Technology of Decision-Making Support Regarding the Possibility of Donation and Transplantation Considering Civil Law

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Summary
The review of known decision-making support systems and technologies regarding the possibility of donation and transplantation showed that currently there are no systems and technologies of decision-making support regarding the possibility of donation and transplantation considering civil law. The paper models the decision-making support process regarding the possibility of donation and transplantation, which is a theoretical basis for the development of rules, methods and technology of decision-making support regarding the possibility of donation and transplantation considering civil law. The paper also developed the technology of decision-making support regarding the possibility of donation and transplantation considering civil law as a component of the Unified State Information System for Organ and Tissue Transplantation, which automatically and free of charge determines the possibility/impossibility of donation and transplantation. In the case of the possibility of donation, the admissible type of donation is also determined – over-life or after-life donation – and data about potential donor is entered in the relevant Donor Register. In the case of the possibility of transplantation, if the recipient needs a transplant of one of the paired organs or a part of the organ/tissue, then data about potential recipient are entered in the Transplantation List from both over-life and after-life donor, otherwise, if the recipient needs a transplant of a non-paired organ or both paired organs, then data about potential recipient are entered only in the Transplantation List from after-life donor.

Keywords:
Donation, transplantation, data on potential donors and recipients, semantic analysis (parsing) of natural language data on potential donors and recipients, decision-making support regarding the possibility of donation and transplantation.

1. Introduction

Transplantation of organs/tissues is sometimes the only means of saving human life and restoring patient's health. Transplantation is used when medical or surgical methods of treatment are not possible, but the patient has the potential for further healthy activity. In total, more than 1 million people with transplanted organs/tissues live in the world today, who lead an active lifestyle and even play sports [1].

According to the Law of Ukraine "On the Application of Transplantation of Anatomical Materials to Humans" [2], transplantation is a special method of treatment that consists in transplanting an organ or other anatomical material taken from a person or an animal into the recipient. Transplantation is the transfer of human cells, tissues, or organs from a donor to a recipient in order to restore their function(s) in the body [2]. Transplantation as a method of treatment is used exclusively in the presence of medical indications, which are determined by the council of doctors of the relevant health care institution or scientific institution, and on the condition that the use of other means and methods for maintaining life, restoring or maintaining health does not give the desired results. Donation is the voluntary transfer of blood and other human organs in order to help heal and recover for other people [2]. There are two types of donation: after-life donation (with the consent of the person during his life or family members after his death) and over-life donation (with the consent of the donor, donation of one of the paired organs or a part of the organ/tissue).

In the developed world's countries, organ transplantation is the standard of treatment for many diseases of the kidneys, heart, liver, lungs, intestines, etc. Ukraine lags behind in the development of organ transplantation by 20-25 years due to the lack of funding for the development of the transplantation system, due to the lack of a single register of donors, due to the ratio of presumption of agreement and disagreement, due to slow development of the transplant coordination service, due to problems of education and training of doctors, due to the lack of a single electronic register of recipients, due to slow development of Unified State Information System for Organ and Tissue Transplantation, etc. [3].

Since the first successful kidney transplant in 1954, organ donation and transplantation has been an important medical treatment that improves the lives of thousands of patients who experienced organ failure(s) [4]. Organ transplantation should be provided by the developed and implemented in medical practice the transplantation system, which ensures clear and coordinated work and interaction of specialists involved in transplant activities [1]. According to the Law of Ukraine "On the Application of Transplantation of Anatomic Materials to Humans" [2], transplant activities should be based exclusively on the

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Unified State Information System for Organ and Tissue Transplantation (USIST), which should be contains data on donors and recipients. According to the authors, the important component of USIST can be technology of decision-making support regarding the possibility of donation and transplantation considering civil law, which will help to make a decision about the possibility or impossibility of donation and transplantation in one or another case with considering the civil law grounds.

Therefore, the development of technology of decision-making support regarding the possibility of donation and transplantation considering civil law is currently an *actual task*, the solution of which is *aim of this study*.

2. Review of Known Decision-Making Support Systems and Technologies Regarding the Possibility of Donation and Transplantation

Let's review of known decision-making support systems and technologies regarding the possibility of donation and transplantation considering civil law.

Today's organ donation and transplantation systems pose different requirements in terms of donor-recipient matching, organ removal, organ delivery, and transplantation with legal, clinical, ethical, and technical constraints and challenges.

The authors of the paper [5] proposed an infrastructure for harmonizing the documentation forms in the field of organ transplantation, which enables worldwide reuse and exchange of organs.

The authors of [6] presented a kidney allocation system which changed the way of allocated kidneys and organ utilization decisions.

The paper [7] describes the Korean Organ Transplant Registry, which has proven that the processes underlying this tool are a good model for launching new nationwide transplant studies.

The paper [8] describes a risk management program in case of serious, persistent or fatal damage of an organ, tissue or cell after transplantation from the over-life donor, which aims to supporting the donors.

In [9] Mexico National Subsystem of donation and transplantation is described, one of which functions is integration and backup of information about donation and transplantation through the National Transplant Registry System. The electronic tool is proposed, which is designed for supporting the decision of the donation and/or transplantation by providing the necessary elements for increasing the efficiency of the organs' distribution and allocation processes.

The authors of [10] created a system for gathering, comparing, analyzing, allocating and responding to serious adverse events and reactions in unrelated donors.

The authors of [11] describe the global database for donation and transplantation, which is an information platform for gathering, analyzing and disseminating information on the legal and organizational framework and annual aggregated data on donation and transplantation activities of the member states of the World Health Organization.

The paper [12] describes the information system for the selection of the donor, the recipient, and the allocation of organs, which is used for the coordination and administration of activities related to the procurement and transplantation of organs.

The paper [13] describes an intelligent decision support system about surrogate motherhood possibility.

Paper [14] proposes the private Ethereum blockchain-based end-to-end organ donation and transplantation system with purpose of the guarantee of fair and efficient process to enhance patient experience and trust. This is a solution for organ donation and transplantation management, which is fully secure, decentralized, traceable, private, auditable and trustworthy.

Authors of [15] describes a uniquely Chinese donor classification system. The Chinese donor classification system recognizes donation after brain death (category I), donation after circulatory death (category II), and donation after brain death followed by circulatory death (category III).

In the survey [4] existing organ allocation algorithms are researched, in particular kidney allocation algorithms, because the kidney is one of the most in-demand organ. The focus of this paper is on blockchain-based decentralized systems which could be the cornerstone technology to solve some of the existing issues in the area of organ donation.

Authors of [16] show that use of websites for information and social-networking sites for communication were the key technologies in current use to support donors and recipients. Authors of [16] note a lack of decision-making tools and specific support for the live donor kidney transplantation decision process.

The maximum benefit in kidney exchanges could only by developing the central kidney exchange program based on the nationwide living donor pool database. In [17] the user-friendly decision support system is developed for the transplantation centers and facilitating their operations. This decision support system can be used as a simulation tool for analyzing different allocation methods.

In [18] the highly discriminatory prediction model for lung donation within the DonateLife network and estimate the untapped lung donors outside of the DonateLife network are developed. A logistic regression model using patient-level data is developed for

characterizing the lung donors within DonateLife network hospitals.

Augmented reality delivers virtual information or some of its elements to the real world. Paper [19] describes usefulness of this technology in promoting organ donations, training transplant surgeons, graft retrieval and allocation, microscopic diagnosis of rejection, treatment of complications and post-transplantation neoplasms.

In [20] the simple donor risk score model for evaluating the quality of donation after cardiac death kidneys is developed. This scoring model is a good noninvasive tool for assessing the quality of kidneys before donation and transplantation and is potentially useful for physicians for making the optimal decisions about donor organ offers.

In [21] an empirical framework of organ donation strategies is developed for facilitating decision-making about donation and transplantation. Authors of [21] use a cognitive mapping approach involving two distinct phases of primary data collection and a sequence of data analytic procedures to elicit and systematically organize strategies for facilitating organ donation.

Authors of [22] develop evaluation of donor informed consent tool, which is designed to assess liver donors' comprehension about the living donation process. Such tool has promising measurement properties and may be useful in the evaluation of informed consent for potential liver donors.

Authors of [23] develop the stratification system for all hospitals taking into account their characteristics in having or not having departments crucial for donor identification and recruitment. Such system is useful for calculating the potential of organ donation from deceased donors, for the calculation of potential donation in the country.

Authors of [24] designed a first-in-class smartphone app to easily and quickly warn the procurement unit about a possible organ donor with the purpose of automating two stages, where the possible donor should be identified in an emergency room and notified to the procurement unit.

The UK DCD Risk Score, which is developed in [25], is a reliable tool to detect high-risk and futile combinations of donor-and-recipient factors in donation-after-circulatory-death (DCD) liver transplantation. It is simple to use and offers a great potential for making better decisions on which graft should be rejected.

The conducted review showed that currently there are no systems and technologies of decision-making support regarding the possibility of donation and transplantation considering civil law. Although the analyzed systems and technologies have considerable potential, these systems and technologies do not consider the requirements of the civil law of any country.

3. Modeling the Decision-Making Support Process Regarding the Possibility of Donation and Transplantation Considering Civil Law

Transplantation and donation are inextricably linked processes, since the presence of a donor is necessary for conducting the transplantation. Transplantation operations always involve two people – the donor and the recipient. Therefore, when modeling the decision-making support process regarding the possibility of donation and transplantation considering civil law, let's distinguish 2 parts – modeling the decision-making support process regarding the possibility of donation considering civil law and modeling the decision-making support process regarding the possibility of transplantation considering civil law.

Let *AECD* is the set of absent prerequisites for donation.

Taking into account the obligation to guarantee the security of the service for a potential living donor and guarantee the rights of a potential deceased donor, it is mandatory for donation to have all the essential prerequisites defined in [1], so the *generalized criterion of the possibility of donation* will be as follows:

- if $AECD = \varnothing$, then donation is possible;
- if $AECD \neq \varnothing$, then donation is impossible.

Taking into account the presented generalized criterion of the possibility of donation, let's present the reference set of essential prerequisites for determining the possibility of after-life donation in the following formalized form:

$$ECDAL = \{dc, noc, nv, di, noleo\}, \quad (1)$$

where *dc* – (availability of written consent of an adult capable potential donor for organ removal after death) or ((absence of disagreement of an adult capable potential donor to become a donor after death) and (availability of written consent of family members (husband/wife, children, parents, siblings) for organ removal after the death of an adult capable potential donor)) or (availability of written consent of legal representatives of a minor potential donor for organ removal after death) or (availability of written consent of legal representatives of an incapable, limited in capacity potential donor for organ removal after death), *noc* – the donor is not an orphan child, *nv* – the donor is not a veteran of the Anti-Terrorist Operation and/or Operation of the Combined Forces, *di* – identification of the potential donor, *noleo* – no objections to the donation from law enforcement officers and/or forensic medical experts and/or the court.

The reference set of essential prerequisites for determining the donor brain death can be presented in the following form:

$$ECDDBD = \{ccbf, cwccbf, ntd, ntc\}, \quad (2)$$

where *ccbf* – complete and irreversible cessation of all brain functions of a potential donor (with a working heart and artificial ventilation), *cwccbf* – certification by a council of doctors of complete and irreversible cessation of all brain functions of a potential donor, *ntd* – no participation of doctors, who will participate in the removal of anatomical materials and their transplantation, in the council of doctors, who will state the death of the brain of a potential donor, *ntc* – no participation of the transplant coordinator in the council of doctors, who will state the death of the brain of a potential donor.

The reference set of essential prerequisites for determining the biological death of a donor can be presented in the following form:

$$ECDBD = \{cbcrf, elcc\}, \quad (3)$$

where *cbcrf* – irreversible cessation of blood circulation and respiratory functions in a potential donor, *elcc* – early and/or late cadaveric changes in a potential donor.

The reference set of essential prerequisites for determining the possibility of over-life donation can be presented in the following form:

$$ECDOL = \{oldc, lhh, npw, nia, nisp, nsmd, ndtr, npdl, npob, opopt, noolleo\}, \quad (4)$$

where *oldc* – (availability of the written consent of an adult capable potential donor for the removal of his organ (permitted for transplantation by the Ministry of Health of Ukraine one of the paired organs or part of an organ) during his life) or (availability of the written consent of the legal representatives of the minor potential donor for the removal of his organ (permitted for transplantation by the Ministry of Health of Ukraine one of the paired organs or part of an organ) during his life) or (availability of the written consent of the legal representatives of an incapable, limited in capacity potential donor for the removal of his organ (permitted for transplantation by the Ministry of Health of Ukraine one of the paired organs or part of an organ) during his life), *lhh* – damage for the potential donor is less than the one that threatened the recipient, *npw* – the potential donor is not a pregnant woman, *nia* – the potential donor is not a foreigner illegally staying on the territory of Ukraine, *nisp* – the potential donor is not a stateless person illegally staying on the territory of Ukraine, *nsmd* – the potential donor does not suffer from severe mental disorders, *ndtrm* – the potential donor does not have diseases which can be transmitted to the recipient, *npdl* – the potential donor is not held in prisons, *npob* – the potential donor has not previously provided an organ or part of it for transplantation, *opopt* – one of the paired organs or part of organ or tissue will be removed from the potential donor, *noolleo* – law enforcement officers and/or a medical expert and/or a court do not oppose the over-life donation of a potential donor.

Taking into account the developed generalized criterion of the possibility of donation and the reference sets of essential prerequisites of donation (formulas (1)-(4)), let's perform the decision-making support process regarding the possibility of donation considering civil law.

If *AECDAL* is the set of absent prerequisites for after-life donation, then:

$$AECDAL = (ECDAL \cup (ECDDBD \cup ECDBD)) \setminus \setminus ((ECDAL \cup (ECDDBD \cup ECDBD)) \cap RECDAL), \quad (5)$$

where *RECDAL* – is the set of available prerequisites regarding potential after-life donation for a specific case (real set, formed from the elements of reference sets *ECDAL, ECDDBD, ECDBD*, which are available in the data on the potential donor).

If *AECDOL* – is the set of absent prerequisites for over-life donation, then:

$$AECDOL = ECDOL \setminus (ECDOL \cap RECDOL), \quad (6)$$

where *RECDOL* – is the set of available prerequisites regarding potential over-life donation for a specific case (real set).

The generalized rule for making a decision regarding the possibility of after-life donation is as follows:

$$If\ AECDAL = \varnothing \quad then\ "after\ life\ donation\ \ is\ \ possible",\ . \quad else\ "after\ life\ donation\ \ is\ impossible" \quad (7)$$

The generalized rule for making a decision regarding the possibility of over-life donation is as follows:

$$If\ AECDOL = \varnothing \quad then\ "over\ life\ donation\ \ is\ \ possible",\ . \quad else\ "over\ life\ donation\ \ is\ impossible" \quad (8)$$

Let's now model the decision-making support process regarding the possibility of transplantation considering civil law.

Let *AECTR* is the set of absent prerequisites for transplantation.

Taking into account the obligation to guarantee the safety of the service for the potential recipient, it is mandatory to have all the essential prerequisites defined in [1], so the *criterion of the possibility of transplantation* will be as follows:

• if $AECTR = \varnothing$, then transplantation is possible;

• if $AECTR \neq \varnothing$, then transplantation is impossible.

Taking into account the presented criterion of the possibility of transplantation, let's present the reference set of essential prerequisites of transplantation, which are mandatory from the point of view of civil law, in the following formalized form:

$$ECTR = \{ rincow, ami, wcr, rnotp, irpt \}, \quad (9)$$

where *rincow* – the presence of a disease in the recipient in which it is impossible to save life and/or restore his health by other (other than transplantation) treatment methods, *ami* – the presence of medical indications for the use of transplantation in the recipient, *wcr* – (availability of written consent of the adult recipient) or ((availability of written consent of the recipient aged 15 to 18 years) and (availability of written consent of parents or other legal representatives of the recipient aged 15 to 18 years)) or (availability of written consent of parents or other legal representatives of the recipient under the age of 15 years) or (urgent case with the existence of a real threat to the life of the recipient), *rnotp* – the recipient needs an organ or tissue, the transplantation of which is permitted by the Ministry of Health of Ukraine, *irpt* – the future transplantation will be carried out by a health care institution or a scientific institution that has the right to carry out it.

Taking into account the developed criterion of the possibility of transplantation and the reference set of essential prerequisites of transplantation (formula (9)), let's perform modeling the decision-making support process regarding the possibility of transplantation considering civil law.

If *AECTR* is the set of absent prerequisites for transplantation, then:

$$AECTR = ECTR \setminus (ECTR \cap RECTR), \quad (10)$$

where *RECTR* – is the set of available prerequisites regarding potential transplantation for a specific case (real set).

The generalized rule for making a decision about the possibility of transplantation is as follows:

$$\begin{aligned} &If\ AECTR = \varnothing\ then\ "transplantation\ \ is\ \ possible", \\ &\quad else\ "transplantation\ \ is\ impossible" \end{aligned} \quad . (11)$$

Conducted modeling the decision-making support process regarding the possibility of donation and transplantation is a theoretical basis for the development of rules, methods and technology of decision-making support regarding the possibility of donation and transplantation considering civil law.

4. Technology of Decision-Making Support Regarding the Possibility of Donation and Transplantation Considering Civil Law

Taking into account the results of the conducted in [1] analysis of the field of civil law that regulates donation and transplantation, as well as the conducted in chapter 3 of this paper modeling the decision-making support process regarding the possibility of donation and transplantation considering civil law, let's develop the technology of decision-making support regarding the possibility of donation and transplantation considering civil law – Fig. 1.

From Fig. 1 it is clear that the main source of information is data on the potential donor and data on the potential recipient. The data on the potential donor are analyzed for the purpose of finding essential prerequisites of donation, which are mandatory from the point of view of civil law (for the purpose of finding the values of the elements of the reference sets *ECDAL, ECDDBD, ECDBD, ECDOL*). The data on the potential recipient is analyzed for the purpose of finding the essential prerequisites of transplantation which are mandatory from the point of view of civil law (for the purpose of finding the values of the elements of the reference set *ECTR*). As a result of the semantic analysis, the following sets are formed: sets of available prerequisites regarding potential donation for a specific case (real sets *RECDAL* and *RECDOL*), a set of available prerequisites regarding potential transplantation for a specific case (real set *RECTR*), and also according to formulas (5), (6) and (10) respectively, the set of absent after-life donation prerequisites *AECDAL,* the set of absent prerequisites for over-life donation *AECDOL,* and the set of absent prerequisites for transplantation *AECTR*, which are entered in the data section of the knowledge base. The rule section of the knowledge base contains the generalized rule for making a decision regarding the possibility of after-life donation (formula (7)), the generalized rule for making a decision regarding the possibility of over-life donation (formula (8)), and the generalized rule for making a decision about the possibility of transplantation (formula (11)), as well as detailed rules developed by the authors in [1] based on the presented generalized rules.

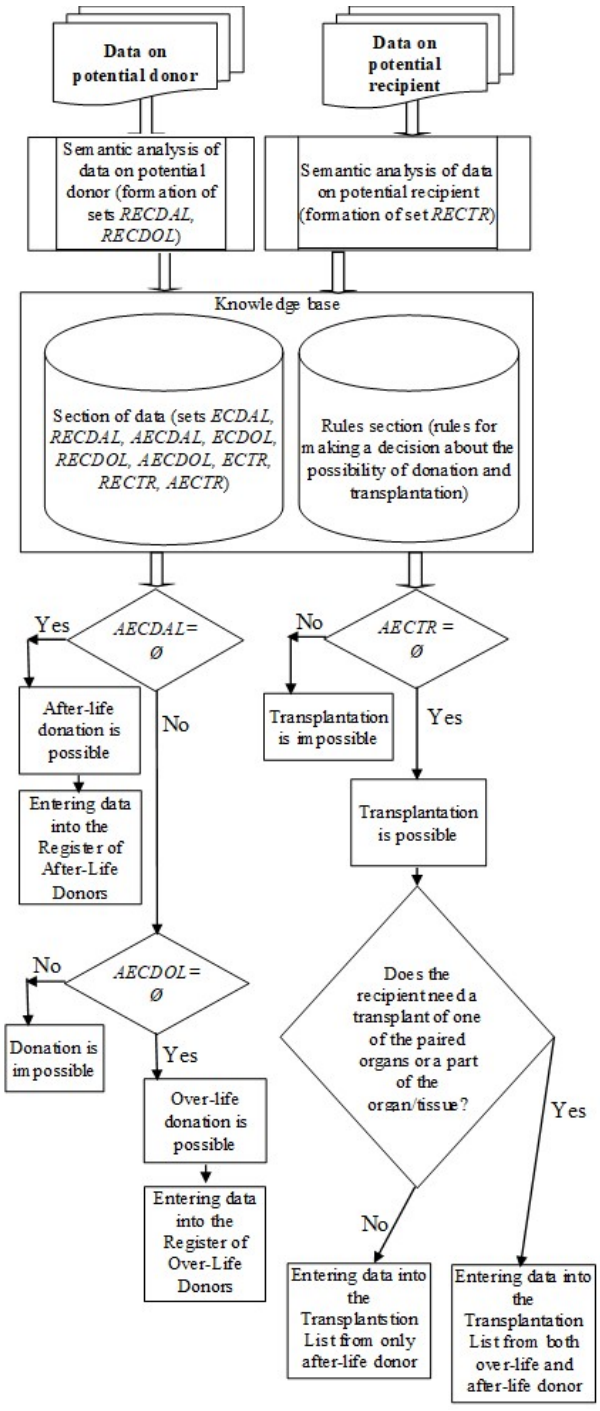

Fig. 1 Technology of decision-making support regarding the possibility of donation and transplantation considering civil law.

Based on the obtained sets of available and absent essential prerequisites, the rules from the rules section of the knowledge base are checked and the possibility/impossibility of donation is determined (in the case of the possibility of donation, the admissible type of donation is also determined – over-life or after-life donation – and data about potential donor is entered in the relevant Donor Register), as well as the possibility/impossibility of transplantation is determined (in the case of the possibility of transplantation, if the recipient needs a transplant of one of the paired organs or a part of the organ/tissue, then data about potential recipient are entered in the Transplantation List from both over-life and after-life donor, otherwise, if the recipient needs a transplant of an non-paired organ or both paired organs, then data about potential recipient are entered only in the Transplantation List from after-life donor).

The method of semantic analysis (parsing) of natural language data on potential donors and data on potential recipients is based on the concept of semantic parsing of natural language specifications of software requirements developed by the authors in [26, 27] and consists of the following steps – Fig. 2.

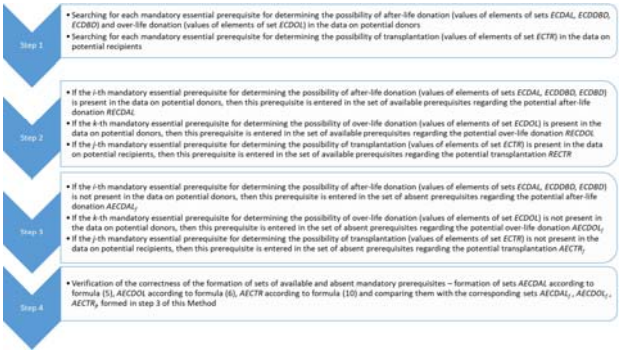

Fig. 2 The method of semantic analysis (parsing) of natural language data on potential donors and data on potential recipients.

5. Operation of the Technology of Decision-Making Support Regarding the Possibility of Donation and Transplantation Considering Civil Law

Let's consider the operation of the developed technology of decision-making support regarding the possibility of donation and transplantation considering civil law on the example of analyzing data on one potential donor and data on one potential recipient, taken from the UNOS (The United Network for Organ Sharing) database.

So, data on one potential donor was submitted to the input of the developed technology of decision-making support regarding the possibility of donation and transplantation considering civil law. The data on the potential donor were analyzed for the purpose of searching for mandatory essential prerequisites of donation (for the purpose of searching for the values of the elements of the reference sets *ECDAL, ECDDBD, ECDBD, ECDOL*

(formulas (1)-(4)) – according to the developed method of semantic analysis (parsing) of natural language data on potential donors and data on potential recipients. As a result of the semantic analysis, the following sets are formed: sets of available prerequisites regarding potential donation for a specific case (real sets *RECDAL = {dc, noc, nv, di, noleo, ntd, ntc}* and *RECDOL = {oldc, lhh, npw, nia, nisp, nsmd, ndtr, npdl, npob, opopt, noolleo}*). Also, according to formulas (5), (6) respectively the set of absent after-life donation prerequisites *AECDAL = {ccbf, cwccbf, cbcrf, elcc}* and the set of absent prerequisites for over-life donation $AECDOL = \varnothing$.

On the basis of the received sets of available and absent mandatory prerequisites *RECDAL, RECDOL, AECDAL, AECDOL,* the rules from the rules section of the knowledge base are checked and the possibility/impossibility of donation is determined. According to the generalized rule for making a decision about the possibility of after-life donation (formula (7)), since the set $AECDAL \neq \varnothing$, then after-life donation is impossible. According to the generalized rule for making a decision on the possibility of over-life donation (formula (8)), since the set $AECDOL = \varnothing$, then over-life donation is possible. Therefore, analyzed data on the potential donor is entered into the Register of Over-Life Donors.

Next, data on one potential recipient was submitted to the input of the developed technology of decision-making support regarding the possibility of donation and transplantation considering civil law. The data on the potential recipient were analyzed for the purpose of searching for mandatory essential prerequisites of transplantation, which are mandatory from the point of view of civil law (for the purpose of searching for the values of the elements of the reference set *ECTR* (formula (9)) – according to the developed method of semantic analysis (parsing) of natural language data on potential donors and data on potential recipients. As a result of the conducted semantic analysis, the set of available prerequisites regarding the potential transplantation for a specific case was formed (real set *RECTR = {rincow, ami, wcr, rnotp, irpt}*). Also, according to the formula (10), the set of absent prerequisites for transplantation is formed: $AECTR = \varnothing$.

On the basis of the received sets of available and absent mandatory prerequisites *RECTR, AECTR,* the rules from the knowledge base rules section are checked and the possibility/impossibility of transplantation is determined. According to the generalized rule for making a decision about the possibility of transplantation (formula (11)), since the set $AECTR = \varnothing$, then transplantation is possible. The recipient needs a kidney transplant (this is one of the paired organs), so his data are entered in the Transplantation List from both over-life and after-life donor.

Therefore, as the considered experiments showed, the developed technology of decision-making support regarding the possibility of donation and transplantation considering civil law ensures the legal correctness of the performed donation and/or transplantation procedure, provides the possibility of a quick and free check of the presence of all essential prerequisites for the possibility of donation (with the determination of its possible type) and transplantation from a legal point of view, protects the doctor and the patient from legal conflicts, and also provides recommendations on the further implementation or non-implementation of donation and transplantation.

6. Conclusions

The development of technology of decision-making support regarding the possibility of donation and transplantation considering civil law is currently an actual task, the solution of which is aim of this study.

The conducted review of known decision-making support systems and technologies regarding the possibility of donation and transplantation showed that currently there are no systems and technologies of decision-making support regarding the possibility of donation and transplantation considering civil law. Although the analyzed systems and technologies have considerable potential, these systems and technologies do not consider the requirements of the civil law of any country.

The paper models the decision-making support process regarding the possibility of donation and transplantation, which is a theoretical basis for the development of rules, methods and technology of decision-making support regarding the possibility of donation and transplantation considering civil law.

The paper also developed the technology of decision-making support regarding the possibility of donation and transplantation considering civil law as a component of the Unified State Information System for Organ and Tissue Transplantation, which automatically and free of charge determines the possibility/impossibility of donation and transplantation. In the case of the possibility of donation, the admissible type of donation is also determined - over-life or after-life donation - and data about potential donor is entered in the relevant Donor Register. In the case of the possibility of transplantation, if the recipient needs a transplant of one of the paired organs or a part of the organ/tissue, then data about potential recipient are entered in the Transplantation List from both over-life and after-life donor, otherwise, if the recipient needs a transplant of a non-paired organ or both paired organs, then data about potential recipient are entered only in the Transplantation List from after-life donor.

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