the field of ophthalmology and encompassing other medical disciplines as well.

One of this research's objectives is to contribute to the ongoing efforts to improve the quality and safety of patient care through the disclosure of insights into the potential of using openEHR structures to the advancement of EHRs in healthcare, particularly in the field of corneal transplantation.

As healthcare continues to evolve, the authors believe that the standardization of clinical records using openEHR structures holds great potential for ensuring that patients receive safe, effective, and high-quality care.

Methods

In this study, a specific methodology was defined that outlines the sequential steps involved in transforming the corneal transplantation records of a Portuguese hospital using the openEHR specifications.

In contrast to traditional approaches, openEHR's advanced modular approach separates data from applications and services, providing a level of flexibility that is unmatched in the industry [20]. This approach enables an easier assimilation to constantly evolving requirements, technological changes, healthcare policies, and other external factors. Moreover, by separating the data layer from the application layer, openEHR can integrate a wide range of health-related data from various sources regardless of the format in which it is stored [20].

By using archetypes and templates as a means of ensuring the consistency and accuracy of clinical data, openEHR is more supple compared to conventional approaches of clinical documentation, which often rely on free-text entries that can be arduous to comprehend and interpret across different patients and clinical settings [20]. The use of archetypes and templates allows healthcare institutions to minimize variability and fragmentation, which contrasts with the current uncoordinated methods. It provides a framework that allows healthcare professionals to customize patient-specific information in a more dynamic and structured way [19]. In addition, it ensures that clinical data remains consistently structured and semantically interoperable, leading to more precise interpretation and sharing of clinical data among different clinical systems.

In this sense, the methodology adopted in this study uses openEHR to contribute to the ongoing efforts to improve the quality and safety of patient care through the implementation of standardized EHRs. (Figure 1) represents in a simplified way the different stages of the methodology carried out in this study.

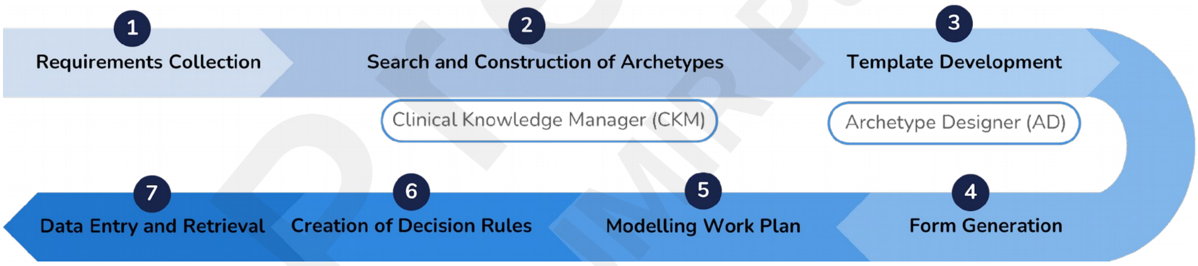

Figure 1. Methodological approach followed in the standardization of corneal transplantation EHRs using openEHR specifications.

Initially, as the objective was to develop a case study on the transformation of corneal transplantation records of a particular hospital institution, a direct line of communication with the medical team was deemed indispensable in order to conduct an in-depth inquiry on the necessary requirements.

After collecting the requirements, the modeling of the openEHR structures that will support the register and management of corneal transplantation records and the timely execution of its associated tasks began, which include archetypes, templates, forms, decision rules, and work plans.

In the next subsections, the characterization of the work developed in each of the stages that compounds the methodology represented in (Figure 1) will be described in detail.

Requirements Collection

The requirements collection is a crucial step in the development of healthcare systems and applications, as it lays the foundation to ensure that the needs and expectations of all parties involved are understood and incorporated into the final solution.

Accordingly, the first step of the methodology started with stakeholder identification, including healthcare professionals and Information Technology (IT) personnel. Overall, the process of collecting requirements for enhancing the corneal transplantation records with openEHR was a collaborative effort between medical staff, the IT personnel of the hospital's information systems department, and the developers.

After identifying a work group, a series of meetings were organized to initiate the requirements-gathering phase. This stage entailed the active participation of stakeholders, who served as the primary source of knowledge for modeling, guiding the design and development of the openEHR structures. During these collaborative meetings, a thorough analysis of the current documentation processes and data management practices was conducted to identify areas for improvement. The meetings were structured to stimulate an active feedback process from the stakeholders regarding existing workflows, specific needs and preferences, and any identified pain points and suggestions for improvement.

Over the course of these conversations, it became apparent that the information system that the hospital used for the management of corneal transplantation records was plagued by significant shortcomings, including the possibility of errors in data entry, loss of information, difficulty in sharing data between healthcare providers, and lack of standardization.

Therefore, the main goal was to address these issues and implement a more reliable and comprehensive information management system that utilizes openEHR structures to mitigate the problems acknowledged. Through a collaborative effort, the stakeholders were able to delimit the scope and define the requirements and use cases of the clinical domain to be modeled.

The work group identified five key events in the corneal transplantation process where data recording actions could potentially take place. These moments were carefully analyzed to ensure that all necessary data are captured with the highest level of accuracy and consistency. (Table 1) provides a description of each key event.

Table 1. Description of the five key events identified within the corneal transplantation process.

Key Event	Description
Corneal Transplantation Proposal	To insert the data concerning the corneal transplantation proposal such as type of transplant, laterality, diagnosis, priority, motive, among others.
Contact for Corneal Transplantation	To record the three possible contact attempts for corneal transplantation, including information such as phone number, date of contact, result, reason, and date of next contact.
Schedule Anesthesia Consultation	To enter data regarding the scheduling of the anesthesia consultation. It contains the

	requesting service, the date of the appointment, the motive, and additional information.
Perform Anesthesia Consultation	To record the result of the anesthesia consultation, the executing service, the execution date of the appointment, and observations.
Manage Suspended Proposal	To register the result of the decision regarding suspended corneal transplantation proposals, either to reinstate to the list or to abandon, and the respective reason.

Modeling and Development of Archetypes, Templates and Forms

Archetypes, templates, and forms are interconnected concepts in openEHR that work together to ensure that clinical data is consistently collected, stored in a structured and meaningful way, and retrievable in a usable format [18, 21]. By providing a standard, flexible, and scalable manner to manage clinical data, they also serve as a foundation for data sharing and exchange among different health systems and organizations, thereby promoting interoperability [22].

Archetypes are reusable, modular building blocks that describe the structure and content of clinical data elements. They define the data types, units, constraints, and other properties of specific clinical concepts, such as patient demographics, test results, and medication information [19, 22].

In turn, templates are collections of archetypes that define a specific clinical record, such as a patient's progress notes, a medication prescription, or a diagnostic test result. Templates provide standardized structure and content for clinical records, ensuring that data is collected consistently, in a usable and meaningful format [19].

Forms, on the other hand, provide a user-friendly interface based on templates for the input and retrieval of clinical data, supporting the entry and display of structured, semi-structured, and unstructured data [23]. Forms can be customized and configured to meet the unique requirements of various clinical scenarios.

In summary, archetypes provide the building blocks for clinical data structures, templates define the standard structures for specific clinical records, and forms serve as a user-friendly interface for the input and retrieval of clinical data.

The development process of the openEHR forms in which data can be introduced in some tasks of the corneal transplantation workflow involves transforming archetypes into templates and later into forms. For representation purposes and to simplify the demonstration of the development process, from now on the description will focus on illustrating the development of the openEHR structures, archetypes, template, and form, related to the corneal transplantation proposal.

As previously stated, the first step involved meetings with domain experts to define the scope of the clinical domain to be modeled and collect data requirements, as specified by the Archetype Modeling Methodology (AMM) [24]. The main stakeholders involved in this process were healthcare professionals who were familiar with openEHR, the archetype development process, and clinical terminologies.

After determining the scope of the modeling process and identifying the clinical concepts and information elements involved, the second step entailed searching the Clinical Knowledge Manager (CKM) for existing archetypes that fit the scope of the modeling scenario under consideration. CKM is an openEHR community pillar that enables worldwide governance of domain knowledge artifacts as well as collaborative development, management, and publishing [25]. It is an open-source library of openEHR archetypes and templates that lays the foundation for both semantic and syntactic interoperability [26].

Some archetypes were used directly, while others did not fully represent the data elements and had to be adapted through specialization. When no corresponding archetypes existed, new ones were created. The openEHR Reference Model (RM) defines four major categories of archetypes: COMPOSITION, SECTION, ENTRY, and CLUSTER. A COMPOSITION is a container class, whereas a SECTION is an organizing class, both of which contain ENTRY objects [27]. The ENTRY class is further specialized into ADMIN_ENTRY, OBSERVATION, EVALUATION, INSTRUCTION, and ACTION subclasses, of which the latter four are kinds of CARE_ENTRY. CLUSTERS are reusable archetypes that can be used within any ENTRY or CLUSTER [16].

For the corneal transplantation proposal, two archetypes were found suitable for use, namely, the service request (Figure 2), which is part of openEHR's INSTRUCTION subclass of the ENTRY class, and the anatomical location (Figure 3), which is part of the openEHR's CLUSTER class.

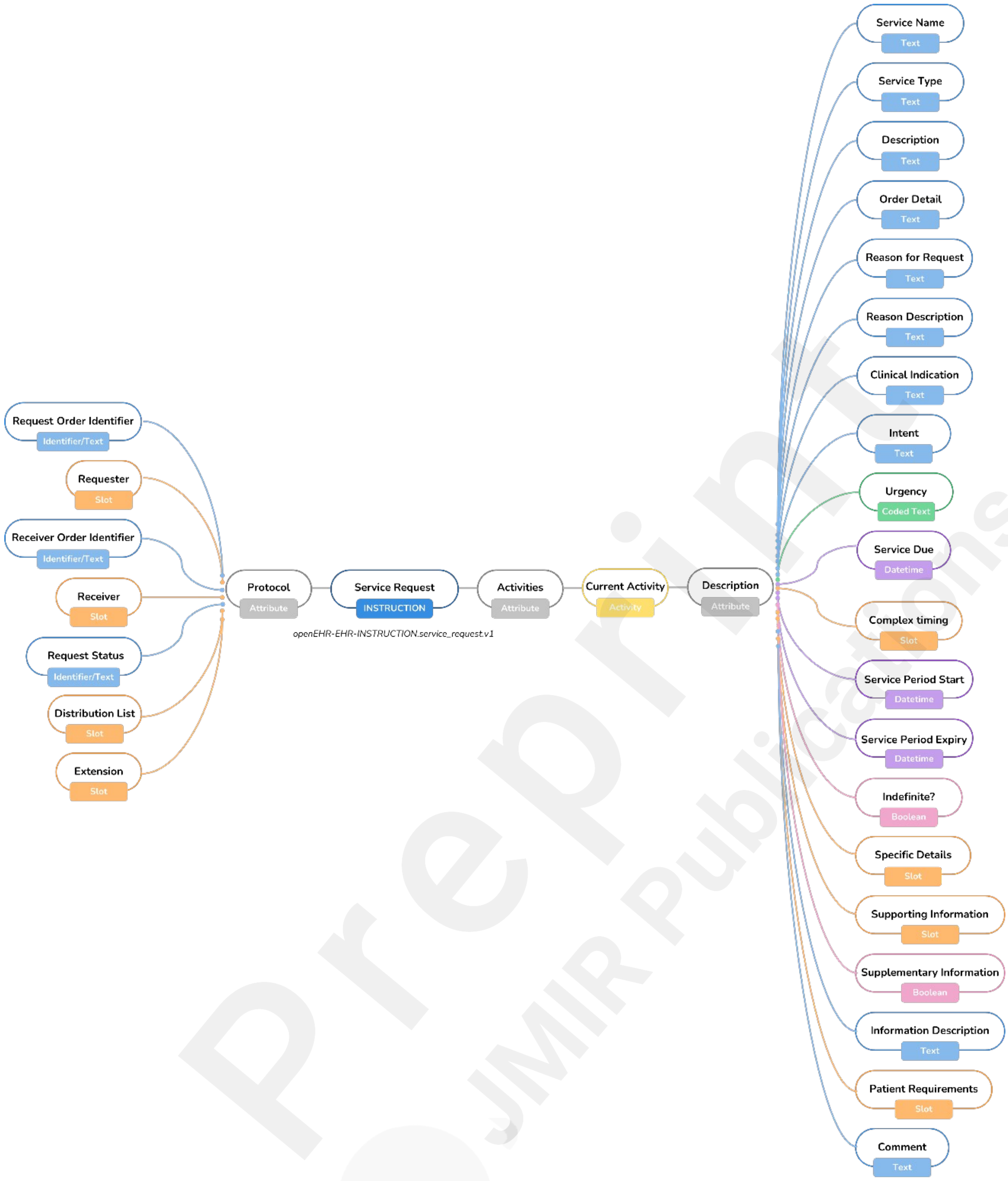

Figure 2. Mind-map view of the “Service Request” archetype.

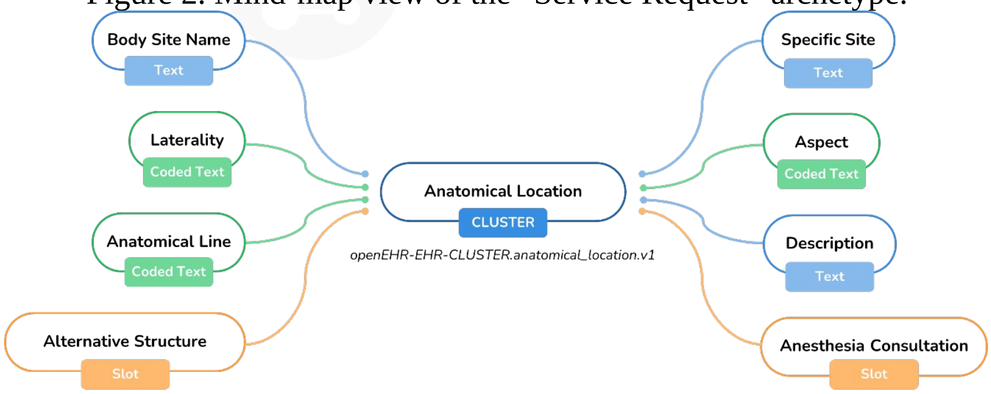

Figure 3. Mind-map view of the “Anatomical Location” archetype.

In addition, a third archetype was created to contemplate some procedure aspects, namely the risk, the complexity, the number of previous surgeries, and the need for anesthesia consultation. This archetype was named “Eye Surgery Details” and belongs to the CLUSTER class. (Figure 4) depicts the archetype's mind map.

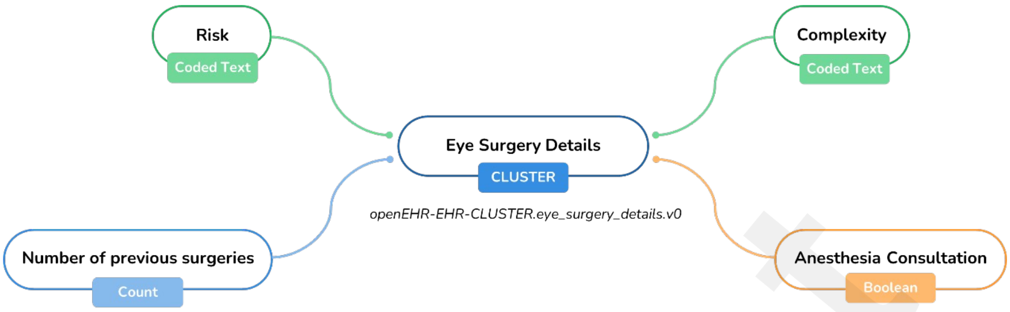

Figure 4. Mind-map view of the “Eye Surgery Details” archetype.

At the end of this step, information concerning applicable data constraints, such as datatypes, cardinality, occurrences, and specific data values (e.g., terminologies for coded values, ranges for numerical values, etc.) are stipulated for each archetype.

It is worth mentioning the use of SNOMED-CT terminologies for mapping the coded values of the “Laterality” item belonging to the “Anatomical Location” archetype. Local terms were used for the remaining coded text items. (Table 2) provides a description of the coded values used for each coded text item.

Table 2. Description of the coded values assigned to each coded text item.

Archetype	Item	Code	Value
Anatomical Location	Laterality	SNOMED-CT::362503005	Left eye
Anatomical Location	Laterality	SNOMED-CT::362502000	Right eye
Anatomical Location	Laterality	SNOMED-CT::362508001	Both eyes
Eye Surgery Details	Risk	at0004	High
Eye Surgery Details	Risk	at0005	Moderate
Eye Surgery Details	Risk	at0006	Low
Eye Surgery Details	Complexity	at0007	High
Eye Surgery Details	Complexity	at0008	Moderate
Eye Surgery Details	Complexity	at0009	Low
Service Request	Diagnosis	H16319	Corneal abscess
Service Request	Diagnosis	H1830	Corneal membrane alterations
Service Request	Diagnosis	H52219	Irregular astigmatism
Service Request	Diagnosis	H18739	Descemetocele

Service Request	Diagnosis	H18519	Corneal endothelial dystrophy
Service Request	Diagnosis	H18719	Corneal ectasia
Service Request	Diagnosis	H1820	Corneal edema
Service Request	Diagnosis	T868499	Corneal graft (complication)
Service Request	Type of Transplant	08R83KZ_tt_d	Total transplantation (right eye)
Service Request	Type of Transplant	08R83KZ_tt_e	Total transplantation (left eye)
Service Request	Type of Transplant	08R83KZ_dalk_d	Anterior Transplantation - DALK (right eye)
Service Request	Type of Transplant	08R83KZ_dalk_e	Anterior Transplantation - DALK (left eye)
Service Request	Type of Transplant	08R83KZ_dsaek_d	Anterior Transplantation – DSAEK (right eye)
Service Request	Type of Transplant	08R83KZ_dsaek_e	Anterior Transplantation – DSAEK (left eye)
Service Request	Type of Transplant	08R83KZ_dmek_d	Anterior Transplantation – DMEK (right eye)
Service Request	Type of Transplant	08R83KZ_dmek_e	Anterior Transplantation – DMEK (left eye)
Service Request	Urgency	at0136	Emergency
Service Request	Urgency	at0137	Urgent
Service Request	Urgency	at0138	Routine

After the discovery and development of the required archetypes, the Archetype Designer (AD) tool was used to assemble and constrain the archetypes into a template that represents the requirements of the corneal transplantation proposal. A template of the COMPOSITION type was created using the "Request for Service" archetype and named "Corneal Transplantation Proposal". To begin, the "Service Request" archetype was incorporated into the content attribute. The template was then modified to remove items that were irrelevant to the clinical context being modeled, such as "Service Type", "Order Detail", and "Intent". Both the "Anatomical Location" and the "Eye Surgery Details" archetypes were imported into the "Specific Details" cluster. The items "Aspect", "Anatomical Line", and "Description" of the "Anatomical Location" archetype were also excluded from the template. Subsequently, some items were assigned specific default values, the content of which can be found in (Table 3).

Table 3. Description of the default values assigned.

Archetype	Item	Default Value

Service Request	Service Name	Corneal Transplantation
Anatomical Location	Body Site Name	Eye
Anatomical Location	Specific Site	Cornea

To facilitate interpretation and manipulation, the template was exported in the Operational Template (OPT) structure and later converted into the JSON Data Template (JDT) structure. Finally, the JDT template was injected into the FormBuilder tool to format the user interface form, which can be consulted in (Figure 5).

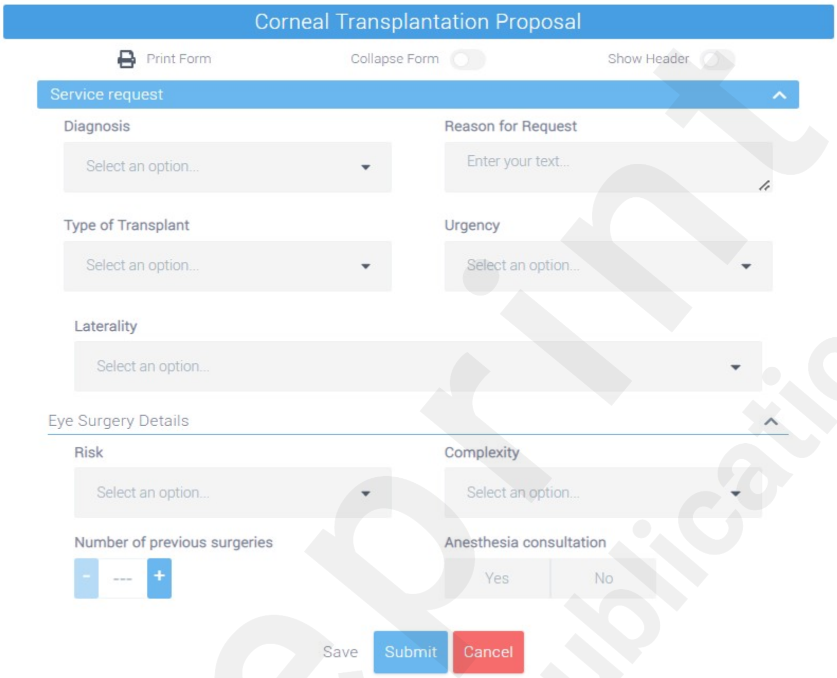

Figure 5. Graphic representation of the user interface form generated from the “Corneal Transplantation Proposal” template.

At the end of this stage, five forms were created. To simplify the identification of each form, (Table 4) assigns an identification label to each form. Following that, each of these forms will be associated to specific tasks in the corneal transplantation workflow, acting as storage schemes for different patient tasks. A more detailed description of the deployment will be provided later in this paper.

Table 4. Forms developed for the corneal transplantation workflow.

ID	Form
F1	Corneal Transplantation Proposal
F2	Contact for Corneal Transplantation
F3	Schedule Anesthesia Consultation
F4	Perform Anesthesia Consultation
F5	Manage Suspended Proposal

Work Plan Modeling

In recent years, a major extension has been incorporated into the openEHR specifications for addressing requirements in the area of clinical process automation, known as Task Planning [18]. TP allows the management of standardized task plans and clinical workflows. The main concept of TP is centered on a plan, or set of plans, that is devised to accomplish a specific goal and pertain to an

active subject [28].
Within the TP specification, in terms of conceptual elements, the formal concept at the highest level of hierarchy is the Work Plan (WP), which encompasses one or more Task Plans (TPs) [29]. A WP defines a series of tasks that need to be performed in a specific order to achieve a clinical goal with respect to a subject, human, or other subject of care [18]. It is worth noting that, since the WP is subject-centric, each subject requires a unique instance of a WP. WPs can organize and monitor the progress of clinical tasks, ensuring that all necessary steps are taken in a timely and efficient manner [29]. In turn, each TP incorporated within a WP is an explicit depiction of the work that must be performed in a particular work context by the principal performer, along with other possible participants [18]. In openEHR, the principal performer refers to the individual or entity responsible for carrying out a specific clinical action, which enables the tracking of clinical actions back to their responsible parties. The data collected through forms and the decision support provided by DLMs can be used to define and update WPs in real-time.

In this study, a WP regarding the corneal transplantation was modeled to ensure that the implementation of the solution proceeds smoothly and is completed within the specified timeline.

The first TP defined in this WP concerns the corneal transplantation proposal. This task is available to certain ophthalmologists in specific contexts. Two TPs related to the anesthesia consultation were also included: scheduling and carrying out the consultation, which are assigned to different groups of professionals. Finally, two more TPs were modeled: one related to the contact for transplantation carried out by administrative staff and one related to the performance of the transplant, which is allocated to the doctor who submitted the proposal in the first instance.

(Figure 6) shows the first TP in a simplified way. It is interesting to note that in this first TP, the proposal form for a corneal transplant is completed in the first performable task. After submission, the execution of the anesthesia consultation relies upon the value assigned to the DV_BOOLEAN field labeled “Anesthesia Consultation” within the “Corneal Transplantation Proposal” form. If this field indicates a true value, the subsequent steps for that patient involve scheduling the anesthesia consultation, conducting the consultation, and eventually establishing contact for the transplantation procedure. On the contrary, if the anesthesia consultation is not necessary, the patient goes to the active waiting list represented by the cornea transplant contact tasks. If the contact is successful, the patient proceeds to perform the transplant, if not, the proposal is suspended and the suspension management task becomes available. All dispatchable tasks presented in this example are connected to other TPs, which mainly have a performable task with one of the modeled forms associated.

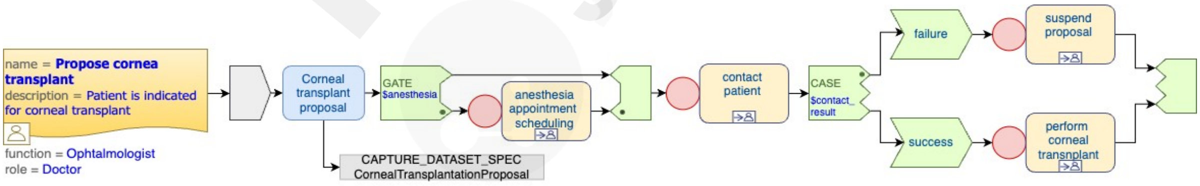

Figure 6. Representation of the top-level task plan.

Later in this article, the main decisions that need to be made in the course of WP will be explained.

Construction of Decision Rules

Clinical decision support is a key component of the openEHR architecture, responsible for automating and enhancing decision-making. The openEHR community defines decision rules and guidelines using a specific syntax, the Decision Language (DL) [30]. DL is a formal language for representing clinical knowledge in decision-making and expressing decision-support logic through rulesets.

Decision Logic Modules (DLMs) are multisectioned modules with a specific structure for defining rules, encompassed in DL. DLMs are computerized decision-making instructions that provide a standardized and automated way to apply decision rules to patient data within the EHR in real time [30,31].

DLMs enable healthcare organizations to implement algorithms and rules to determine the best course of action for a given patient [32]. The output from a DLM can be used to guide clinical decision-making, provide alerts or notifications to healthcare providers, or drive automated actions within the EHR, such as ordering tests or medications [18].

In order to ensure the efficiency of the solution, decision rules were established for forms and task plans to define the logic and actions that should be taken based on specific data inputs. The rules are stored in a standardized structure that can be applied to patient data at runtime.

Overall, by automating the application of decision rules, DLMs can help reduce the risk of errors and variability in decision-making, providing more consistent care [33].

Form Decision Rules

The DLMs allow the forms to automatically adapt to the specific constraints for a given patient or scenario and to the responses of the healthcare professional filling in the form fields, ensuring that the information entered is always consistent with established clinical guidelines and best practices. The data collected through the forms is used as input for DLMs to support the delivery of real-time decision support.

By automating the process of adjusting forms to specific scenarios and inputs, the solution can provide decision support to healthcare providers, guiding them through the process of entering data and making clinical decisions.

Hence, according to the requirements gathered in the first stage of the methodology, two DLMs were created for guiding healthcare professionals in the process of filling in the forms F1 – “Corneal Transplantation Proposal” and F2 – “Contact for Corneal Transplantation”. (Table 5) describes the association between the forms, DLMs, and rules.

Table 5. Association between forms, DLMs and rules.

Form	DLM	Rule	Rule Description
F1	DLM1	R1	If the patient’s age is equal or superior to 75 years, anesthesia is mandatory.
F2	DLM2	R1	In the 1st contact section, if the patient intends to leave the transplant list, the motive is mandatory.
F2	DLM2	R2	In the 2nd contact section, if the patient intends to leave the transplant list, the motive is mandatory.
F2	DLM2	R3	In the 3rd contact section, if the patient intends to leave the transplant list, the motive is mandatory.
F2	DLM2	R4	In the 1st contact section, if the patient needs to postpone the contact, the next contact is mandatory.
F2	DLM2	R5	In the 2nd contact section, if the patient needs to postpone the contact, the next contact is mandatory.

F2	DLM2	R6	In the 3rd contact section, if the patient needs to postpone the contact, the next contact is mandatory.
F2	DLM2	R7	If contact with the patient is not established, the 2nd contact section is displayed.
F2	DLM2	R8	If contact with the patient is not established, the 3rd contact section is displayed.

(Table 6) and (Table 7) describe the rules associated to each DLM, including the condition(s) necessary to trigger a certain action. As the names of the fields were the same for the three sections of the form, it was decided to include the prefix of the section to which the field belongs in the "Field" columns of (Table 6).

Table 6. Decision logic associated to the form “Contact for Corneal Transplantation”.

Conditions			Rules	
Field	Operator	Value	Field/Section	Action
1st Contact - Result	equal	Cancellation	1st Contact - Motive	isMandatory
2nd Contact - Result	equal	Cancellation	2nd Contact - Motive	isMandatory
3rd Contact - Result	equal	Cancellation	3rd Contact - Motive	isMandatory
1st Contact - Result	equal	Postpone contact	1st Contact - Next contact	isMandatory
2nd Contact - Result	equal	Postpone contact	2nd Contact - Next contact	isMandatory
3rd Contact - Result	equal	Postpone contact	3rd Contact - Next contact	isMandatory
Result	equal	Unsuccessful contact	2nd Contact	isVisible
Result	equal	Unsuccessful contact	3rd Contact	isVisible

Table 7. Decision logic associated to the form “Perform Anesthesia Consultation”.

Conditions			Rules		
Field	Operator	Value	Field	Action	Value
Age	greaterThanInclusive	75	Anesthesia	isEqualTo	Yes

Work Plan Decision Rules

The DLM rules built to support the necessary decisions in the modeled WP were crucial for the correct functioning of the respective materializations.

The first rule to be processed concerns the decision on whether or not the patient should proceed to an anesthesia appointment. If the priority of the proposal is urgent, the patient does not need an anesthesia appointment. If it is not urgent, the need for an anesthesia consultation is decided by the

"Anesthesia" field filled in by the physician in the "Corneal Transplantation Proposal" form.

Regarding the anesthesia consultation, a rule was created to verify the success of the consultation and thus decide whether the patient goes to the contact for transplantation or not. This rule uses the data entered by the anesthesiologist in the respective form.

Then, the most complex rule was built to support the decision after the patient was called for transplant. (Figure 7) represents the logic behind the decision to be taken after the transplant contact, where up to three contacts with the patient can be registered.

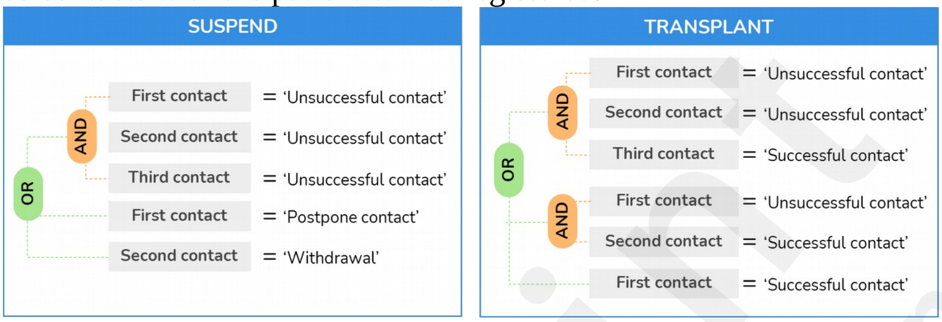

Figure 7. Decision logic associated to the WP.

Finally, there is still a decision that is made for suspended patients, which is based on whether they are removed from the transplant waiting list and the WP ends or the patient is re-inserted on the transplant contact list, making the respective performable task available.

Ethical considerations

In this study, all patient demographic information were anonymized through the use of openEHR separation of the Demographic Information Model (DIM) and Clinical Information Model (CIM). This approach ensures that personal identifiers are not linked to clinical data, thereby maintaining patient confidentiality and minimizing the risk of re-identification. Furthermore, the data analysis conducted in this study focuses on performing statistical analyses at an administrative level. This includes examining the quantity of tasks available, the completion rate of these tasks, and referencing solely the number of patients enrolled in the study. The analysis is restricted to aggregate data, ensuring that individual patient identifiers and clinical details are not disclosed. This methodological approach allows for a comprehensive evaluation of the operational aspects of the study without compromising patient confidentiality or violating ethical standards. The data structure of the generated forms can be found at https://ckm.openehr.org/ckm/. Given these protections, the study qualifies for an exemption from ethical review.

Results

Deployment and Architecture Overview

The openEHR ecosystem provides a comprehensive solution for managing healthcare data by combining different tools and technologies. In openEHR, forms, DLMs, and WPs interact in a complementary manner to support the provision of effective and efficient clinical care. These modules ensure that patient data is accurate, consistent, and accessible, and provide data validation, automated actions, and real-time decision support to ensure that the best course of action is taken for each individual patient. Furthermore, the integration of these modules allows the organization and tracking of the progress of clinical tasks to ensure that all necessary clinical tasks are performed in a timely and efficient manner.

Once the modeling and validation of all openEHR structures supporting corneal transplantation EHRs were concluded, it was necessary to integrate them into an automated solution. The implementation step involved the integration of a set of tools from the openEHR ecosystem, which include FormBuilder, TPEngine, and DLMEngine.

FormBuilder is a web application that is designed to generate user interface forms from openEHR templates. It provides a platform for healthcare professionals who possess modeling knowledge to customize the user interface forms by adjusting the formatting, such as choosing colors, fonts, and determining if fields should be shown or hidden. Additionally, it allows for the association of functions and refsets to form fields, which can add further functionality to the form. By utilizing FormBuilder, healthcare professionals can streamline the process of data entry by creating forms that are intuitive and optimized for their specific clinical workflows.

In turn, the TPEngine is a tool that manages all workflows modeled by the professionals, including materialization, task status, decision management, and allocation of performers. To accomplish this, the TP module defines a formal model for processing tasks and workflows. This tool is designed to translate graphical workflow models into executable models of an organized plan that, when carried out by an engine, notifies employees of tasks. Overall, the TPEngine provides an automated solution for managing and executing complex workflows in the healthcare setting.

The DLMEngine, on the other hand, is a decision logic engine that is responsible for processing clinical or operational rules and triggering specified events based on predefined conditions. This engine plays a crucial role in supporting the logic of forms and TPs. Accordingly, it receives requests from both FormBuilder and TPEngine. It ensures that decision rules are executed correctly and consistently, leading to improved patient care and outcomes.

(Figure 8) illustrates the different interactions that occur between these openEHR modules.

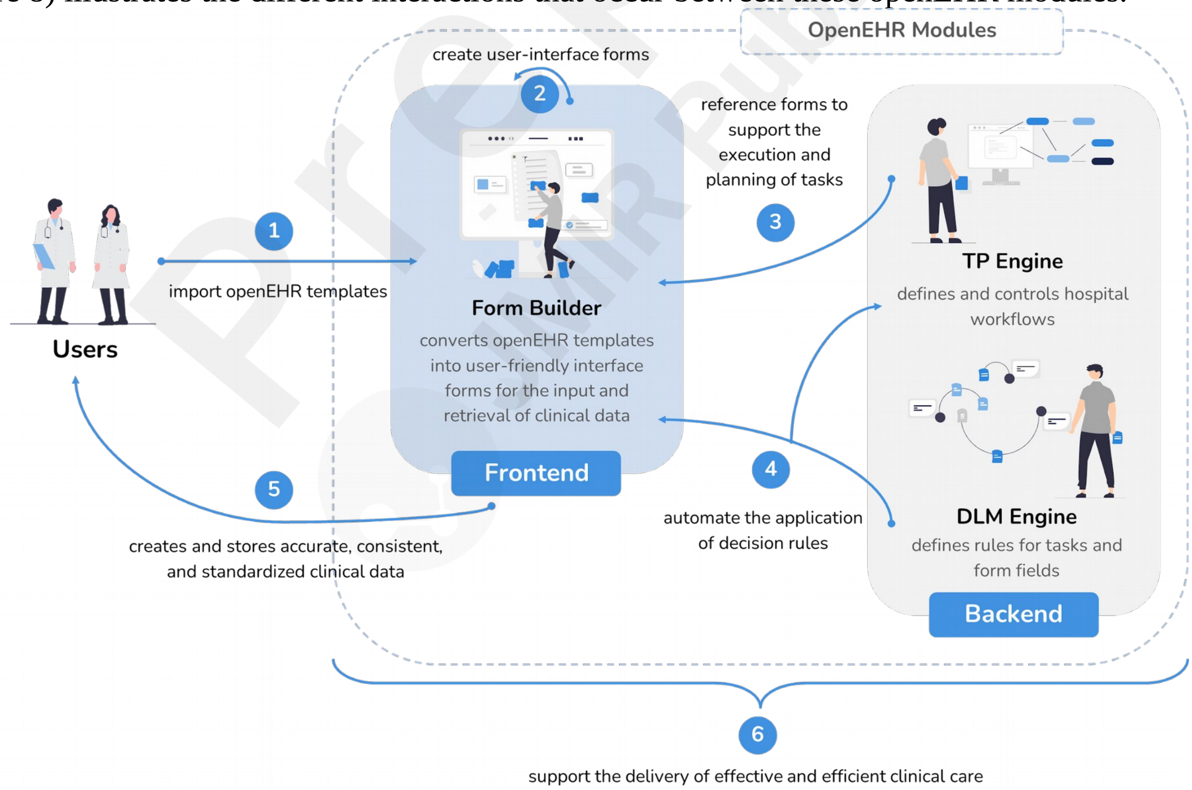

Figure 8. Representation of openEHR modules and their interactions.

The integration of all these components was also explored in this research.
Regarding the integration of FormBuilder and the DLMEngine, the process starts when a healthcare

professional updates a form field. Whenever the value of a field changes, FormBuilder performs an internal processing to check whether that field is a condition of any rule within the DLM associated with the current form. If so, FormBuilder identifies each associated rule and for each of them verifies if there are more associated conditions that already have a value assigned to them. When all the conditions of a rule have an assigned value, FormBuilder triggers a POST request to the DLMEngine with the input variables. This is a well-defined sequence of computational tasks that need to be followed to properly implement the specific set of rules that have been modeled for each form. For better understanding, a graphical representation of the processing that occurs in the FormBuilder to verify the need to trigger any rule requests is presented in (Figure 9).

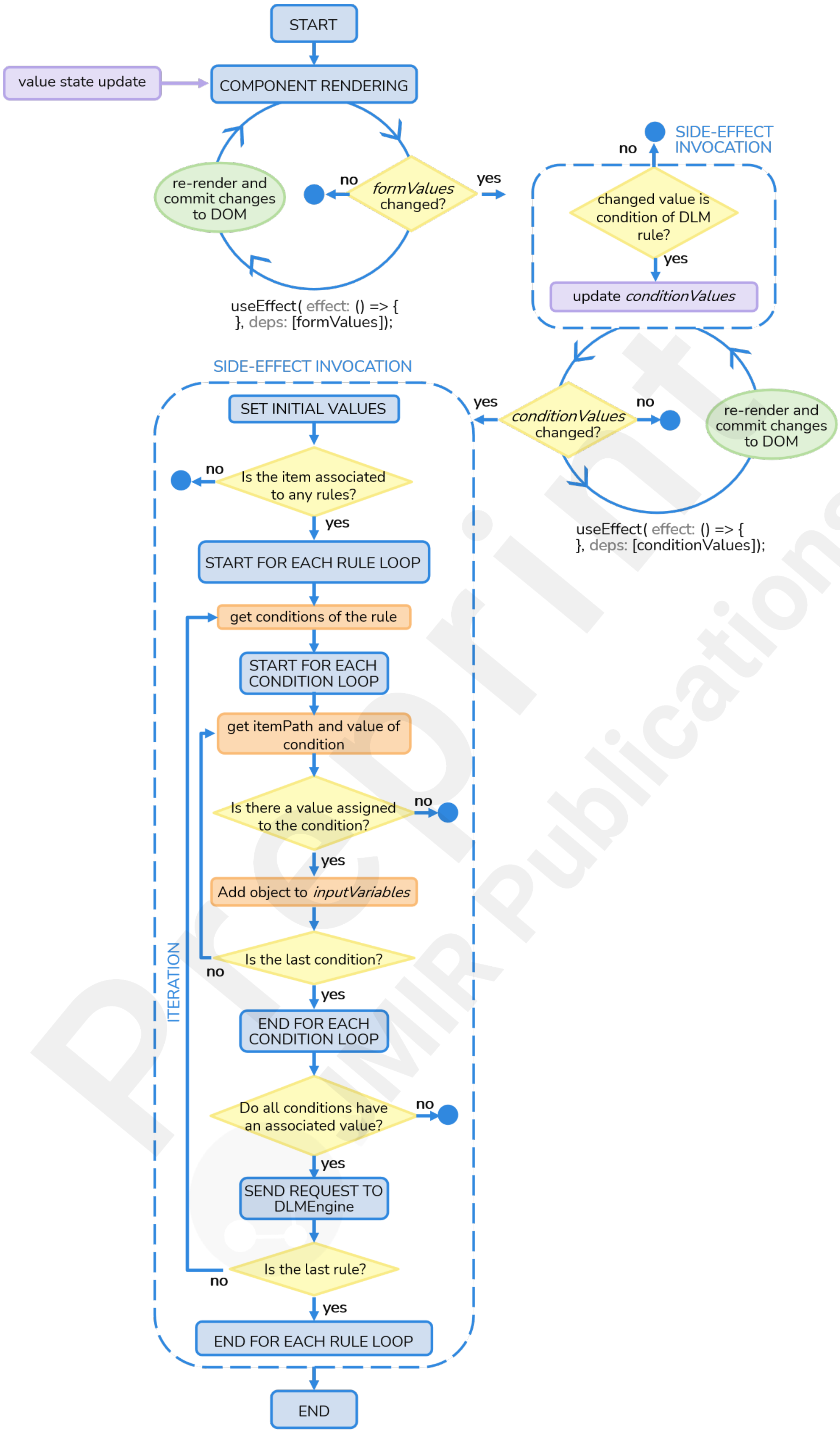

Figure 9. A schematic illustration of the logic flow that occurs in the FormBuilder process responsible for initiating rule requests.

Upon receiving the input variables, the DLMEngine checks whether the conditions are met for executing a given rule. If the values assigned to the form fields do not fulfill a rule, an empty object is returned. On the other hand, if the values meet the conditions for executing a rule, the engine returns the path of the affected field and the type of event to execute. FormBuilder then triggers the necessary actions for each field, depending on the response. (Figure 10) serves as an exemplification of the HTTP requests that are exchanged between the FormBuilder, front-end server, and the DLMEngine, back-end server, in two distinct scenarios. In the first scenario, the health professional enters a value that triggers the execution of a rule, while the second scenario does not involve the activation of any rule. This diagram provides a clear representation of the data flow and communication between the two servers during the execution of the rule-based system.

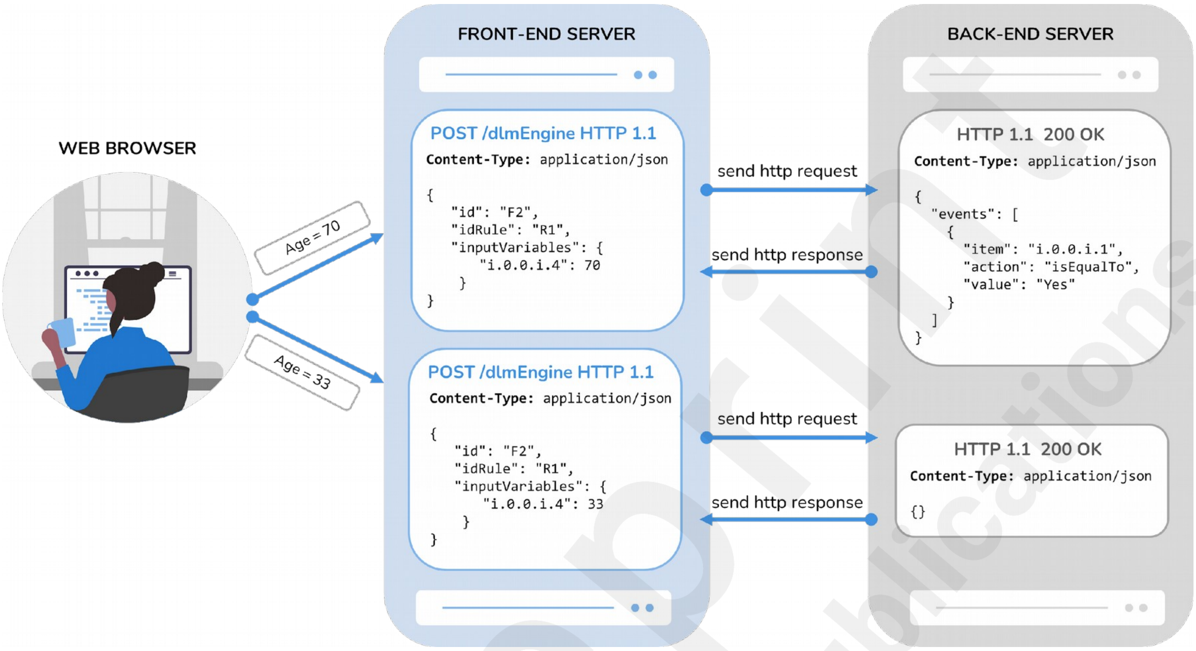

Figure 10. Diagram of HTTP request and response interactions between the Form Builder, which acts as the front-end server, and the DLMEngine, which serves as the back-end server, in two distinct settings.

The integration of the DLMEngine with the TPEngine represents a remarkable achievement in the openEHR ecosystem. The successful interaction between the two enables the handling of all conditional structures encompassed in a WP, including condition groups, decision groups, and event groups, with the support of the DLMEngine. In general, when the path of a WP materialization reaches a decision point, a request is issued to an Application Programming Interface (API) provided by the DLM engine, with the variable associated with that point. In turn, the DLMEngine processes the rules and conditions associated with the request that was made and returns a response. Through the response received, TPEngine manages to associate it with the respective branch (decision branch, condition branch or event branch) and proceed with its execution.

In the openEHR ecosystem, the TPEngine can refer openEHR forms to support the planning and execution of hospital tasks. By providing a user-friendly interface for entering and retrieving data, the FormBuilder makes forms available to healthcare professionals that can be used to collect data required for various tasks and it ensures that the collected data is accurate and standardized. Furthermore, the responses given by healthcare professionals in certain fields of the form can be determinant to define which path should be triggered after submitting the form. By integrating TPEngine and FormBuilder, healthcare providers can ensure that relevant information is captured and acted upon as part of the patient's care plan, leading to improved patient outcomes and increased efficiency in healthcare delivery. This integration enhances the quality of care provided to patients and enables healthcare professionals to make informed decisions based on accurate and timely data.

After successfully integrating these components in a symbiotic IT environment, it was possible to install the solutions in the Portuguese hospital in order to implement and evaluate them in a real-world setting.

This hospital has established a collaborative relationship with the research center where the working group has been inserted for several years. Given this existing partnership, the hospital was deemed an ideal site to deploy and assess the newly developed solution.

Considering the current IT infrastructure of the hospital, the amalgamation of the proposed solution was not hampered by any intricate integration challenges and unfolded as a straightforward process. In order to streamline the workflow and improve efficiency, the FormBuilder was integrated into a web application already implemented in the hospital that presents a detailed listing of the tasks assigned to a certain user. This integration enables healthcare professionals to view a comprehensive list of assigned tasks and submit completed forms directly through the portal. The TPEngine is the mechanism that controls and triggers the tasks made available to the medical team on the professional portal. As a result, the professional portal serves as a centralized hub for task management and data collection, enhancing the overall clinical workflow.

To ensure that only authorized healthcare professionals had access to corneal transplantation tasks, it was necessary to create specific members for this purpose within the demographic of professionals with their respective capabilities, roles, and functions. Once the members of each team were established, they were associated to the respective tasks. By establishing a clear hierarchy of roles and responsibilities, the hospital is able to ensure that the tasks related to corneal transplantation are being accessed and completed by qualified and authorized personnel.

The collaboration between the healthcare institution and the research center has paved the way for the exchange of knowledge and resources, allowing for a more efficient and effective implementation of the solution. Furthermore, this cooperation has fostered a culture of innovation and continuous improvement in the hospital's clinical practices, ultimately yielding beneficial outcomes for the patients.

The main challenges encountered during deployment were related to the lack of healthcare professionals with knowledge in openEHR and modeling skills. As a result, the team conducted several demonstrations and provided comprehensive documentation to facilitate the users' adoption of the tools. Despite these challenges,
the feedback and acceptance from medical staff were generally positive, as they reported ease of adaptation and expressed satisfaction with the provided tools.

Statistical Analysis

In a data-driven world, statistical analysis has become critical to gain insights and draw conclusions that may not be immediately apparent through simple visual inspections. It holds particular significance in the realm of health research, where it can be used to evaluate the effectiveness and efficiency of IT solutions, such as EHRs, telemedicine platforms, and other digital health tools. In this way, healthcare professionals can identify areas for improvement, including the streamlining of workflows, the enhancement of usability, and the resolution of technical glitches, ultimately leading to improved patient outcomes and enhanced quality of care.

Overall, the importance of data analytics in the healthcare domain cannot be overstated, as it has the potential to significantly impact the lives and well-being of countless individuals. Hence, to verify the efficiency and performance of the solutions offered to manage the corneal transplantation process, this section presents an analysis of the data gathered over the period of study from May 1st, 2022 to March 31st, 2023. This analysis will include relevant indicators and charts. Prior to presenting the data analysis, a brief overview of the data collection process will be provided.

The data collection process for this research study required careful planning, attention to detail, and adherence to ethical guidelines to ensure the accuracy and validity of the data. First, the databases and tables of interest were selected. Then, an anonymization process was carried out in order to preserve the identity and privacy of the patients, which involved removing any personal identifying information from the data. Once the data had been anonymized, the relevant SQL queries were developed in order to extract the data required. Finally, after the data had been extracted, it was meticulously organized into descriptive statistics, in the form of indicators, charts, and graphs, to ease interpretation and help convey the findings.

(Figure 11) includes the graphical representation of key indicators in the corneal transplantation process, including task volume, task conclusion and patients enrolled. The task volume represents the number of tasks available for healthcare professionals to fill out the corresponding forms, while task conclusion corresponds to the number of tasks successfully submitted by healthcare professionals. On the other hand, patient enrollment indicates the number of patients registered in the corneal transplantation list.

Figure 11. Single number indicators of corneal transplantation, including task volume, task conclusion and patient enrollment.

A donut chart was used in (Figure 12) to visually depict the proportion of concluded tasks in comparison to the number of available tasks. This graphical representation provides a clear and concise overview of the overall task completion rate and offers a general picture of how well tasks are being managed and completed. The number of available and completed tasks can help to gauge the workload of healthcare professionals and assess the capacity of the system to handle the demands of the workflow. A higher number of completed tasks relative to available tasks indicates that the system is functioning efficiently and effectively. Meanwhile, a lower completion rate could suggest potential bottlenecks or areas for improvement in the system's design or implementation.

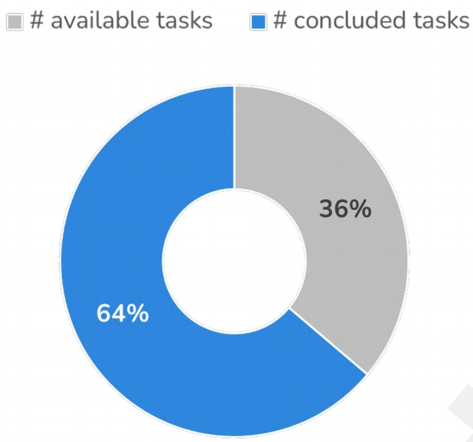

Figure 12. Proportional analysis of task conclusion and task availability within the corneal transplantation workflow.

The total number of corneal transplantation forms submitted by healthcare professionals over time can be consulted in (Figure 13). This graphical representation allows the visualization of trends and patterns in form submission and provides insights into the volume and frequency of tasks completed.

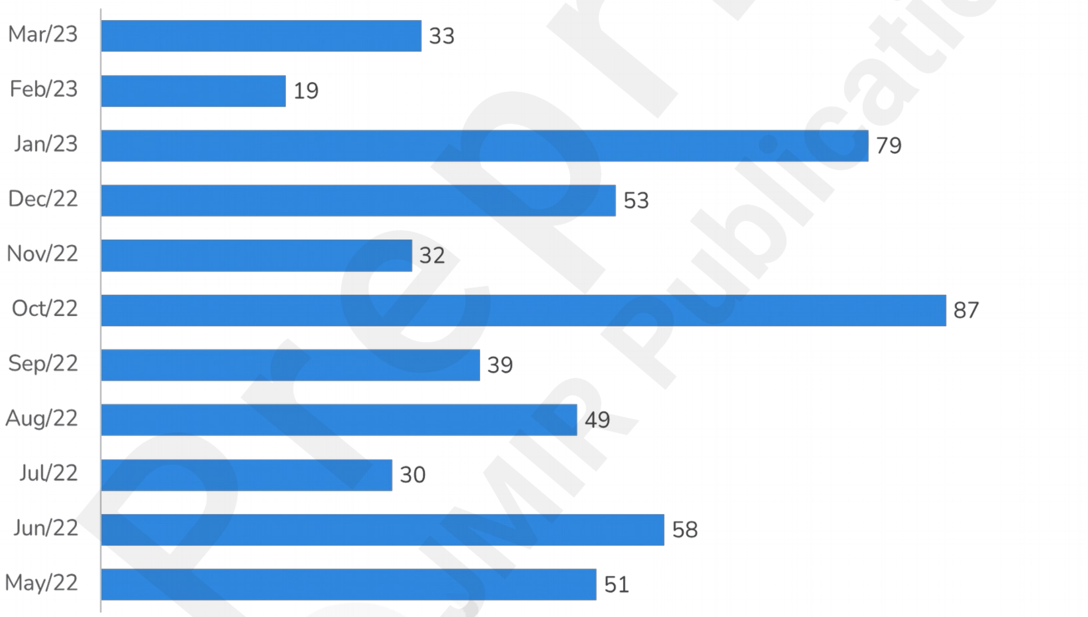

Figure 13. Total number of corneal transplantation tasks submitted over time.

Since the corneal transplantation workflow is a complex process involving the completion of a variety of different tasks, a pie chart was used in (Figure 14) to help visualize the distribution of these tasks across the different form categories. This chart displays both the numerical and percentage distribution of submitted tasks according to each respective form category.

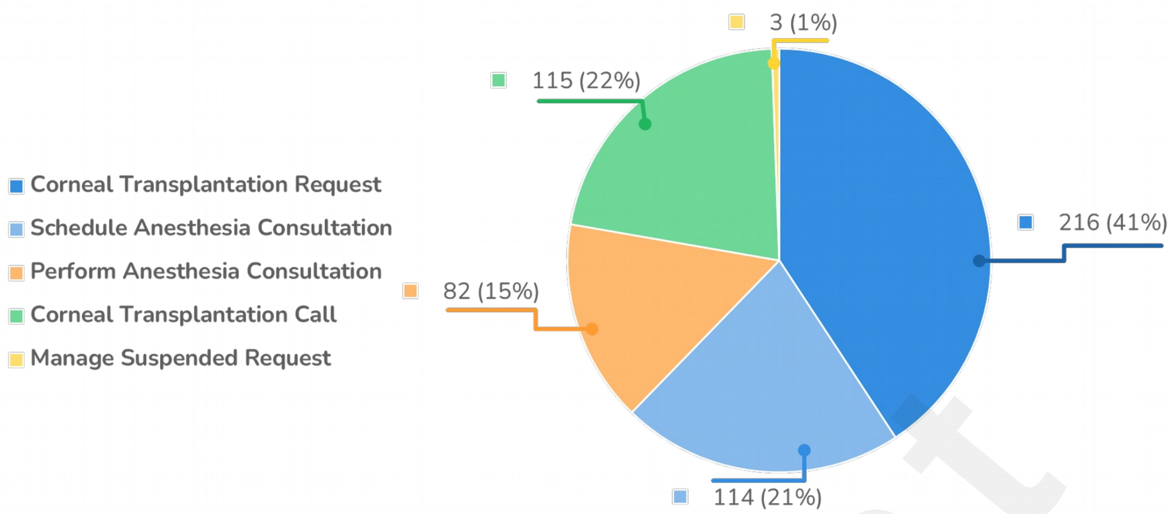

Figure 14. Categorization analysis of submitted forms within the corneal transplantation workflow.

Last but not least, to provide a comprehensive visualization of the number of tasks submitted over time for each form category, a stacked bar chart was employed in (Figure 15). This chart displays the total number of tasks completed and submitted for each form category over the period of time under consideration, helping to assess the relative contributions of each form category to the overall workflow.

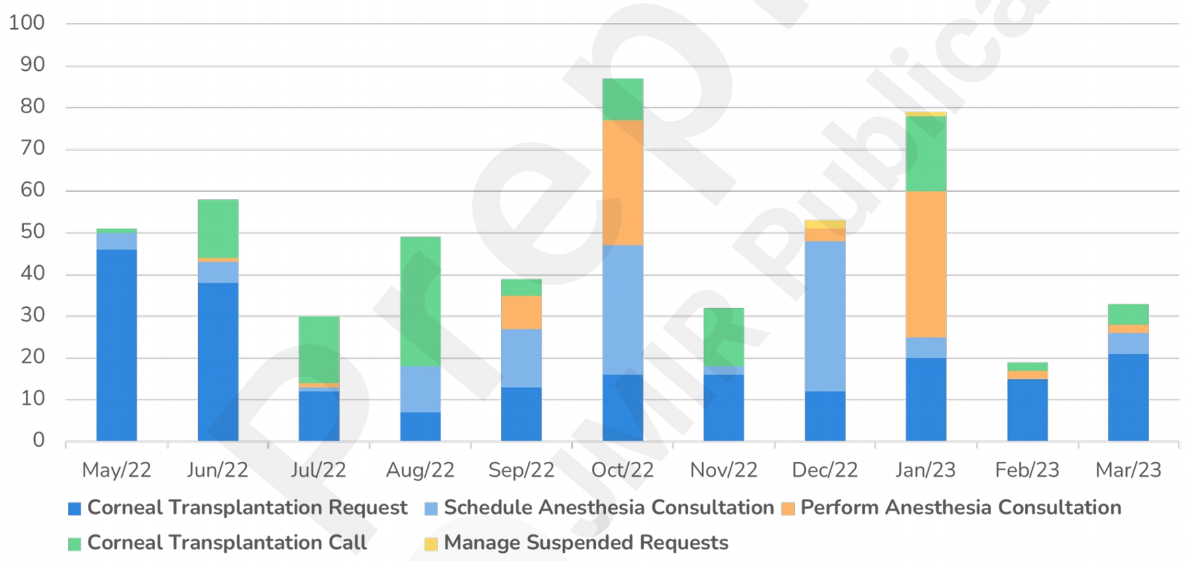

Figure 15. Number of submitted tasks within the corneal transplantation workflow for each form over time.

Discussion

Principal Findings

The findings of the current study offer a comprehensive and in-depth overview of the incorporation of various components of openEHR specifications, particularly the interaction of openEHR forms, WPs, and DLMs, which had not yet been fully covered in the scientific literature.

In order to evaluate the impact of the solution, the openEHR structures were incorporated into a workflow and integrated into the healthcare institution. The present study demonstrates the effects of the intervention on the corneal transplantation workflow, which was previously characterized by inadequate automation and an intensified risk of data loss. The use of the new technologies has the potential to substantially influence the workload of healthcare professionals and, consequently, affect patient care outcomes. Therefore, in addition to providing a thorough description of the implementation process, this study also presents a statistical analysis of its effects.

The indicators presented in the statistical analysis section, which are represented in (Figure 11), show the number of available tasks, completed tasks, and patients enrolled in the corneal transplantation list during the timeframe of this study.

The number of available tasks is 830, which represents the total number of tasks that need to be completed. Of these tasks, 530 have been completed, indicating that the completion rate of the tasks is therefore 64%.

The number of available and completed tasks, represented in (Figure 12), can help to gauge the workload of healthcare professionals and assess the capacity of the system to handle the demands of the workflow. A higher ratio of completed tasks to available tasks indicates that the system is working efficiently and effectively. A lower completion rate, on the other hand, may suggest potential bottlenecks or areas for improvement in the system's design or implementation.

As a result, a 64% completion rate falls short of expectations. This lower rate could be explained by a number of factors. First, the hospital may have limited resources to complete the tasks within the workflow, leading to delays in completing the tasks. Furthermore, the healthcare professionals responsible for completing the tasks within the workflow may not have received enough training or may be inexperienced, which may imply some reluctance in adopting the new technologies.

Because the majority of the available tasks within the studied workflow regard the “Contact for Corneal Transplantation”, which represents the active waiting list for corneal transplantation, the workflow completion depends on external factors such as patient health and availability of donor organs. These dependencies directly affect the time required to complete the tasks and, consequently, the total workflow.

Due to the complexity of the corneal transplantation process, a multidisciplinary service team is required, namely the anesthesia team and the ophthalmology team, which can cause communication issues among the teams and, as a result, delays in task completion.

These factors may also explain the fluctuations in the number of task submissions over time depicted in (Figure 13). Hence, as a result of the influence of these factors, it was not possible to establish patterns in the data over time, as expected given the non-seasonal nature of the data.

Furthermore, the enrollment of 197 patients is a significant aspect of the data as it serves as a critical contextual element in assessing the workload. It should be noted, however, that the number of enrolled patients, as previously mentioned, does not accurately reflect the total number of corneal transplantation proposals submitted. This is because a single patient may be registered multiple times to undergo different procedures. As a result, the number of enrolled patients may not be a direct indicator of the workload or the number of tasks that need to be completed in a corneal transplantation workflow.

In this sense, to gain a more comprehensive understanding of workload management within a hospital setting, a more specific study on the different types of tasks available was required. This analysis enables more detailed scrutiny of the specific challenges and constraints associated with each task type and allows for the identification of more targeted solutions to enhance efficiency and productivity.

A quick look into (Figure 14) reveals a higher rate, 41%, of completed tasks associated with the “Corneal Transplantation Proposal” in comparison to the remaining tasks. This rate can be explained by the lack of resources to perform the transplants at a quicker pace. It is also worth noting that the form with the lowest submission rate is associated with the “Management of Suspended Proposal”, indicating the fewer cases in which the corneal transplantation proposals were suspended.

Finally, (Figure 15) depicts the number of submitted tasks according to each form over time. In the first months, it is possible to observe that the tasks associated with the “Contact for Corneal Transplantation” increased, whereas the number of “Corneal Transplantation Proposal” decreased. From August of 2022, it can be seen a higher number of submitted tasks pertaining to the “Schedule Anesthesia Consultation”. As a result, a month later, it is possible to observe an increase in the number of tasks pertaining to the form “Perform Anesthesia Consultation”.

The findings of this analysis emphasize the importance of effective workload management within a hospital setting. By monitoring and analyzing the number of tasks available and completed, hospitals can identify areas for improvement and ensure that patient care is not jeopardized. Additionally, the study can help to identify potential bottlenecks and areas of inefficiency in current workflows, informing the design and implementation of targeted interventions to enhance the effectiveness of healthcare operations.

Limitations

A paper outlining the implementation steps of clinical standards in a hospital setting is a valuable resource for identifying best practices and areas for improvement, as well as for advancing patient care. However, it is important to acknowledge its potential limitations to fully understand its impact on healthcare.

Resource limitations are an important concern to consider as the implementation of openEHR specifications requires staff time and training, which can pose additional challenges for healthcare organizations. One difficulty encountered in this study was the staff workload as the implementation of the solution presented in this paper required them to attend training sessions and meetings, as well as to review new policies and procedures. Changes in work processes and team dynamics were an additional threat to the implementation of the solution as it was necessary to update team members' permissions and roles.

Training was another area where difficulties were met, as healthcare providers had to learn new skills and competencies to use the specifications effectively, which involved getting accustomed to new technology and tools. This was particularly challenging for those who were less comfortable with technology, limiting their willingness to adopt new practices and posing resistance to change.

Finally, it was essential to consider time constraints because the findings discussed in this paper pertain to the duration of the study. The adoption of clinical standards is an ongoing process, and the paper may not be able to fully capture the long-term effects of the implementation.

Conclusions

Traditional healthcare is plagued by the use of disparate systems for managing patient data, leading to a fragmented view of medical records as well as inconsistencies and gaps in clinical information. Without standardized and efficient systems in place, there is a higher risk of medical errors, miscommunication, delayed or inadequate diagnoses, and suboptimal treatment decisions, which can ultimately compromise patient safety and healthcare quality. In addition, this issue underscores the importance of interoperability in healthcare.

In the case of corneal transplantation, accurate and timely management of patient information is critical for the success of the procedure and the well-being of the patient. Hence, this study proposes the adoption of clinical standards, specifically openEHR, to address these challenges by enabling the creation of a comprehensive and shared patient record. The paper provides insights into the use of openEHR in healthcare and contributes to the incessant efforts to improve the quality and safety of patient care.

The implementation of openEHR specifications to standardize corneal transplantation records and streamline its workflow can yield significant benefits to patients, healthcare providers, and the healthcare system as a whole. Standardized EHRs can ensure the accuracy, consistency, and completeness of data entry and management, leading to increased patient safety and reduced medical errors. Furthermore, it serves as a centralized repository for clinical data, enabling healthcare providers to access information more easily and facilitating the seamless exchange of data between different healthcare systems. openEHR can also support clinical decision-making by providing real-time access to patient data and enabling clinicians to make more informed decisions about patient care.

In summary, the process that connects openEHR forms, work plans, and DLMs ensures that the best course of action for a given patient is taken by providing real-time decision support, data validation, automated actions, and ensuring that patient data is accurate, consistent, and accessible, as well as that all necessary clinical tasks are performed in a timely and efficient manner.

Although the study focuses on the implementation of clinical standards in a specific healthcare setting, the principles and strategies used to implement openEHR specifications remain relevant and applicable in other health contexts. Hence, the findings of the study hold considerable value for healthcare professionals, hospital administrators, and technology developers, providing critical insights into the implementation of openEHR specifications within a hospital setting and paving the way for the development of innovative solutions to optimize healthcare operations.

In light of these benefits, it is clear that the adoption of openEHR structures for the standardization of corneal transplantation records represents a critical step forward in the pursuit of safer, more effective, and higher-quality care. Hence, the authors believe that using openEHR specifications will become standard practice in the healthcare industry in the near future.

Future research could focus on the application of artificial intelligence algorithms to data extracted from standardized EHRs, as training algorithms on reliable, consistent, and high-quality data leads to more robust and trustworthy results. This can enable a more efficient and effective clinical data analysis, maximizing the potential of openEHR to drive meaningful improvements in healthcare outcomes.

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Conflicts of Interest

None declared.

Abbreviations

AD: Archetype Designer
AMM: Archetype Modeling Methodology
API: Application Programming Interface
CKM: Clinical Knowledge Manager
DL: Decision Language
DLM: Decision Logic Module
EHR: Electronic Health Record
HIS: Health Information System
IT: Information Technology
JDT: JSON Data Template
OPT: Operational Template
RM: Reference Model
TP: Task Plan
WHO: World Health Organization
WP: Work Plan

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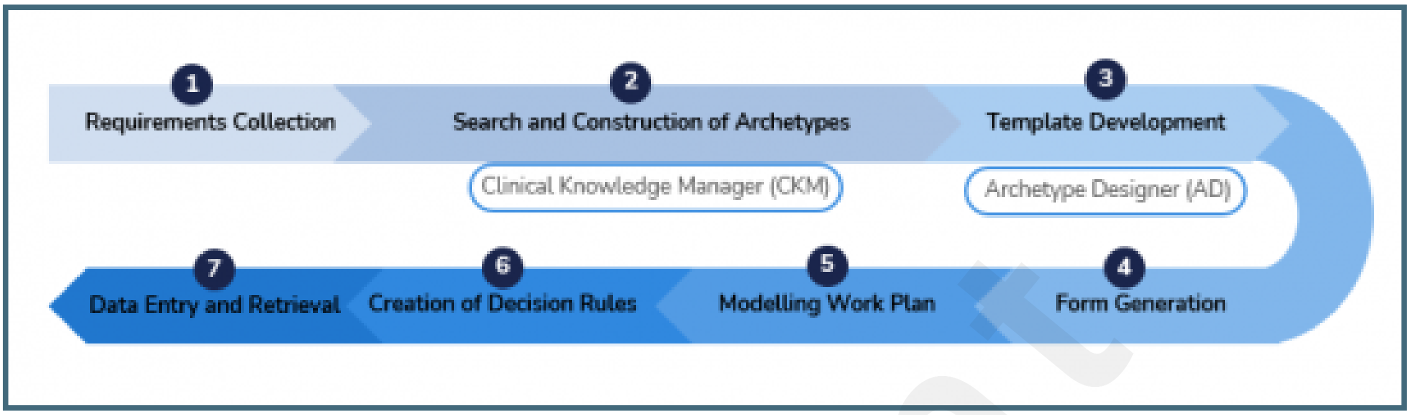
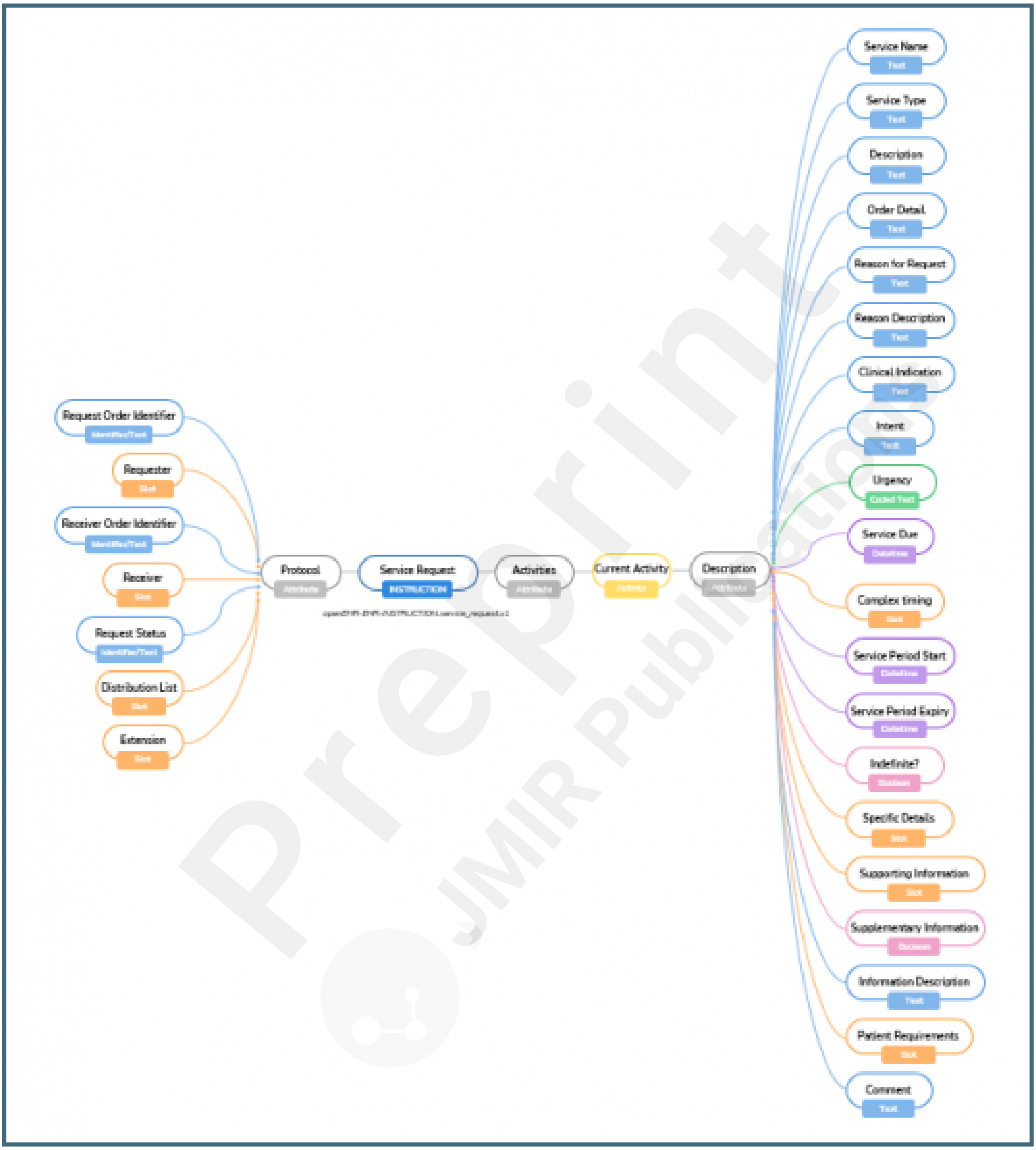
Supplementary Files

Figures

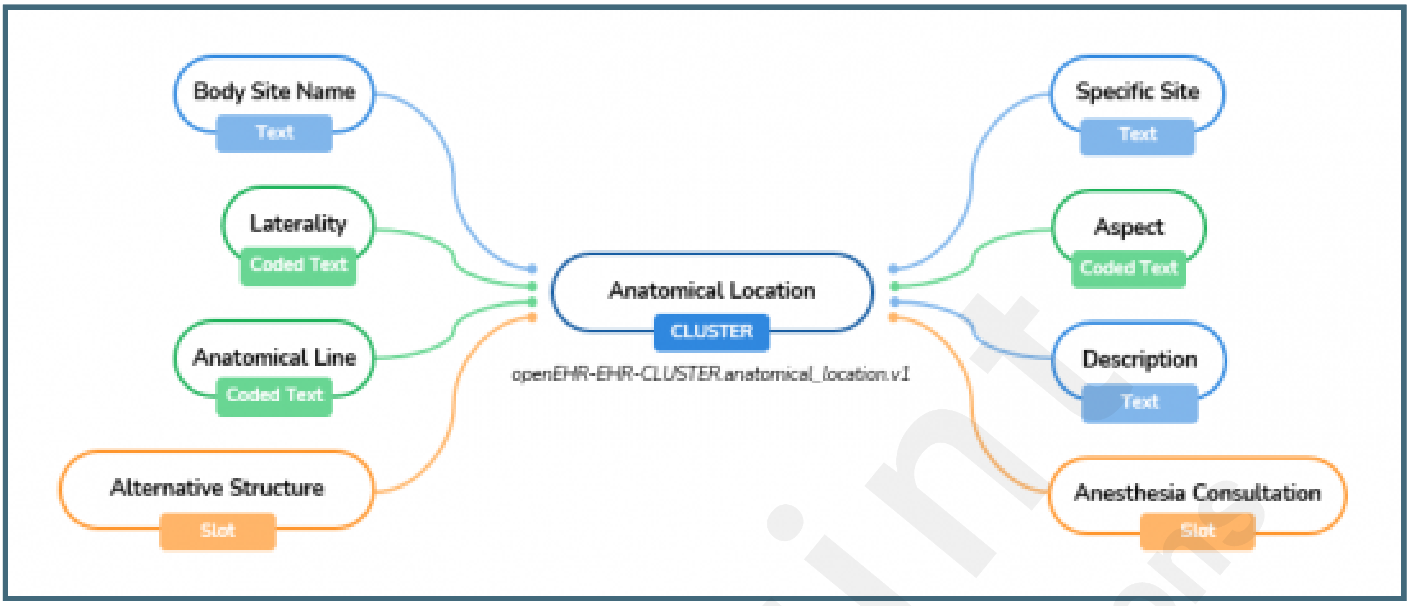
Methodological approach followed in the standardization of corneal transplantation EHRs using openEHR specifications.



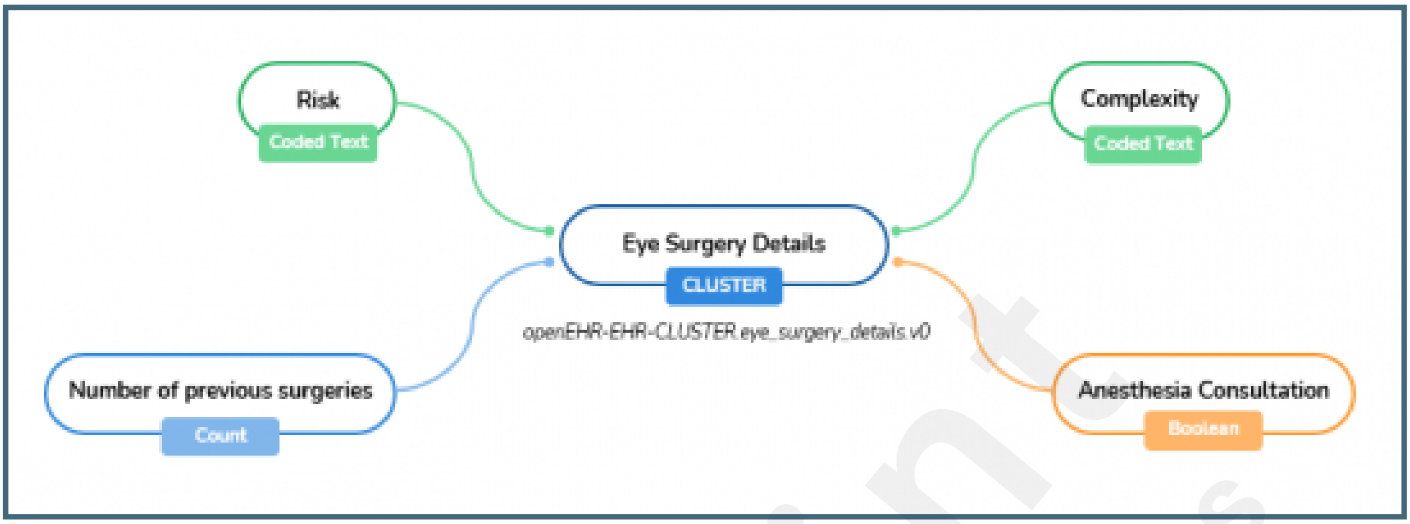
Mind-map view of the “Service Request” archetype.



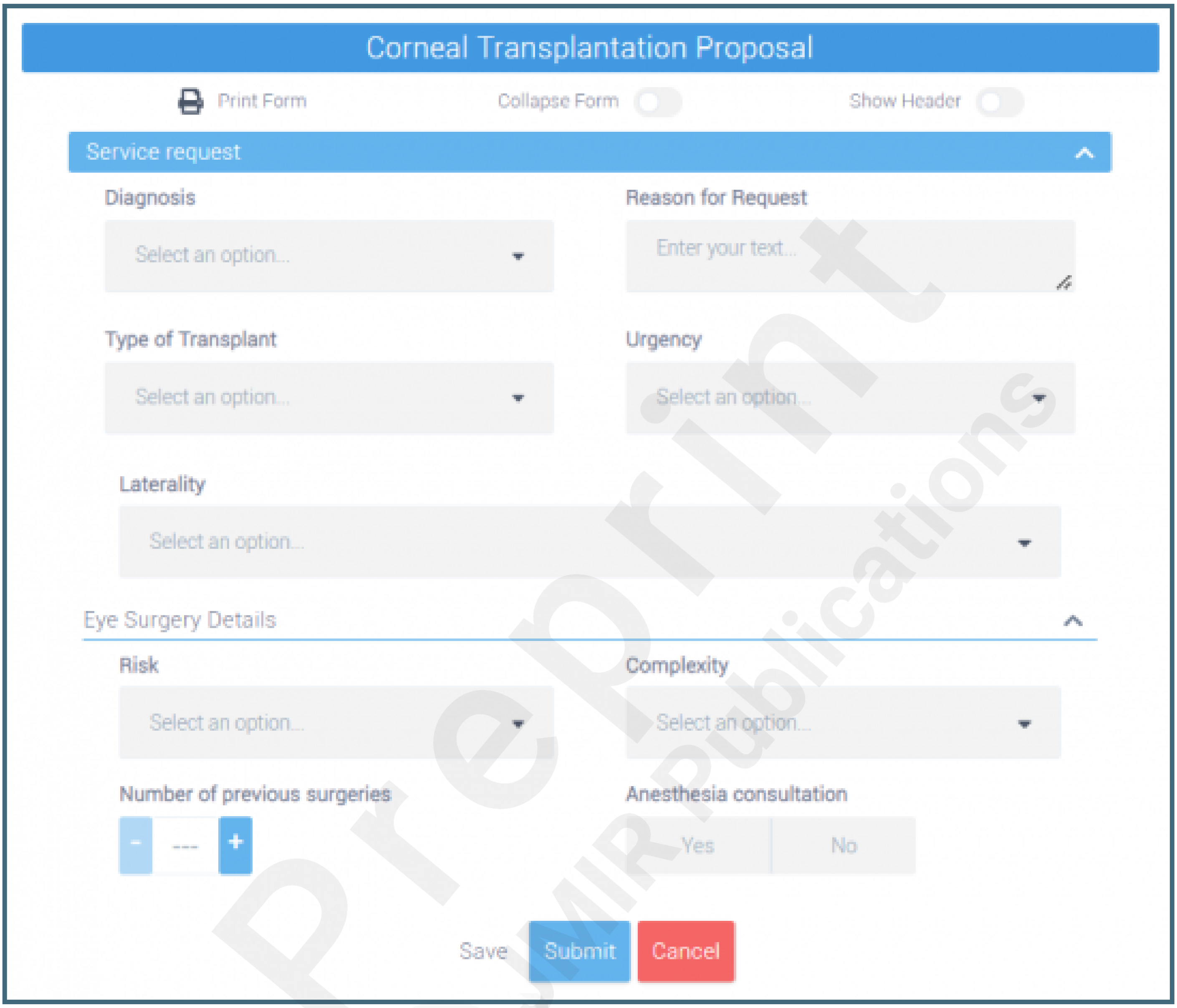
Mind-map view of the “Anatomical Location” archetype.



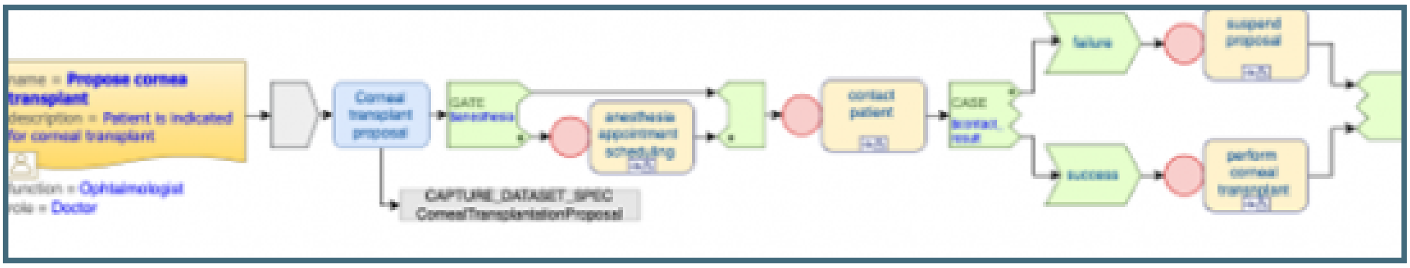
Mind-map view of the “Eye Surgery Details” archetype.



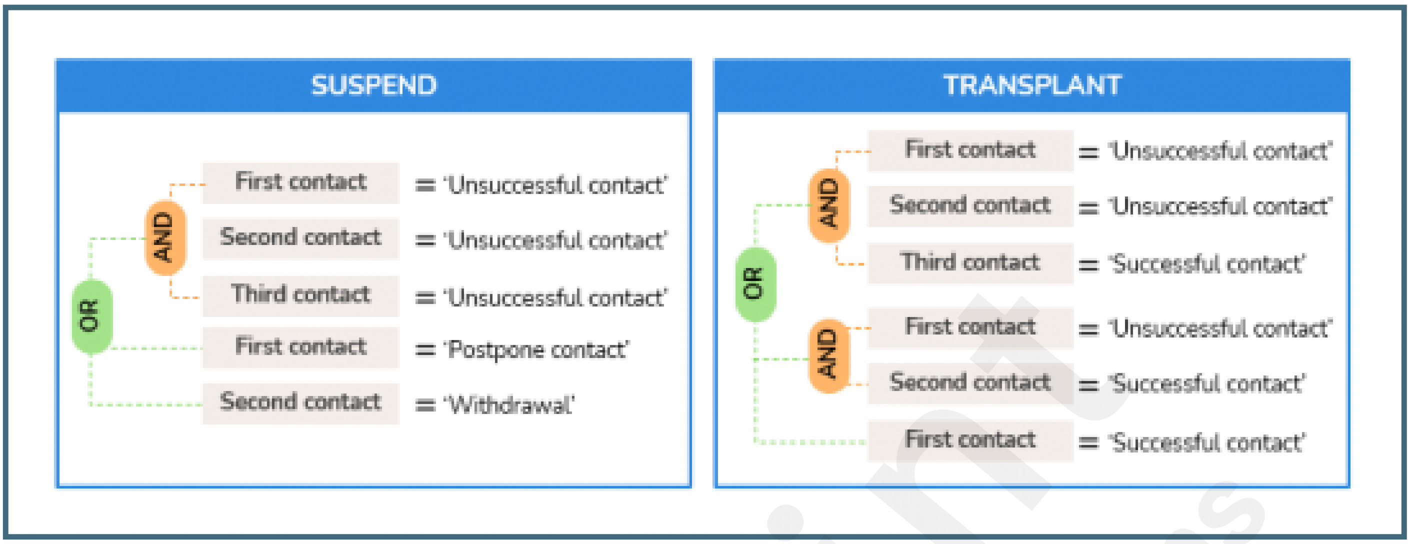
Graphic representation of the user interface form generated from the “Corneal Transplantation Proposal” template.



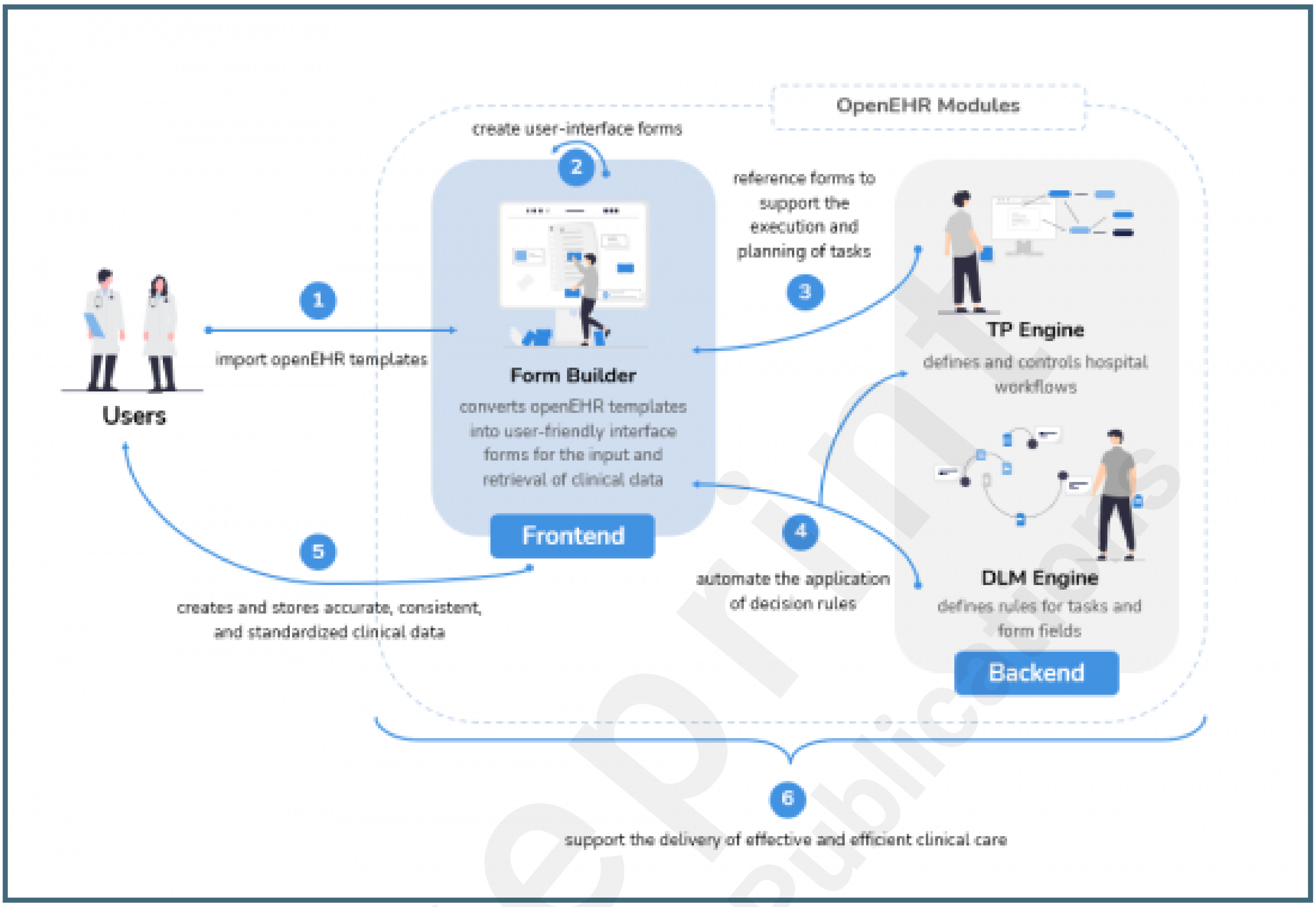
Representation of the top-level task plan.



Decision logic associated to the WP.



Representation of openEHR modules and their interactions.



A schematic illustration of the logic flow that occurs in the FormBuilder process responsible for initiating rule requests.

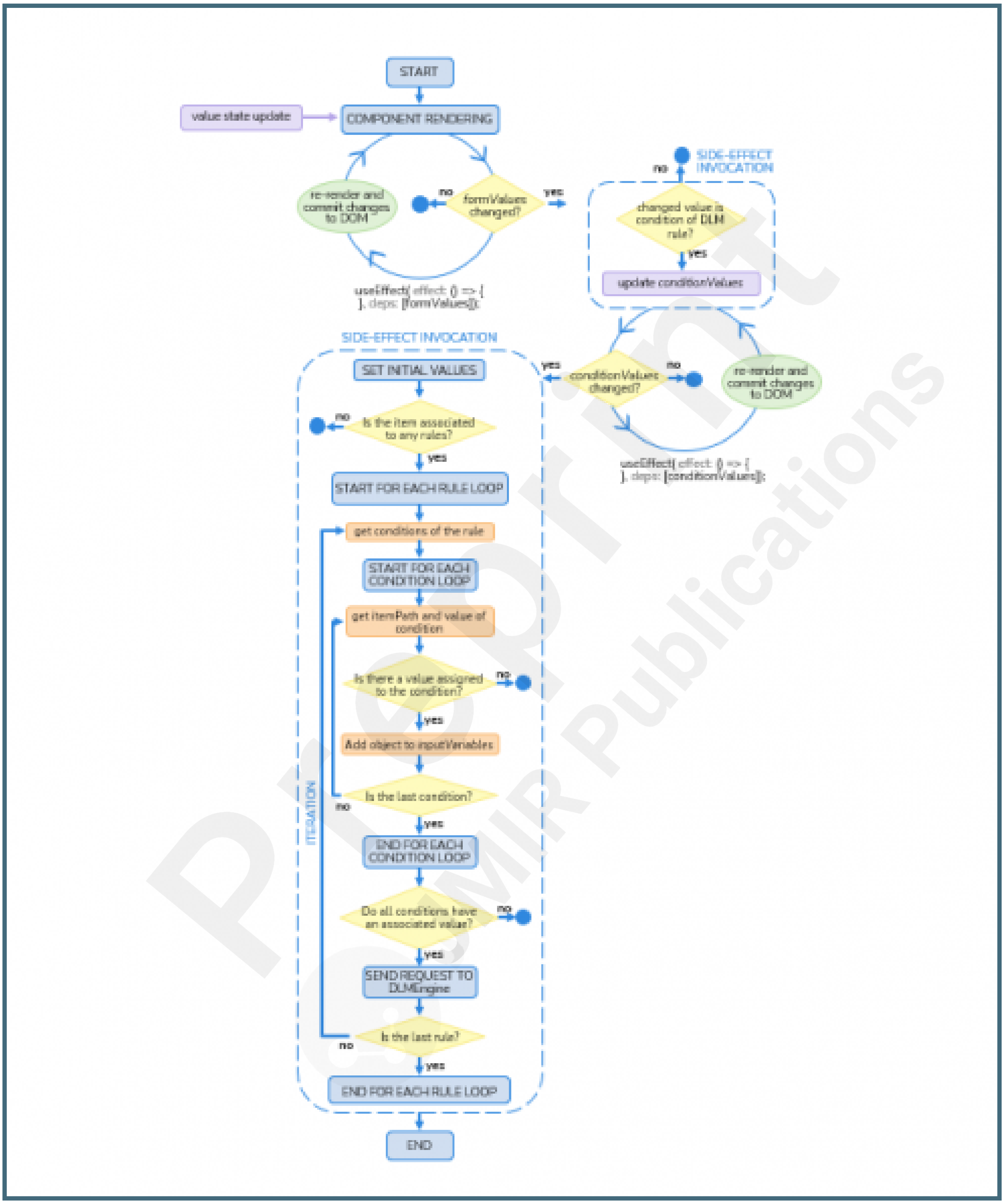
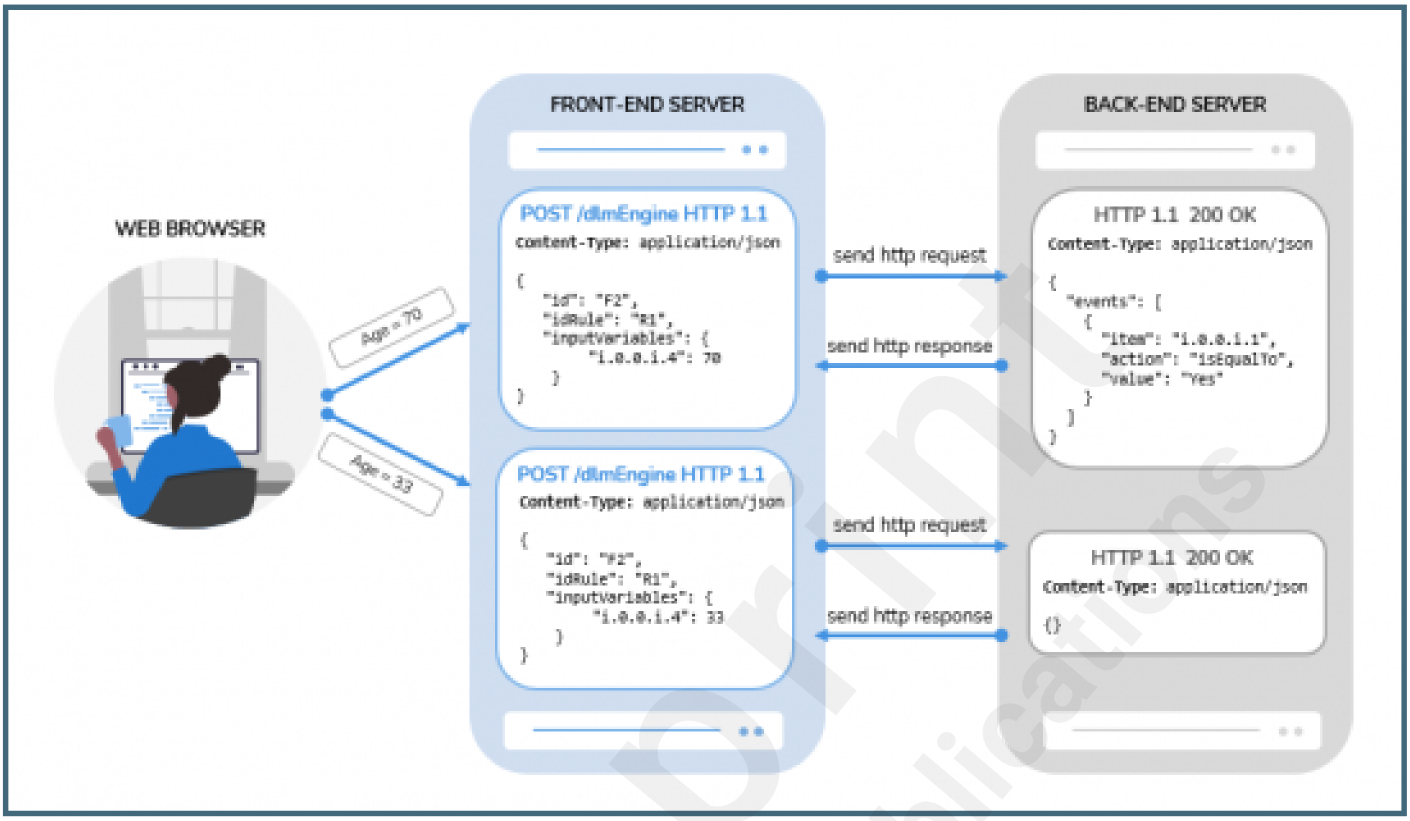
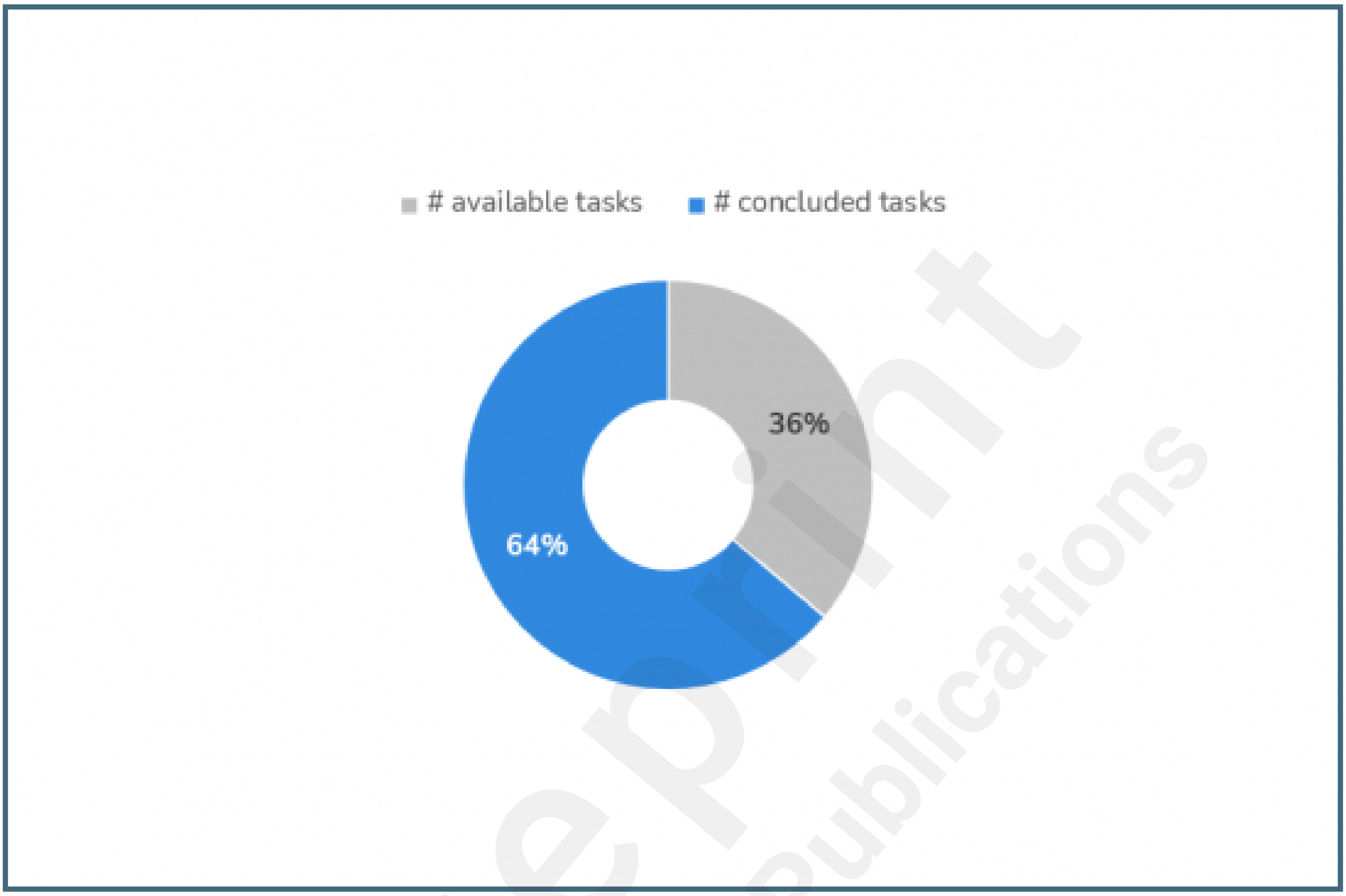


Diagram of HTTP request and response interactions between the Form Builder, which acts as the front-end server, and the DLMEngine, which serves as the back-end server, in two distinct settings.

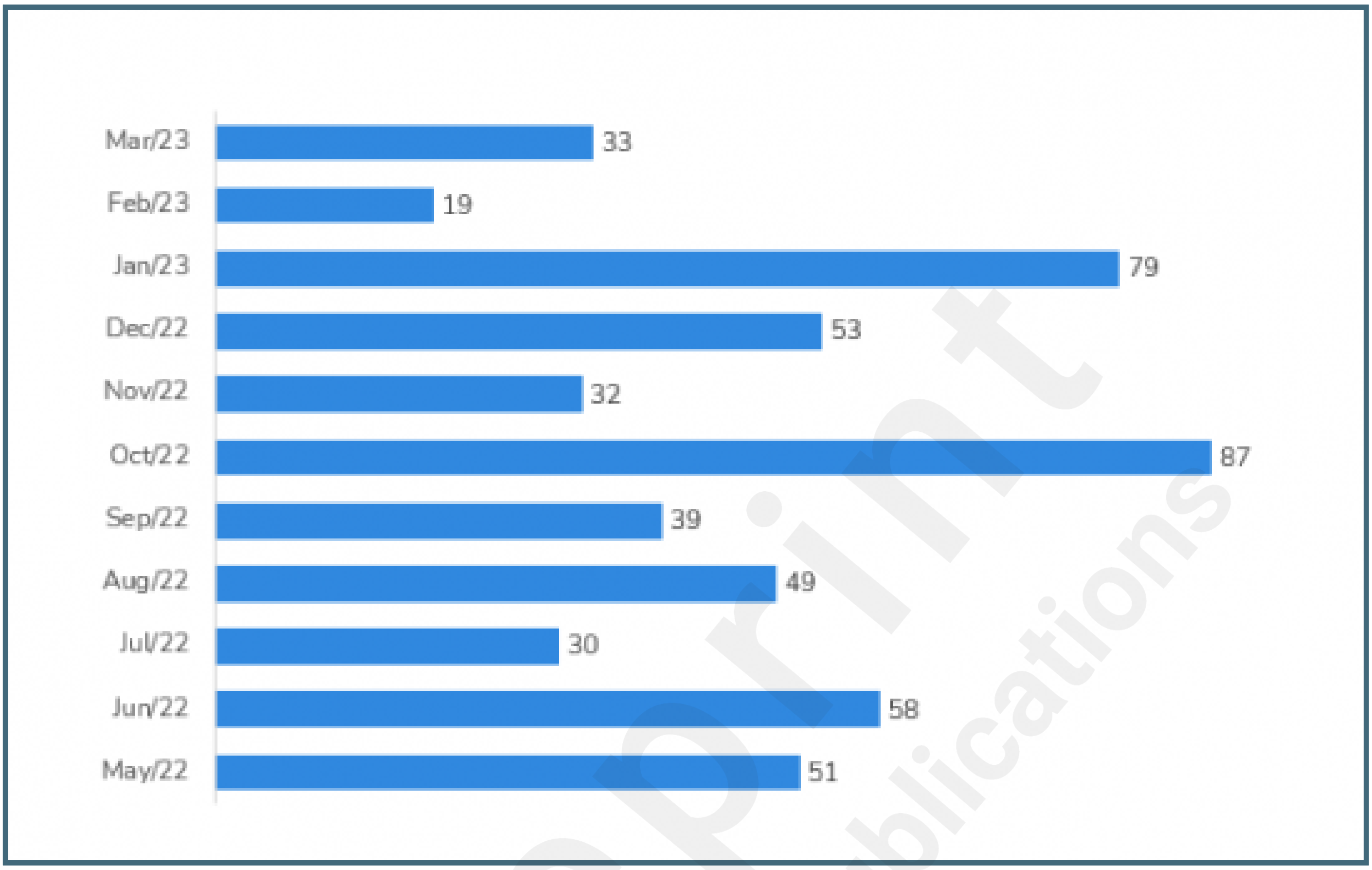


Single number indicators of corneal transplantation, including task volume, task conclusion and patient enrollment.

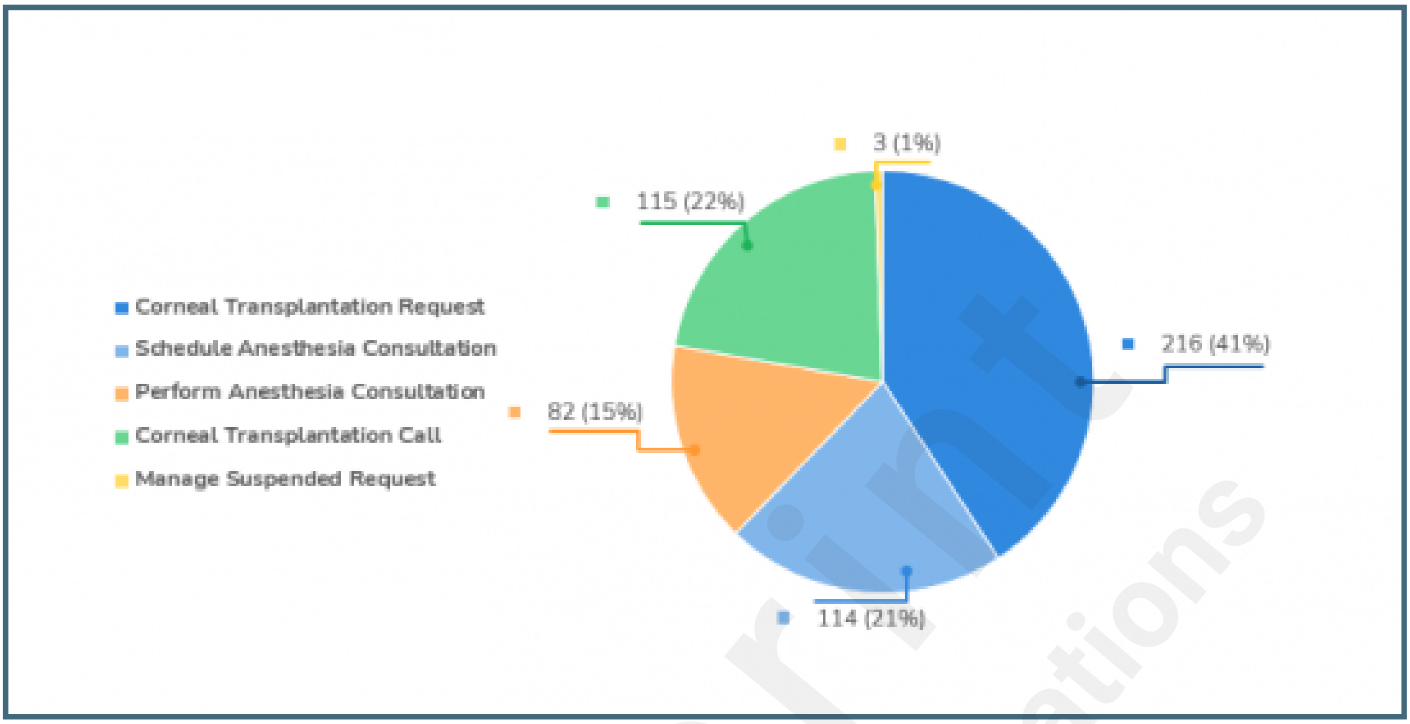
Proportional analysis of task conclusion and task availability within the corneal transplantation workflow.



Total number of corneal transplantation tasks submitted over time.



Categorization analysis of submitted forms within the corneal transplantation workflow.



Number of submitted tasks within the corneal transplantation workflow for each form over time.