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Patients' Prioritization on Surgical Waiting Lists: A Decision Support System

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Abstract: Currently, in Chile, more than a quarter-million of patients are waiting for an elective surgical intervention. This is a worldwide reality, and it occurs as the demand for healthcare is vastly superior to the clinical resources in public systems. Moreover, this phenomenon has worsened due to the COVID-19 sanitary crisis. In order to reduce the impact of this situation, patients in the waiting lists are ranked according to a priority. However, the existing prioritization strategies are not necessarily systematized, and they usually respond only to clinical criteria, excluding other dimensions such as the personal and social context of patients. In this paper, we present a decision-support system designed for the prioritization of surgical waiting lists based on biopsychosocial criteria. The proposed system features three methodological contributions; first, an ad-hoc medical record form that captures the biopsychosocial condition of the patients; second, a dynamic scoring scheme that recognizes that patients' conditions evolve differently while waiting for the required elective surgery; and third, a methodology for prioritizing and selecting patients based on the corresponding dynamic scores and additional clinical criteria. The designed decision-support system was implemented in the otorhinolaryngology unit in the Hospital of Talca, Chile, in 2018. When compared to the previous prioritization methodology, the results obtained from the use of the system during 2018 and 2019 show that this new methodology outperforms the previous prioritization method quantitatively and qualitatively. As a matter of fact, the designed system allowed a decrease, from 2017 to 2019, in the average number of days in the waiting list from 462 to 282 days.

Keywords: waiting list; elective surgery; decision support system; psychosocial support systems; prioritization and vulnerability; biopsychosocial criteria

1. Introduction

Public health systems are under constant stress due to an increasing demand for more and more complex healthcare provision [1]. In Chile, for example, approximately 1.6 million people are waiting for medical attention and more than a quarter million are waiting for surgical intervention (https://www.emol.com/noticias/Nacional/2017/04/18/854610/, accessed on 1 June 2019). Authors such as [2,3] show that, while waiting, the condition of these patients not only worsens, but some of them develop other morbidities and, in extreme cases, die.

In such a scenario, the use of decision support systems (DSSs) for the coordination of tactical and operative decisions is fundamental for ensuring an effective and efficient provision of healthcare services. For instance, in [3–5], the authors manifest that waiting list management, in the planning phase of the surgeries, is one of the most critical operations in clinical decision making, but it is also critical in the management of emergency services see, for example, [6] or when scheduling therapeutical procedures such as a radiotherapy see, for example, [7]. Due to its relevance, different DSSs for surgery scheduling have been devised over the last years [8–11]. A crucial component of any clinical scheduling setting corresponds to the prioritization of patients, that is, a *ranking* of patients, according to ad-hoc scoring criteria that ensure fairness and clinical effectiveness of the corresponding healthcare service.

Most DSSs for surgery prioritization rely only on clinical criteria, such as main disease, severity, morbidities, and similar characteristics (see, e.g., [9,10]). However, in [12,13] the World Health Organization (WHO) recognizes the need for considering other dimensions of patients; such as their social and psychological contexts, resulting in a holistic comprehension of health and life quality. As a matter of fact, according to the Commission on Social Determinants of Health, the concept of "social determinants of health" encompasses the circumstances in which people are born, grow up, live and get old. Structural factors, such as socio-political and socio-economic context in combination with intermediate factors, such as material circumstances, biological, behavioral, psychosocial factors, are strongly linked to the morbidity and mortality of patients [14]. The seminar work by [15] was one of the first in recognizing the need of systemically incorporating, not only the biological criteria but also the psychological and social one. Since then, some of the few examples where biopsychosocial dimensions are included in prioritization of patients are [16–19].

From a public healthcare point of view, an effective management of a waiting list relies, on the one hand, on recognizing the specificity of the clinical conditions and social context of the patients (i.e., embodied by biopsychosocial criteria), and, on the other, on incorporating the criteria and experience of the professionals in charge of the corresponding clinical unit. Therefore, designing and implementing ad-hoc decision-support systems for the prioritization of patients is crucial for adequately representing their healthcare needs and for helping physicians to decide, according to their criteria, which patients should be selected for scheduling their surgeries.

Taking this into account, we designed a DSS for the biopsychosocial-based prioritization of patients in an (elective) surgical waiting list. The proposed DSS feautures an electronic form that allows to characterize patients by means of biopsychosocial variables, a prioritization scheme that allows ranking patients according to clinical and social vulnerability criteria, and a time-dependent ordering strategy that ensures a timely and clinically effective scheduling of surgeries. In particular, the designed system was implemented in the otorhinolaryngology unit in the Hospital of Talca, Chile. At the moment of the design of this tool, this clinical unit had third largest waiting list in the Hospital, with an average, between 2015 and 2018, of 1107 patients waiting for an elective surgery. In this paper, we present the novel methodological features of the designed system; these features respond to the clinical and managerial gaps highlighted in the reviewed literature as well as by the local professionals and clinical authorities. Furthermore, the obtained results show the effectiveness of the designed tool and, therefore, of the methodologies that comprised it.

Our contribution and paper outline This paper features three methodological contributions. First, an ad-hoc medical record form that captures twenty biopsychosocial variables that allow capturing the clinical and social condition of the patients. The second contribution corresponds to a dynamic scoring scheme that recognizes that patients' clinical conditions evolve differently while waiting for the required elective surgery. Finally, the third contribution corresponds to a novel methodology for prioritizing and selecting patients based on the corresponding dynamic scores and additional clinical criteria. As explained before, these features were embedded into a specially designed decision-support system that was implemented in the otorhinolaryngology unit in the Hospital of Talca, Chile, in 2018. When compared to the previous prioritization methodology, the results obtained from the use of the system during 2018 and 2019, show that this new methodology outperforms the previous prioritization method quantitatively and qualitatively. As a matter of fact, the designed system allowed a decrease, from 2017 to 2019, in the average number of days in the waiting list from 462 days to 282 days.

The paper is organized as follows: Section 2 presents a literature review on prioritization methods and waiting list management. In Section 3, we present the main features of the proposed methodology. The results obtained from the implementation of the designed system are presented in Section 4 Finally, in Section 6 we draw conclusions and venues for future work.

2. Related Literature

2.1. Waiting Lists: The Gap between Demand and Supply of Health Care

Public health issues constitute one of the main priorities in the design of public policies [20], and as a result, expert systems have been created to support their implementation [21]. This demographic reality translates into the need for various clinical services; one of the most complex services (clinically, administratively and budgetary) corresponds to surgical interventions [17]. Despite the efforts of several States and organizations to provide public health services with sufficient resources (clinical staff, infrastructure, supplies, etc.) to adequately solve the needs for surgeries, the growing demand for this type of service has brought many health services to a critical situation [22]. This situation manifests itself with growing waiting lists, waiting times that exceed the recommendation associated with the respective diagnoses and, in extreme cases, the death of patients waiting for surgery; see, for example, the diagnoses presented in [2,3] for the English and Canadian contexts, respectively.

One certainty in the design of public health policies is that the growth of the gap between demand and supply of health care is difficult to close, and for this reason, predictive models have been made to control this gap [1]. Therefore, the focus should not only be on how many patients are waiting (volume on the waiting list), but also on how many wait beyond what is recommended (vulnerability or quality of the waiting list) [3–5]. For that it is necessary to recognize the characteristics of the patients (from clinical, social and psychological standpoints), and then order them on the waiting list in order to ensure the clinical effectiveness of the surgical interventions. This ordering process is known as prioritization, and as it is detailed, for example, in [16–18], today there is consensus on the need of incorporating it in the different instances of decision making (strategic, tactical and operational, both in clinical and administrative areas).

2.2. Strategies for Patients' Prioritization

In both literature and practice, it is possible to find prioritization strategies based on different criteria. The simplest are based solely on the clinical severity of patients, which depends strictly on diagnosis and waiting time; examples of this type of strategy are detailed in [9,10]. Other strategies, however, also consider personal and social variables (e.g., age, socioeconomic vulnerability, family situation, etc.), with the aim of providing a clinical response that incorporates deeper aspects of social justice. Examples of this type of strategy can be found in [23], applied to a regional reality in Italy; in [24], focused on a hospital in Catalonia, Spain; or in [25], which presents the results of a prioritization system applied to the waiting list for surgical intervention in pediatric patients in Canada. All these works, and many others, such as [20], are examples of the application of the paradigm proposed by [15], where the need to consider patients not only from their clinical condition but also from their psychological and social dimension is exposed. This constitutes the biopsychosocial model, which corresponds to an attempt to scientifically include the human domain in the experience of the disease from a systems theory perspective. Moreover, it is known that the social, psychological effects and the non-opportunity to solve surgical problems can increase the deterioration of the health of patients [26]. The foregoing should quickly pose a clinical management challenge for public hospitals.

The Western Canada Waiting List Project, compiled by [27], developed in Canada between 1998 and 2001, and in which 19 health care institutions participated (11 health authorities regional, four medical associations, and four health research centers), is of particular importance for the objectives and scope of this work. The objective of that project was to propose prioritization systems for five services (cataract surgery, general surgery, hip and knee replacement, magnetic resonance imaging, and infant mental health), which required a far-reaching multidisciplinary emphasis. In our opinion, the main conclusion of this initiative is the confirmation that the management of a waiting list depends not only on the clinical service associated with it (e.g., waiting for medical attention, or waiting for oncological surgery), but it is also necessary to consider the organizational culture of the respective hospital or regional service, the socioeconomic profile of patients, and the collective acceptance of the criteria used for prioritization. In this last aspect, and as described in the final report of the work [27], defining the prioritization criteria is a process that requires carrying out surveys (to physicians, clinical staff, administrative staff, patients, etc.), their statistical validation, socialization of results, carrying out complementary sampling, and in silico tests for the validation of the final model. The main result of this Canadian project corresponded to a software, which main function is the automation of the prioritization process, and its functionalities correspond to the consolidation of patient information and the incorporation of criteria by users. Additionally, several scientific articles were published associated with this project exposing the results obtained in the different stages of development and research, such as [28,29].

In addition to the examples presented above, and in particular to the project developed in Canada, there are recent works in the field of models and algorithms for the design of prioritization strategies in waiting lists. An example can be found in [30]; in this work the authors propose prioritization tools (based exclusively on waiting times) for three surgeries (cholecystectomy, surgical repair of the carpal tunnel and inguinal/femoral hernia), achieving reductions of 2% to 15% of the total waiting times. An important observation of that work is that deficiencies in information systems can lead to underestimating the real magnitude of the volume and vulnerability of waiting lists. Another recent work corresponds to [31]. In this article, a prioritization system consisting of three stages is proposed. The first stage corresponds to a hierarchical analysis process to formalize the objectives and goals of the different actors linked to the public health reality; the second corresponds to the application of techniques (enveloping analysis of data, in this case) to obtain a preliminary prioritization; and the third stage incorporates dynamic aspects associated with the evolution of the condition of patients and changes in the waiting list in order to obtain a definitive prioritization. The system is applied to the waiting list for orthopedic implant surgeries at Shohada University Hospital, Iran. The results show that the proposed system improves by 30% the effectiveness measured as the number of patients who are operated within the maximum waiting time.

In some studies, to establish the prioritization of patients on surgical waiting lists, variables such as the severity of the disease, the rapidity, and progression of the disease and pain are defined as the most important criteria. However, the socio-economic level, social limitations and self-induced diseases, are also important, although in a lower degree [9]. Additionally, some authors propose that a universal tool of patient priority is expected, based on a linear scale of points using three dimensions: (i) clinical and functional, (ii) expected benefit and, (iii) social role [24].

It is worth mentioning that additional methods have been used to prioritize patients in the waiting list. For instance, in [32] a hybridized metaheuristic strategy, combining nature inspired algorithms, is proposed for patient prioritization; in [32] the authors devise a simulation-based approach for patient prioritization that forecasts how patients would evolve on time; and in [33,34], the authors design expert-based approaches such as DELPHI, for ordering patients in the waiting list.

2.3. Importance of Biopsychosocial Variables

Several authors such as [35–37], among others, emphasize the importance of adopting biopsychosocial variables for characterizing patients in healthcare decision-making settings.

This importance stems from the fact that the well-being of patients is conditioned by their clinical, psychological and social dimensions, which dynamically interact among each other. As a matter of fact, in [34,36,38] one can find comprehensive studies on how social experiences and situations influence on the physiological and psychological condition of patients, and why such dimensions must be considered in clinical decision-making. Likewise, in [37] the authors describe a prioritization method that incorporates the fact that the genotipic features of a patient conditions her/his susceptibility to some diseases and other clinical conditions. The interaction among clinical, psychological and social variables is further analyzed in [39] as a key feature to understand and treat some chronic conditions.

It is precisely due to this capacity for holistically portraying the condition and well-being of patients that we have adopted a biopsychosocial approach as part of our decision-making setting.

2.4. Prioritization Systems in Chile: Recent Evidence

For the particular case of the Chilean system, we would like to draw attention to two relatively recent studies on waiting list prioritization tools. The first one corresponds to [40], where the author presents a prioritization system based on the grouping of diagnoses and aggravating factors associated with maximum waiting times. This system is implemented within a computer tool that gathers information from the patient and proposes a prioritization, to be used by physicians and by the nurses in charge of patients waiting for surgical attention, allowing a better administration and analysis of waiting lists and better programming of interventions in the surgical wards. The prototype of this tool was tested in the urology unit of Dr. Exequiel Gonzalez Cortes Pediatric Hospital, Santiago, and its application allowed a 32% decrease in the number of patients with a waiting time that exceeded the maximum recommended given their clinical condition. The second one corresponds to the more sophisticated tool presented in [41]. This article shows the results obtained from the implementation of a prioritization methodology (based exclusively on clinical criteria) which objective was to achieve a balance between opportunity (proportional to the number of interventions carried out within the maximum waiting time) and justice (proportional to the number of interventions carried out according to the prioritization). The proposed methodology was implemented in all the medical specialties of Dr. Exequiel Gonzalez Cortes Pediatric Hospital, and the published results show that, although the effectiveness of the system was improved, very different results are produced among the services. Complementary, in a press release published on October 2017, the implementation of a pilot prioritization system at the Institute of Neurosurgery and at the Hospital of La Florida, developed by the School of Public Health of the University of Chile, is reported (http://www.clinicasdechile.cl/noticias/hospitales-prueban-nuevo-sistema-para-priorizar-pacientes-en-listas-de-espera/, accessed on 1 June 2019). In the note, it is detailed that, as proposed in our work, the system considers, in addition to clinical criteria, social criteria.

2.5. Justification of the Chosen Method

In light of the presented literature review, and the methods proposed therein, it is clear that waiting list issues can be effectively addressed by optimized patients' ranking strategies. However, as the same literature reveals, the clinical effectiveness of prioritization strategies strongly relies on how it responds to the specificity of patients and their context. Hence, the main findings that justify the chosen method can be summarized as follows:

1. The international evidence shows the clinical and social importance of incorporating methodologies for the prioritization of waiting lists, with the objective of adequately responding to the clinical needs of the population. However, in Chile, there are few examples in this area, demonstrating the urgency for developing and implementing prioritization tools (in the particular case of this proposal, for waiting lists of elective interventions).

2. One of the elements that transversely appears in international evidence is the need of defining, weighting and adjusting the prioritization criteria according to the clinical conditions, demographic characteristics of the patients, and social context of the region where the tool is implemented.

These conclusions reveal the importance of developing prioritization systems for elective surgeries in the surgical units of Chilean hospitals, considering adaptations according to the particular reality of each healthcare center.

3. A Decision Support System for Biopsychosocial-Based Prioritization of Patients: Novel Methodological Features

3.1. Waiting List Management: National and Institutional Context

In June 2019, the MINSAL prepared a report for the Chilean parliament describing the surgery waiting list situation for years 2017 and 2018 (during the period we designed and implemented the proposed system). According to this document, by December 2017 over 285 thousands patients were waiting for an elective surgery, with an average waiting time of 466 days; and by December 2018, there were over 250 thousands patients and an average waiting time of 385 days. These numbers give an idea of the enormous challenge faced by the public healthcare system, and the need for developing specially designed protocols and tools, at a national scale as well as a local scale, to address this problem. In consequence, and as explained before, the tool and the results presented in this paper are part of efforts of the Hospital of Talca to overcome the waiting list problem.

The information system of the Hospital of Talca is an in-house platform (SISMAULE), which is comprised by several modules and sub-modules that support most of decision making processes. Unfortunately, the system was designed several years ago and according to a different organizational and clinical context, and, until the development of our tool, it did not feature any waiting list management module, which deteriorated the capacity of the Hospital to provide timely and effective surgical solutions.

The design of this prioritization tool was carried out in the otorhinolaryngology unit of the Hospital of Talca, during a 5 months period (between February and June, 2018). Afterwards, during July and August, 2018, we carried out a trial period, and from September 2018 the system was implemented with the support of the R&D department of the Hospital. The team involved in the design and implementation process was comprised by 5 experienced nurses (with more than 5 years in the unit) and 7 physicians (of all of them otorhinolaryngologists). In the remainder of this section we will describe the methodological aspects of the main components of our decision support system.

3.2. Collecting Psychosocial and Clinical Data: An Ad-Hoc Medical Record Form

As explained before, in collaboration with the clinical team of the unit, we designed an ad-hoc medical record form that allows to characterize the patients on the surgical waiting list by means of different biopsychosocial variables. The devised ad-hoc form is shown in Appendix A. As can be seen, the form is divided into two parts; the first collects general information and psychosocial characteristics of the patient' situation, and the second collects more detailed clinical information. Both types of entries, psychosocial and clinical, were defined and agreed in collaboration with the physicians involved in this project.

As can be seen from the record form, the general information collected from a patient corresponds the common variables gathered when handling patients that are admitted to a waiting list; personal information, the diagnosis that caused the admission to the waiting list, name of the treating physician, and co-occurrence of other diseases. On the contrary, the psychosocial variables collected by the record from aim at defining a much broader profile of the personal and social condition of the patient and her/his inner (family circle), and how the clinical condition affects her/his personal life. For instance, patients are requested to inform whether there are relatives that depend on them, and physicians are requested to inform, according to their criteria, if the disease of the patient is likely to burden the patient' capacity to work or study. Likewise, the additional collected clinical variables aim at describing in a much more precise way the health situation of the patient as well as the symptomatology of the disease that affects the patient. For instance, the physicians are requested to inform how urgent, according to their criterion, the patient should undergo through the surgery and, complementary, to provide an estimation of the probability that the patient' health improves due to the surgery. In Section 3.3 we describe all the variables collected in the medical record form.

During the design phase (February to June, 2018), the medical record form was revised several times. These revisions were performed on the basis of preliminary records obtained from 205 patients that entered, during that period, to the surgical waiting list. The information from these patients was used for adjusting, enhancing and validating the record form, and later for an in silico preliminary testing of the functionalities of the prioritization system. The records from these 205 patients were statically analyzed, mainly by descriptive tools, in order to identify patterns, outliers and correlations. The results of this analysis were presented to the clinical team of the otorhinolaryngology unit in order to discuss whether the considered variables, and the collection method, were suitable for capturing the necessary biopsychosocial information for building an effective waiting list prioritization system. In Table 1 we group these 205 patients according to four characteristics: age, gender, type of patient (whether they are new patients or they are being already treated in the otorhinolaryngology unit), and the number of other pathologies.

Table 1. Summarized characterization of the 205 patients that took part in the design phase.

Characterization of the 205 Patients							
Age Group	**n**	**Gender**	**n**	**Type of Patient**	**n**	**Other Pathologies**	**n**
0–20	126	Male	100	New	38	0	150
21–40	25	Female	150	Treated	167	1	38
41–60	32					2	13
+60	22					3	3
						+3	1

3.3. Clinical and Psychosocial Characterization of Patients: Biopsychosocial Variables

In the following, we explain each of the clinical and psychosocial variables used in this research.

3.3.1. Clinical Status of the Patients: Clinical Variables

We now define the variables that characterize the clinical status of the patients:

1. **Progression and severity of the disease** (`Sever`): This variable is associated with problems the disease generates and its progression, such as; hearing loss, recurrent tonsillitis, balance alterations, smell disorders, severe disorders of the voice and swallowing, head and neck tumors, among other severities. Some authors classify the severity of the disease as the most critical variable [9,24,27,42–45]. For [11] and its hierarchical system to prioritize orthopedic surgery patients, the severity of the disease has as subfactors; (i) pain and (ii) difficulty in carrying out activities. In our study, the value that `Sever` can take are "low", "medium" and "high", according to hearing loss, recurrent tonsillitis, balance disorders, among others.
2. **Urgency** (`Urg`):This variable indicates the level of urgency of each patient admitted to the surgical waiting list possesses. All this according to the clinical characteristics and the psychosocial factors associated with each patient [27,44]. `Urg` takes values between 0 and 100, where 0 represents a patient who did not show urgency and 100 to a patient who could present the highest level of urgency. We classify as 0 the level of urgency 0, 1 the level of urgency 10, 2 the level of urgency 20, and so on until classifying the level of urgency 100 as 10.

3. **Clinical judgment maximum wait time** (`Jclin`): The variable `Jclin` indicates the maximum time (measured in months) that the patients should wait to solve their surgical problem [26,46]. In [11] they cite a delay relation indicator (DR), which is composed of the time the patient has been waiting on the waiting list and the maximum time that the patient should wait (according to the physician's criteria).
4. **Sleep disorder** (`Tsuen`): This variable is associated with the sleep disorder problem that can be complex for some patients, as it can generate other diseases [47], such as sleep apnea syndrome [48]. Some medical specialties, such as otorhinolaryngology, have worried about the consequences this variable can have on the patients' health [49]. In our work, the value that `Tsuen` can take are "low", "medium" and "severe".
5. **Probability of improvement with surgery** (`Pmcx`): With the variable `Pmcx` we refer to the probability of improving the functionality, pain, general progress or other characteristics related to the patient's illness waiting [24]. If we focus on the future benefits of the surgically treated patient, they reveal the importance of this variable within the criteria of prioritization of surgery [9,27,42,45,50–53]. The physician indicates for each patient if the probability of improving with surgery is "low", "medium" or "high".
6. **Probability of developing comorbidities without surgery** (`Com`): The variable `Com` is considered as a result of waiting, where patients can develop comorbidities. Some authors incorporated it to the development of the capacities within the study of prioritization of the patients in the waiting list [24,44,51,54–56]. In our work, physicians indicate if patients, according to wait, developing comorbidities without surgery with probability "low", "medium" or "high".
7. **Affected area** (`Hanor`): On clinical examination, physicians may find abnormal findings that increase the clinical complexity of the patient. According to the possible findings, the values that `Hanor` parameter can take are "no presence", "low presence" and "high presence".
8. **Diagnosis of admission to the waiting list** (`Diag`): The `Diag` variable indicates the diagnosis that caused the admission of the patient to the surgical waiting list. The physicians that participated in this project grouped all the potential pathologies into 18 diagnoses.
   These 18 diagnoses are listed in Table 2. Additionally, we also report in this table how frequent these diagnoses are presented among the 205 patients admitted to the waiting list during the design phase.
9. **Other additional pathologies** (`Opat`): The variable `Opat` identifies the number of additional pathologies that suffer the patients addmitted to the waiting list (besides the diagnosis that caused her/him to be admitted into the waiting list). Variable `Opat` associates five categories; 0 if the patient presents none of the pathologies from the list, I if the presents 1 pathology, II if the presents 2 pathologies, III if presents 3 pathologies, and IV if presents 4 or more pathologies.
   In Table 3 we report the list of the additional pathologies that are more likely to suffer the patients treated in the otorhinolaryngology unit.
10. **Other functional limitations** (`Olim`): The `Olim` variable refers to difficulties directly associated with the patient's disease in waiting. The problems stand out for; breathe, eat, drink liquids, perform sports, recreational activities or hobbies, among others. The value that `Olim` can take are "no", "medium" and "severe".
11. **EVA scale pain** (`Dolor`): As cited by the International Association for the Study of Pain (IASP), pain is an unpleasant sensory and emotional experience related to an existing or potential tissue injury of each individual [57].
    For the clinical variable of pain, some authors such as [9,24,28,42,44,45,52,56], demonstrated the relevance of this variable when prioritizing patients on the waiting list. In our study, the `Dolor` variable takes values from 0 to 10, where 0 implies no pain and 10 maximum pain for a patient.

12. **Need for critical beds** (`Ccrit`): The `Ccrit` variable is used to indicate if a patient requires a critical bed. For this and when the patient enters the surgical waiting list, the physician must indicate "yes" or "no", depending on the patient's conditions.

Table 2. List of diagnoses that group the pathologies of the patient admitted to the waiting list and number of patients that suffer from these diagnoses from the 205 patients admitted to the waiting list during the designed phase.

Diagnoses	Number of Patients
Complicated otitis media	10
Cholesteatoma of the ear	6
Complicated chronic sinusitis	4
Obstructive tonsil and apnea	13
Otitis media with effusion	1
Nasal polyp with apnea	3
Obstructive sleep apnea	0
Obstructed lacrimal obstruction	3
Frontal mucocele	1
Septodesk with apnea	1
Simple chronic sinusitis	1
Hypertrophy of tonsils and adenoids	78
Recurrent or chronic tonsillitis	31
Tympanic perforation	21
Nasal polyp without apnea	4
Tear ducts obstruction	7
Septo-deviation without apnea	17
Rinodeviation	4

Table 3. List of additional pathologies with high prevalence among the otorhinolaryngology patients admitted in the waiting list.

Additional Pathologies
Bronchial asthma
Immunosuppressed
Risk of malignancy
Sleep apnea syndrome
Diabetes
Language disorder
Valvulopathy
Arterial hypertension
Rheumatic arthritis
Risk of complications
Hearing loss
Neurological complications
Infectious complications
Depression
Chronic lung disease
Nutritional diseases
Down's Syndrome
Gastrointestinal disorders

3.3.2. Pyschosocial Status of the Patients: Psychosocial Variables

We now define the variables that characterize the psychosocial status of the patients:

1. **Time on the surgical waiting list** (`Tlist`): We use the `Tlist` variable to quantify the time the patient has been on the waiting list (e.g., days, weeks, months or years). This

is the critical variable that patients consider and emphasize when they have a health problem, which is considered as a management variable in [9,24,44,46,50,52,58].

2. **Study capacity** (`Dest`): The `Dest` variable is used to identify those patients, admitted to the waiting list, that suffer from difficulties for continuing their studies due to their clinical condition. This variable is only valid for patients pursuing formal studies, and it can take values "yes" or "no".
3. **Family activities** (`Lfam`): The `Lfam` variable is used to indicate if the patient on the waiting list has difficulties for performing domestic and family activities. For this, the pshysician indicates "yes" or "no". The limitation of family activities has been considered in the following studies [9,24,44,45,50,52,53,59–62].
4. **The patient needs a caregiver** (`Ncuid`): This variable is used to indicate if a patient needs a caregiver; therefore `Ncuid` we use "yes" or "no". This situation of waiting for patient care has been evidenced in [63], but mainly in patients with pathologies associated with mental problems [64,65].
5. **Responsibility in caring for another person** (`Rcuid`): The `Rcuid` variable indicates if the patient, despite being on the surgical waiting list, has the responsibility of caring for another person. Hence, `RCuid` with a "yes", if the patient has the responsibility of caring for another person and "no" in another case. Some authors identify this variable from a psychosocial point of view [9,11,27,45,53,61].
6. **Working capacity** (`Dtrab`): The variable `Dtrab` measures the patient's working condition by indicating "yes" or "no". This criterion does not apply to students or retirees. Some works have defined this variable as necessary for an adequate prioritization process since many patients face a social reality, which forces them to work. This is how [9,24,26,27,44,45,52,53,61,66] have established that the diminished working condition should be considered for patients awaiting surgery.
7. **Access** (`Acc`): Given the conditions of rurality present in the Region of Maule [67], where the Hospital of Talca is inserted, it is essential to consider the condition of rurality of patients to assess to centers of public health to solve their surgical problems. The values that `Acc` variable can take are "urban", "rural" and "high rurality".
8. **Difficulty in transferring from/to the hospital** (`Dtras`): The `Dtras` variable indicates if a patient, given their psychosocial condition, has difficulty moving to and from the hospital. For this work, the `Dtras` variable takes values "yes" or "no".

3.4. Clinical and Social Characterization of Patients: Biopsychosocial Scoring, Vulnerability and Dynamic Scoring

In this section, we present the qualitative and quantitative yield, the prioritization of patients and, therefore, the order the waiting list for informed and more effective surgery planning decision-making. The first element corresponds to a biopsychosocial-based scoring function that evaluates the clinical and psychosocial status of a patient according to a weighting scheme based on the opinion of the team of physicians that participated in this project. The second element corresponds to a vulnerability function that depends on the amount of time that the patient has been waiting beyond the maximum waiting time suggested by the physician. And, finally, the third element corresponds to a dynamic scoring scheme that encompasses the the judgment of physicians regarding the influence of different diagnoses on the time-dependent clinical evolution of the patients in the waiting list.

3.4.1. Biopsychosocial Scoring Function

For a given patient, her/his biopsychosocial score is computed by a scoring function based on a weighting scheme that encodes the criteria of the participating physicians with respect to the relevance, on the patients' health, of the different variables that characterize the clinical and social status of the patients (described in Sections 3.3.1 and 3.3.2).

The first element of this scoring function corresponds to the weights associated to the biopsychosocial variables. For estimating these weights, we performed the following procedure. We asked each physician to estimate the relevance of each of the 20 biopsychosocial variables in the prioritization of a patient. In particular, for each variable, physicians were asked to assign a relevance score between 0 (no relevant) and 10 (very relevant); let $\mu_{i,m}$ be the relevance score assigned by physician $m \in \{1, \ldots, 7\}$ to variable $i = \in \{1, \ldots, 20\}$. Table 4 reports the relevance scores assigned by the seven physicians to the 20 variables. Once these scores are gathered, the corresponding weight (or relative relevance) for each variable $i = \{1, \ldots, 20\}$, w_i, is given by

$$w_i = \frac{1}{W} \sum_{m=1}^{7} \mu_{i,m}, \tag{1}$$

where

$$W = \sum_{i=1}^{20} \sum_{m=1}^{7} \mu_{i,m}. \tag{2}$$

For example, for variable `Sever`, the sum of the corresponding $\mu_{i:\texttt{Sever},m}$ values is 69; hence, the weight associated to variable `Sever` is given $w_{i:\texttt{Sever}} = 69/853 = 0.081$, as $W = 853$. From the Table 4, we can observe that the average relevance score associated to the clinical variables es 0.054 and for the psychosocial variables is 0.044; this means that the psychosocial variables are almost 80% as relevant as the clinical variables. This demonstrates the importance of considering the personal and social contexts of the patients when we prioritize them in the waiting list.

Table 4. Relevance scores assigned by the seven physicians to the 20 biopsychosocial variables.

					m				
Variable	**Definition**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	w_i
`Sever (*)`	`Severity`	10	10	10	9	10	10	10	0.081
`Urg (*)`	`Urgency`	8	8	10	10	10	9	10	0.076
`Jclin`	`Maximum waiting time`	3	8	8	10	8	9	10	0.066
`Tsuen (*)`	`Sleep disorder`	6	10	7	7	6	10	8	0.063
`Tlist`	`Time on list`	7	9	5	9	9	6	8	0.062
`Pmcx (*)`	`Expected improvement due to surgery`	1	10	8	9	4	10	5	0.055
`Dest (*)`	`Capacity to study`	5	8	8	8	4	6	7	0.054
`Com (*)`	`Chances of developing comorbidities`	1	10	7	7	5	9	6	0.053
`Lfam (*)`	`Capacity of participating in family activities`	5	8	8	7	4	6	7	0.053
`Hanor (*)`	`Affected area`	2	6	7	8	5	10	6	0.052
`Opat`	`Presence of other pathologies`	2	7	6	7	4	9	5	0.047
`Diag`	`Diagnosis`	2	9	9	2	5	6	6	0.046
`Olim (*)`	`Other limitations`	2	7	4	7	5	3	10	0.045
`Ncuid`	`Need of a caregiver`	5	9	6	4	5	1	7	0.043
`Rcuid`	`Patient cares for another person`	5	10	5	8	5	1	3	0.043
`Dolor (*)`	`Pain scale`	1	4	4	7	5	3	10	0.040
`Dtrab`	`Capacity to work`	5	8	8	5	4	1	1	0.038
`Acc`	`Type of residence area`	5	7	4	1	2	6	3	0.033
`Dtras`	`Difficulty in transfering`	5	7	3	1	4	1	3	0.028
`Ccrit`	`Need for clinical bed`	1	8	6	1	2	1	1	0.023
								$\sum_{i=1}^{20} w_i$	1.0

The second element of the scoring function corresponds the values that each patient, say p, associates to each of the biopsychosocial variables; let $\alpha_{i,p}$ be the value of variable i associated to patient p. These values embody the clinical and social condition of the patient in the waiting list. Both, numerical (such as `Urg`, `Com`, or `Opat`) and categorical (such as `Sever`, `Tsuen`, or `Dtrab`) variables were mapped into normalized values by incorporating the physicians criteria with respect to the impact of different ranges in the case of numerical variables and categories in the case of categorical variables. For instance, in the case of the numerical variable `Urg`, which represents the urgency of the patient admitted to the waiting list and it can takes (integer) values between 0 and 10, the corresponding $\alpha_{i:\texttt{Urg},p}$ value, for a given patient p, is calculated according to the following rule. Each of the seven physicians were asked to assign a score between 1 and 10 to each of the eleven possible values of variable `Urg`. Then, for each of these eleven values we calculated the sum of the received scores; the total score received by `Urg` = 0 was 0, by `Urg` = 1 was 6, by `Urg` = 2 was 11, by `Urg` = 3 was 16, by `Urg` = 4 was 25, by `Urg` = 5 was 35, by `Urg` = 6 was 41, by `Urg` = 7 was 47, by `Urg` = 8 was 58, by `Urg` = 9 was 64, by `Urg` = 10 was 70. Hence, if the urgency of a patient p receives, for instance, value 6 when admitted to the waiting list (i.e., `Urg` = 6), the corresponding $\alpha_{i:\texttt{Urg},p}$ value is given by

$$\alpha_{i:\texttt{Urg},p} = \frac{41}{0+6+11+16+25+35+41+47+58+64+70} = \frac{41}{373} \approx 0.110;$$

likewise, if the urgency is `Urg` = 10, we get $\alpha_{i:\texttt{Urg},p} = \frac{70}{373} \approx 0.188$, and if `Urg` = 4, we get $\alpha_{i:\texttt{Urg},p} = \frac{25}{373} \approx 0.067$. Likewise, in the case of the categorical variable `Sever` (the severity of the disease) the corresponding $\alpha_{i:\texttt{Sever},p}$ value, for a given patient p, is calculated by a procedure equivalent to the one followed for variable `Urg`. Each of the seven physicians were asked to assign a score between 1 and 10 to each of the categories of variable `Sever`, that is, "low", "medium" and "high". Then, for each category we calculated the sum of the received scores; the total score received by category "low" was 7, by category "medium" was 31, and by category "high" was 70. Therefore, if the severity of the disease of a patient p is considered as "medium" (i.e., `Sever` = medium), the corresponding $\alpha_{i:\texttt{Sever},p}$ value is given by

$$\alpha_{i:\texttt{Sever},p} = \frac{31}{7+31+70} = \frac{31}{108} \approx 0.29;$$

likewise, if the severity is "low", we get $\alpha_{i:\texttt{Sever},p} \approx 0.06$, and if it is "high", we get $\alpha_{i:\texttt{Sever},p} \approx 0.65$.

It is important to point out that, in the case of numerical variables that take values in non-closed intervals (such as `Jclin`, which corresponds to the maximum number of months that a patients can wait before undergoing the required surgery), physicians suggested to define intervals and then to associate categories to them. For instance, in the case of `Jclin` category I was associated to those patients whose maximum wait time was between 0 and 3 months, category II to maximum wait between 4 and 6 months, category III to maximum wait between 7 and 9 months, category IV to maximum wait between 10 and 12 months, ..., and category X to maximum wait equal or larger than 60 months. In Appendix B we present the detailed procedure associated to each of the 20 biopsychosocial variables.

Therefore, the biopsychosocial score of patient p, s_p, is given by the weighted sum of corresponding $\alpha_{i,p}$ values, $i \in \{1,\ldots,20\}$, that is,

$$s_p = \sum_{i=1}^{20} w_i \alpha_{i,p}. \tag{3}$$

Evidently, the higher the value of s_p, the higher the priority of patient p to undergo the corresponding surgical procedure.

One important aspect concerning this scoring scheme is that some of the biopsychosocial variables are time dependent, that is, the corresponding $\alpha_{i,\cdot}$ values evolve along the waiting time. As a matter of fact, those variables in Table 4 that associate a '*' symbol correspond to those variables whose values depend on the time in the waiting list; further details on how this dependency is incorporated in the prioritization scheme is presented in the following sections.

3.4.2. Dynamic Scoring and Vulnerability

One drawback of the scoring function encoded by s_p is its rather static nature, that is, there is only one out of twenty variables, variable `Tlist`, whose corresponding value evolves as the waiting time increases. However, clinical conditions are likely to worsens as time passes by, specially for those patients requiring a surgery; therefore, the higher priority should be assigned. Furthermore, authors such as [11], among others, have emphasized on the fact that diseases evolve differently and, therefore, patients different clinical conditions, should be prioritized differently. Such methodology should enable a dynamic prioritization during the surgical waiting process.

For this project, we designed a dynamic methodology based on recognizing, on the one hand, that some of the biopsychosocial variables evolve negatively during the time that patients wait for the surgery, and on the other hand, that this evolution strongly depends on the main diagnosis of the patients. Therefore, the dynamic nature of these variables should be considered when prioritizing the patients on the waiting list. Let I be the set of time-independent biopsychosocial variables, and let I^* be the set of time-dependent biopsychosocial variables (marked with '$*$' in Table 4). Hence, the corresponding score of patient p, whose main diagnosis is j, after t days in the waiting list is given by

$$\begin{aligned} s'_p(t) &= s'_p(I) + s'_p(I^*, j, t) \\ &= \sum_{i \in I} w_i \alpha_{i,p} + \sum_{i^* \in I^*} w^*_i \alpha_{i^*,p}(j, t), \end{aligned}$$

where $\alpha_{i^*,p}(j, t)$ corresponds to the value associated to the time-dependent variable i^* after the patient p, whose main diagnosis is j, has been t days in the waiting list. The definition of $s'_p(t)$ means that the score of a given patient increases for every additional day in the waiting list.

The values associated to the time dependent component of $s'_p(t)$ are computed by the following procedure:

1. For a given diagnoses j and a given time interval h ($h = 1$ corresponds to 0–90 days, $h = 2$ to 90–180 days, $h = 3$ to 180–360 days, and $h = 4$ to 360–540 days), the team of physicians agreed upon a *worsening factor* $\lambda_{j,i^*}(h) \in [0, 1]$ for each time-dependent variable i^*. This factor represents by how much the variable i^* worsens during the interval h.
   These intervals and worsening factors were defined by team of physicians, based on clinical records and their clinical experience. Two validation meeting were convened for agreeing upon the final values. Physicians considered up to 540 days in the waiting list as any patient that reaches that waiting time is immediately scheduled for surgery, regardless of her/his condition.
2. Let $\tilde{\alpha}_{i^*,p}(k, h)$ be the value associated to variable i^* for a given patient p on the k-th day of the time interval h; this value is given by

$$\tilde{\alpha}_{i^*,p}(k, h) = \left(1 + \frac{k}{d_h} \lambda_{j,i^*}(h)\right) \tilde{\alpha}_{i^*,p}(d_{h-1}, h - 1),$$

   where d_h corresponds to the number of days of time interval h. For ease of notation, we assume that $h = 0$ corresponds to moment that the patient is admitted to the waiting list, that is, $d_0 = 0$ and, therefore, $\tilde{\alpha}_{i^*,p}(d_0, 0) = \alpha_{i^*,p}$, for all patients p and variables i^*.

3. Finally, considering the previous definition, we get that after t days in the waiting list, the value of time-dependent biopsychosocial variable i^* associated to patient p, whose main diagnosis is j, is given by

$$\alpha_{i^*,p}(j,t) = \begin{cases} \left(1 + \frac{k}{90}\lambda_{j,i^*}(1)\right)\alpha_{i^*,p} & \text{, if } 0 \leq t \leq 90 \\ (1 + \frac{t-90}{90}\lambda_{j,i^*}(2))\tilde{\alpha}_{i^*,p}(90,1) & \text{, if } 90 < t \leq 180 \\ \left(1 + \frac{t-180}{180}\lambda_{j,i^*}(3)\right)\tilde{\alpha}_{i^*,p}(180,2) & \text{, if } 180 < t \leq 360 \\ (1 + \frac{t-360}{180}\lambda_{j,i^*}(4))\tilde{\alpha}_{i^*,p}(360,3) & \text{, if } 360 < t \leq 540 \end{cases}.$$

In order to better understand the previously outlined process, let us consider the following example. For the case of the diagnosis j :"hypertrophy of tonsils and adenoids", the physicians agreed that the value associated with the time-dependent variable Urg would worsen by 10% during the first 90 days ($h = 1$), that is, $\lambda_{j,i^*:\texttt{Urg}}(1) = 0.1$. Likewise, in the case of the following 90 days ($h = 2$), the physicians agreed that the variable Urg would worsen by a 20% ($\lambda_{j,i^*:\texttt{Urg}}(2) = 0.2$); for the next 180 days ($h = 3$), Urg would worsen by a 30% ($\lambda_{j,i^*:\texttt{Urg}}(3) = 0.3$); and for the next 180 days ($h = 4$), Urg would worsen by a 40% ($\lambda_{j,i^*:\texttt{Urg}}(4) = 0.4$). Now, let us consider a patient p, diagnosed with hypertrophy of tonsils and adenoids, who, when admitted to the waiting list, the treating physician assigned an Urg value equal to 6, which corresponds to $\alpha_{i:\texttt{Urg},p} = 0.110$. Therefore, at the 10th day in the waiting list, the dynamic value of the score associated to Urg variable is

$$\tilde{\alpha}_{i:\texttt{Urg},p}(10,1) = \left(1 + \frac{10}{90}\lambda_{j,i:\texttt{Urg}}(1)\right)\tilde{\alpha}_{i:\texttt{Urg},p}(0,0) = (1+0.1)0.110 = 0.121.$$

Likewise, after 250 days in the waiting list (the $250 - 180 = 70$th day of interval $h = 3$), the dynamic value of the score associated to Urg variable is

$$\tilde{\alpha}_{i:\texttt{Urg},p}(70,3) = \left(1 + \frac{70}{180}0.3\right)(1+0.1)(1+0.2)0.110 = 0.162.$$

In Figure 1 we show, for six different diagnoses, the relative increase of $\sum_{i^* \in I^*} w_i^* \alpha_{i^*,p}(j,t)$ considering one patient for each diagnoses. From the curves shown in the figure it is clear that the prioritization scores vary very differently depending on the main diagnosis of a patient. While for a patient that suffers from hypertrophy of tonsils and adenoids the time dependent component of the score increases by a 1.6 factor after 90 days in the waiting list, the same component increases only by a 1.2 factor after 90 days for those patients suffering from recurrent or chronic tonsillitis.

In the context of waiting list management, a more intuitive scheme is used to represent deterioration of patients' health while she/he waits in the waiting list. Such scheme is based on a so-called *vulnerability* function which depends on the time in the waiting list and time that patient *should* wait (according to the treating physician' criterion). Similar as in [11], the vulnerability of a given patient p at a given moment t, $v_p(t)$, if given by

$$v_p(t) = \frac{t - f_p}{\texttt{Jclin}_p}, \tag{4}$$

where f_p is the admission date of the patient to the waiting list and $\texttt{Jclin}_p$ corresponds to the maximum time that the patient should wait for the surgery according to the treating physician (see Section 3.3.1). Function $v_\cdot(t)$ is effective in mapping the clinical urgency of patients as time passes by; therefore, the longer a patient waits, the more vulnerable her/his health is and, in consequence, the higher priority should be assigned.

The resulting values of $v_p(t)$ can be interpreted in three possible ways; (i) $v_p(t) < 1$ means that the patient has been on the waiting list for less than the time indicated by the physician (*non-vulnerable*), (ii) $v_p(t) = 1$ means that the patient has been on hold for the same amount of time as indicated by the physician (*slightly-vulnerable*), and (iii) $v_p(t) > 1$, indicates that the patient has been on the waiting list longer than indicated by the physician (*vulnerable*). The key feature of function $v_p(t)$ is that its value is relative with respect to $\texttt{Jclin}_p$. For instance, if two patients, p and p', were admitted to the waiting list on the same day and the treating physicians indicated $\texttt{Jclin}_p = 1$ month and $\texttt{Jclin}_{p'} = 6$ months, respectively, then their vulnerability after six months of wait is given by

$$v_p(6) = \frac{6}{1} = 6 \quad \text{and} \quad v_{p'}(6) = \frac{6}{6} = 1;$$

so, although both patients have been waiting for 6 months for a surgery, patient p' is 6 times more vulnerable than patient p. Evidently, such a difference should be represented when prioritizing patients.

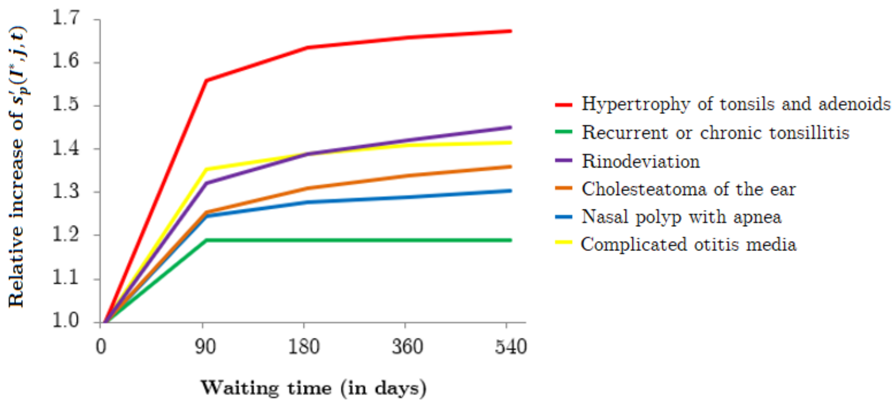

Figure 1. Time-dependent score increase for six different diagnoses (one patient is considered for each diagnosis).

As will be described in the following section, by updating the values of $s'_p(t)$ and $v_p(t)$, for all the patients in the waiting list, we are able to dynamically prioritize them and, therefore, effectively encode the impact of the waiting time on the clinical condition of the patients. This allows much more effective management of the waiting list as timely decisions can be made with respect to the medical status of the patient.

3.5. Selecting Prioritized Patients for Surgery Scheduling

As described before, functions $s'_p(t)$ and $v_p(t)$ are effective in embodying the biopsychosocial status of patients in the waiting list. We now describe how this dynamic information is used to select a shortlist of prioritized patients for scheduling their corresponding surgeries; this corresponds to the final component of our prioritization decision-support system. Every week, the otorhinolaryngology unit is informed of the availability (given in time slots) of operating rooms for the next seven days. Given this availability, the unit must select the patients, from the waiting list, whose corresponding surgical procedures will be scheduled in this time period. This selection is performed according to the following procedure:

1. For each patient p in the waiting list, update the values of $s'_p(t)$ and $v_p(t)$, considering that t is associated to the end of the scheduling horizon of seven days. Let $\bar{s}'(t)$ be the average value of $s'_{\cdot}(t)$ among all patients.
2. Classify patients into four groups: Group 1: patients with $s'_p(t) \geq \bar{s}'(t)$ and $v_p(t) \geq 1$; Group 2: patients with $s'_p(t) \geq \bar{s}'(t)$ and $v_p(t) < 1$; Group 3: patients with $s'_p(t) < \bar{s}'(t)$ and $v_p(t) \geq 1$; and Group 4: patients with $s'_p(t) < \bar{s}'(t)$ and $v_p(t) < 1$ (see the four quadrants in Figure 2).
3. Classify patients into three groups: Group A: patients suffering from diagnosis of Type A; Group B: patients suffering from diagnosis of Type B; and Group C:

patients suffering from diagnosis of Type C (see the three colors in which patients are represented in Figure 2).

4. Schedule as many surgeries as possible for patients from Group 1 and Group A in the available operating-room time slots; if operating-room time slots are still available, then schedule as many surgeries as possible for patients from Group 1 and Group B; and if operating-room time slots are still available, then schedule as many surgeries for patients from Group 1 and Group C as possible.
5. If all patients of Group 1 are selected and there are still operating-room time slots; repeat the previous procedure for patients from Group 2, 3 and 4, consecutively.

The classification of diagnoses in Types A, B and C is done by physicians according to the influence of time on the worsening of the clinical condition of the patients. Diagnoses of Type A are those that worsen very quickly (see "hypertrophy of tonsils and adenoids" in Figure 1), diagnoses of Type B are those that worsen relatively quickly at early stages of the disease but then the condition remains rather stable (see "Cholesteatoma of the ear" in Figure 1), and diagnoses of Type C are those that worsen rather slowly (see "Recurrent or chronic tonsillitis" in Figure 1).

The procedure described above is performed automatically by the devised tool. The list of all patients whose surgeries are proposed to be scheduled within the informed available operating-room time, corresponds to the list of selected prioritized patients. This list is refined by the clinical team according to additional considerations that are not included in the decision-making system; for instance, surgeons' availability, special clinical supplies availability, unexpected changes in the patients conditions (e.g., selected patients have preferred to be treated in a private hospital and do not require a surgery anymore), and so forth.

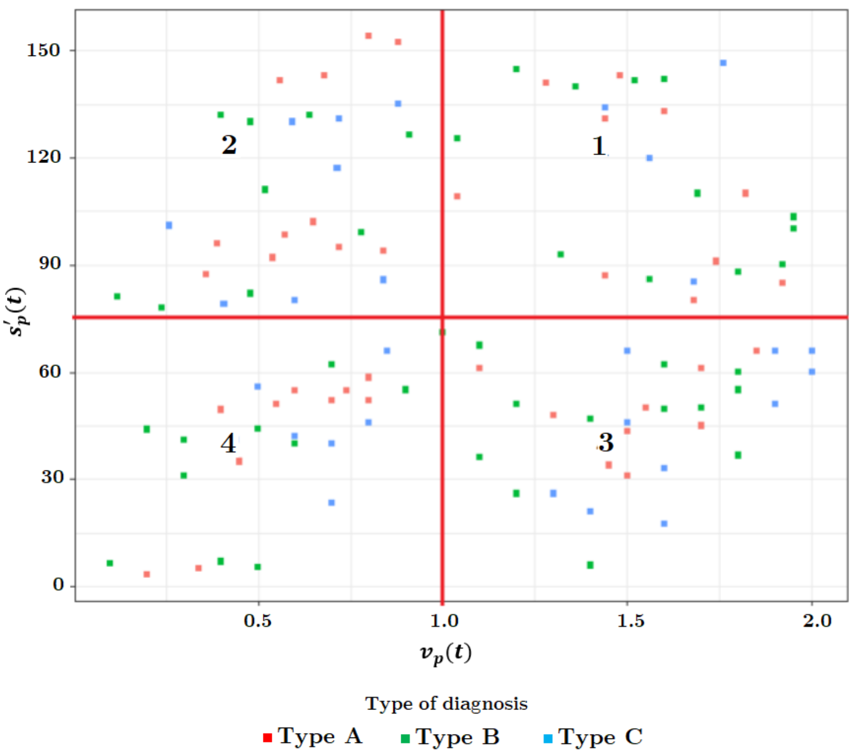

Figure 2. Graphical representation of the classification of patients in the waiting list, at a given moment t, according to score $s'_p(t)$, vulnerability $v_p(t)$ and diagnoses type (Types A, B and C).

For a better understanding of how the biopsychosocial score and the vulnerability evolve as patients wait in the waiting list, we provide in Appendix C a figure, Figure A2, where the values of $s'_p(\cdot)$ and $v_p(\cdot)$ are plotted for six patients and for four different values of t: when they enter to the waiting list, after one month, after two months and after three months in the waiting list. As can be seen in the figure, after three months in the waiting list, the vulnerability and the score evolve quite differently among the six patients. This shows the capacity of the designed decision-support system to differentiate among patients according to the time in the waiting list and their social and clinical conditions.

Let us consider an artificial case resembling a typical patient. Consider a 10 years old patient who was admitted to the waiting list on 31.08.2018. When entering the waiting list, the condition of the patient, characterized by the variables from Table 4, was given by "`Sever, medium`", "`Urg, 5`", "`Jclin, VIII`", "`Tsuen, medium`", "`Tlist, 0-3`", "`Pmcx, high`", "`Dest, NA`", "`Com, medium`", "`Lfam, no`", "`Hanor, low presence`", "`Opat, 0`", "`Diag, recurrent or chronic tonsillitis`", "`Olim, medium`", "`Ncuid, yes`", "`Rcuid, no`", "`Dolor, 6`", "`Dtrab, NA`", "`Acc, urban`", "`Dtras, no`", "`Ccrit, no`". Therefore, the day the patient entered to the waiting list ($t = 0$), the vulnerability is $v_p(0) = 0$, and the score, mapped from the values of the corresponding variables and using Equation (3), is $s_p = 3.830$, which places the patient in the 78th position of the waiting list. In Table 5 we report how the score $s'_p(\cdot)$ and vulnerability $v_p(\cdot)$ change over time after five months in the waiting list and how the ranking of the patient, that is, their position in the waiting list, evolves. We can observe that while the patient was in the 78th position when entering the waiting list, after twelve months she/he was in the 6th position (i.e., the scheduling of the corresponding surgery is imminent).

Table 5. Evolution $s'_p(\cdot)$, $v_p(\cdot)$ and rank of patient along time.

t	$s'_p(\cdot)$	$v_p(\cdot)$	`rank`
`31.08.2018`	3.830	0	78
`30.11.2018`	4.519	0.5	43
`28.02.2019`	4.519	1	18
`31.05.2019`	4.519	1.5	15
`31.08.2019`	4.519	2	10
`01.10.2019`	4.519	2.17	6

4. Results and Comparison with Previous Prioritization Method

We now present the results obtained by the use of the designed system during 2018 and 2019 (recall that the trial and implementation phases were carried out from July and September 2018, respectively), and compare them with the performance of the waiting list during 2015, 2016 and 2017. As agreed with the authorities of the Hospital, and following the Chilean Ministry of Health recommendations, the most important quantitative dimension to evaluate the performance of the waiting list corresponds to the average number of days that the patients, in the waiting list, have been waiting for a surgery. Additionally, we also compared the results from a more qualitative perspective; a list of attributes were defined with the clinical team the method was compared to the previous protocol. The results obtained from these comparisons are reported in the remainder of this section.

4.1. Average Number of Days Waiting for Surgery

As explained before, at a given moment t, the most important quantitative dimension to evaluate the performance of the waiting list corresponds to the average number of days that the patients in the waiting list have been waiting for a surgery until moment t. Note that this measure is monthly requested to public Hospitals by the Chilean Ministry of Health, and is crucial for the performance evaluation of clinical units in public Hospitals. At a given moment t, the average waiting time in the waiting list comprised by n patients, $a_{swl}(t)$, is computed by

$$a_{swl}(t) = \frac{1}{n} \sum_{p=1}^{n} (t - f_p),$$

where f_p is the admission date of patient p; so $t - f_p$ is nothing but the number of days that patient p has been waiting in the waiting list up to moment t.

Table 6 shows the values of $a_{swl}(t^*)$, for $t^* \equiv$ last day of the year (which is the standard procedure to compare the performance of the waiting list management), and the corresponding number of patients n, for years 2015, 2016, 2017, 2018 and 2019. The reported results show that, if we compared the average value of $a_{swl}(t^*)$ for 2015, 2016 and 2017 with the average value $a_{swl}(t^*)$ for 2018 and 2019, the proposed system is capable of reducing in almost a 40% the average time of the patients in the waiting list. Furthermore, this is possible even when the the number patients in the waiting list has increased (1307 patients were in the waiting list at the end of 2019, while only 998 patients were in the waiting list at the end of 2015) and the available resources are basically the same. The results shown in Table 6 reveal a remarkable capacity of the proposed system in managing the waiting list from a biopsychosocial perspective, especially with respect to the influence of the waiting time.

Table 6. Evolution of a_{swl} along the time.

t^*	n	a_{swl}
31.12.2015	998	419
31.12.2016	1200	470
31.12.2017	1123	496
31.12.2018	1108	281
31.12.2019	1307	282

The reduction in the value of $a_{swl}(t^*)$ is explained by two reasons. The first reason corresponds to the relevance of the waiting time in the prioritization of the patients due to the proposed methodology: the dynamic score $s'_p(t)$, the vulnerability $v_p(t)$, and the classification of diagnoses in Types A, B and C, are all factors that induce higher priorities to those patients that have spent longer periods in the waiting list. The second is a more operative reason; with the previous system, the clinical team lacked a systematic procedure to prioritize patients and, in some cases, it even happened that they could have biased their priorities to the patients that they could eventually recall (i.e., patients that are likely to have been recently admitted to the waiting list), which is the complete opposite of the goals of any prioritization scheme.

The obtained results have helped us to explain to the physicians, to the other members of the clinical team and to Hospital authorities, that the number of patients in the waiting list is not the most relevant feature to consider when evaluating the performance of the waiting list. As a matter of fact, when comparing two methods in equivalent periods, one might have more patients on the waiting list in one of them but still have a better performance with respect to the value of $a_{swl}(t)$.

4.2. Qualitative Evaluation of the Prioritization Method

In order to evaluate the proposed prioritization method, it is important to point out that the previous (surgical waiting list) prioritization strategy of the otorhinolaryngology unit was performed by a case-by-case analysis. This strategy was carried out at a weekly meeting, on the basis of non-standardized clinical information and (typically printed) historical data. This process was therefore imprecise and it made almost impossible to handle, simultaneously, more than 100 patients properly (although there were more than 1000 patients in the waiting list at almost any moment).

For a qualitative comparison of the previous and proposed method we organized three evaluation sessions with the clinical team. In the first session we asked them, individually, to define a list of qualitative attributes that they thought should be used to assess the performance of surgical waiting list management. In a second session, we presented them the opinions gathered in the first session and asked them, in a group activity, to agree upon a shortlist of attributes and define a way of assessing them. Finally, on a third session we presented, using preliminary records and historical data, a quantitative comparison of both methods trying to link the attained results with the shortlist of qualitative attributes. Based on this presentation, the clinical team refined the list of attributes and the two prioritization methods were qualitatively assessed. In Table 7 we present the results obtained after this assessment; as can be seen, from a qualitative perspective, the clinical team agrees that the proposed method outperforms the previous method.

It is very important to point out that, for the participating physicians, the fact that they are able to know the clinical situation of all their patients in real time, expressed by the score and vulnerability indices, represents an important advantage for improving their planning capacities as well as the perception and satisfaction of the patients. Besides, due to the unbiased nature of the system, the election of patients is done faster and more fairly. Moreover, as the system is automatic, the otorhinolaryngology unit team has more time for other clinical activities, increasing the overall performance of the unit.

After various validation tests, physicians have decided to use the proposed system for supporting the clinical decision-making processes when planning surgeries.

Table 7. Comparison of the physicians evaluation of the main qualitative attributes between the previous prioritization method and the method proposed in this research.

Qualitative Atributes	Previous Method	Proposed Method
Prioritization	Subjective	Greater objectivity
Profile discrimination	Manual observation	System observation
Timely selection	Rarely	Frequently
Equitable	Sometimes	Always
Physician satisfaction	Low	High
Side effects due to the waiting time	High	Medium
Presurgical process	Same	Improvement
See all patients orderer	No	Yes

5. Discussion

In this paper, we have proposed a prioritization approach that recognizes that patients should be prioritized not only with respect to their clinical condition, but also with respect to their personal and social context. Although this characteristic has been greatly appreciated by the team involved in this work as well as by the Hospital authorities, the quantitative evaluation of the system' performance was made only with respect to the average waiting time (see Section 4.1). Notwithstanding, and despite the results are not characterized from a psychosocial perspective, it is important to consider that in the scoring function $s'_p(t)$ the relevance scores of the psychosocial variables are, in average, 80% as important as the scores of the clinical variables. Therefore, as the prioritization strategy described in Section 3.5 relies on both, the biopsychosocial score and the (time-dependent) vulnerability, the psychosocial characteristics actually have a relevant influence on the patient selection.

When compared to related works, such as [11,33,34], our methodology and results present similarities and differences. The main similarities correspond to the direct involvement of experts in the design and validation of the prioritization criteria, as well as the incorporation of different variables (besides waiting time) for ranking patients. As for differences, we could first highlight that while in our prioritization method the values of the variables that characterize the condition of patients change over time according to specific profiles and a dynamic strategy, the other methods incorporate rather simple strategies where patients score linearly evolves over time. Another difference is that the results presented in this paper correspond to the (automatized) application of the method to over 1000 patients (the whole waiting list of the considered clinical service), while the aforementioned papers present results obtained after applying the corresponding prioritization strategies on few dozens of patients. Nonetheless, the main difference with respect to the revised literature corresponds to the results that we report regarding the reduction of the waiting time; while our method contributed to reduce, in one year, the average waiting time from 462 days to 282 days, the other works provide limited results with respect to this performance criterion.

A relevant issue, that should be taken into account when evaluating the performance of the designed system, is the diversity of the physicians criteria with respect to some of the qualitative and quantitative clinical dimensions that characterize the patients condition. This diversity is manifested, for instance, when assigning the relevance of the the 20 biopsychosocial variables (see Table 4 in Section 3.4.1). From the reported values, it is clear that for the same variable, different physicians might expressed divergent judgments regarding its relevance in the clinical progression of the patients, Therefore, the obtained scores (and, ultimately, the prioritized waiting list), are sensitive to this variability. In order to reduced this sensitivity, the proposed methodology could be complemented with further strategies such as cluster analysis, decision trees, support vector machine, among others see, for example, [68]; these strategies would allow us to measure and predict the score and the vulnerability in a more automated way, without depending solely on clinical criteria.

Furthermore, due to the process carried out in the design and implementation of the proposed decision support system, the criteria of the clinical team of the otorhinolaryngology unit, in particular of the physicians, strongly shaped its functionality. Therefore, if the composition of the clinical team undergoes through important changes (which is unlikely to occur in the short term considering the contractual conditions of the participating professionals), some of the features of the system, in particular those based on the professionals criteria, should be updated in order to represent the clinical judgment of the new professionals. In consequence, when adapting the proposed tool within a different unit, it is not only necessary to define an ad-hoc set of biopsychosocial variables (for a correct characterization the patients), but it is also necessary to consider if and how the professional crew of these units change over time.

The reported results make clear that the proposed prioritization criterion improves medical decision-making concerning the previous prioritization method since the patient is seen from his biopsychosocial perspective and not only from the clinical point of view, also it adds more objectivity, transparency and equity in the patient selection process and also optimizes the hours of the health team. Although the above generates advantages, it is necessary to make constant updates to the criteria and the system, since the conditions of the patients and the clinical techniques may vary over time.

6. Conclusions and Future Work

In this paper, we have described the main features and obtained results of a decision-support system, designed and implemented, for the prioritization of the surgical waiting list of patients of the otorhinolaryngology unit at the Hospital of Talca, Chile. The designed tool aims at prioritizing patients not only with the respect to the time in the waiting list, but with respect to a wider wellness perspective that encompasses the clinical and social situation of the patients.

As shown in the results section, the designed system allowed for informed and objective clinical decision making. In fact, the clinical team that participated in the design of this prioritization system greatly appreciated the transparency, effectiveness and usability of the devised system. These features, ultimately benefited the patients on surgical waiting lists. As a matter of fact, the reported results show an improvement in the management of patients on surgical waiting lists; before the use of the system, patients waited, in average, 462 days for a surgical intervention was, and after the implementation of the tool (from September 2018), the average waiting time, considering 2018 and 2019, decreased to 282 days (even when the tool was fully functional only four months in 2018).

From a managerial point of view, it is important to point out that the designed prioritization tool was not only validated by the otorhinolaryngology unit, but also by the Hospital authorities. Such validation is crucial for a successful development of this type of decision-support systems. As a matter of fact, for the implementation of a system as the one presented in this paper, it is necessary to ensure a combined effort with the R&D department of the Hospital, and following the institution' clinical, ethical and administrative procedures. Such procedures include a regular monitoring protocol in order to ensure that clinical and ethical regulations are effectively and consistently fulfilled. Additionally, from an operational and tactical point of view, it is necessary to consider formal procedures for permanently updating and adapting the DSS to contingencies as well as to new operational scenarios. Among these contingencies and operational scenarios one can find, for instance: (i) the current sanitary crisis is causing a major disruption in healthcare systems, which in the near future will turn into an overwhelming demand for healthcare services and an inevitable revision of the prioritization criteria; (ii) future changes in the protocols and regulations of the national healthcare authority will require to adjust procedures as well as the waiting list management criteria; or (iii) a pronounced change in the demand for surgical procedures and/or future limitations or enhancements of clinical resources will require to revise prioritization criteria in order to ensure effective and efficient provision of surgical procedures.

Finally, we would like to highlight that the presented methodology could be enhanced by incorporating other actors in the design phase; for instance, the relatives of the patients or even the patients themselves. Likewise, from a methodological point of view, the system could be improved by embedding further prioritization strategies based, for instance, on supervised learning algorithms in order to (i) predict the order of priority and vulnerability of patients and, generally (ii) improve the clinical management of the other surgical services of the care center. Likewise, the developed tool could be extended to other surgical services and areas of the institution with on-demand problems, such as (i) ambulatory consultations, (ii) medical imaging and (iii) endoscopy procedures, among others.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Patient profile on the surgical waiting list
OTORHINOLARYNGOLOGY
Nº: __________

General Information (completed by the nursing team)	Psychosocial Information (completed by the nursing team)
Name of patient: Nº file:	Dicreased condition or ability to work: ☐ Yes ☐ No ☐ n/a
Patient age: Rut: Phone:	Dicreased condition or ability to study: ☐ Yes ☐ No ☐ n/a
Sex: ☐ M ☐ W	Limitation in carrying out domestic and family activities: ☐ Yes ☐ No
Type of attention: ☐ Urgency ☐ New ☐ Control ☐ Other:__________	Patient needs a caregiver: ☐ Yes ☐ No
Income diagnosis surgical waiting list :	Patient has responsability in the care of third parties: ☐ Yes ☐ No
	Difficulty in transfer from / to the hospital: ☐ Yes ☐ No
Name of the physician:	Address (access): ☐ Urban ☐ Rural ☐ High rurality
Other pathologies: ☐ No ☐ Yes / → ☐ 1 ☐ 2 ☐ 3 ☐ +3	Time on surgical waiting list: ☐ days ☐ months ☐ years

Clinical Information of the patient (Completed by the physician)	
Belongs to program: ☐ GES ☐ No Ges ☐ PPV ☐ Otro:___	Other functional limitations of the patient[1]: ☐ No ☐ Medium ☐ Severe
Patient requires special equipment in surgery: ☐ No ☐ Yes Which?: ______________________________	Abnormal findings in the affected area[2]: ☐ No ☐ Low presence ☐ High presence
Patient requieres special inputs in surgery: ☐ No ☐ Yes Which?: ______________________________	Progression and severity of the disease[3]: ☐ Low ☐ Medium ☐ Severe
The proposed surgery in long-lasting (> 3 hours): ☐ Yes ☐ No	Probability of improvement with surgery: ☐ Low ☐ Medium ☐ High
Requieres critical care bed: ☐ Yes ☐ No	Probability of development of comorbidities without surgery: ☐ Low ☐ Medium ☐ High
Sleep disorder: ☐ Low ☐ Medium ☐ Severe	In your clinical judment, ¿what should be the maximum waiting time for this patient? ________days ________ weeks ____________ months
Pain EVA **(enclose)**: 0 1 2 3 4 5 6 7 8 9 10	Rate the urgency or relative priority of this patient **(enclose)** (without urgecy) 0 ---10---20---30---40---50---60---70---80---90---100 (very urgent)

The patient was on the waiting list prior to this diagnosis: ☐ Yes ☐ No	Current surgical diagnosis:

[1] Breathe, eat food, drink liquids, perform sports, recreation or hobbies, etc.
[2] Consider additional complications in organs such as ears, nose, throat, head and neck.
[3] Hearing loss, recurrent tonsillitis, balance disturbances, smell disorders, severe disorders of the voice and swallowing, head and neck tumors, among other severities.

Figure A1. Survey to measure the prioritization of otorhinolaryngology patients in the Hospital of Talca, Chile.

Appendix B

This appendix details the opinion given by physicians to each of the values that can take the $\alpha_{i,p}$ associated with each of the variables are:

1. `Sever`. For a given patient p, the corresponding $\alpha_{i:\texttt{Sever},p}$ value corresponds to $\alpha_{i:\texttt{Sever},p} \approx 0.06$ when the `Sever` category of patient p is "low", $\alpha_{i:\texttt{Sever},p} \approx 0.29$ when the category is "medium", and $\alpha_{i:\texttt{Sever},p} \approx 0.65$ when the category is "high".

2. `Urg`. For a given patient p, the corresponding $\alpha_{i:\texttt{Urg},p}$ value corresponds to $\alpha_{i:\texttt{Urg},p} \approx 0$ when the `Urg` category of patient p is "0", $\alpha_{i:\texttt{Urg},p} \approx 0.016$ when the category is "1", $\alpha_{i:\texttt{Urg},p} \approx 0.029$ when the category is "2", $\alpha_{i:\texttt{Urg},p} \approx 0.043$ when the category is "3", $\alpha_{i:\texttt{Urg},p} \approx 0.067$ when the category is "4", $\alpha_{i:\texttt{Urg},p} \approx 0.094$ when the category is "5", $\alpha_{i:\texttt{Urg},p} \approx 0.110$ when the category is "6", $\alpha_{i:\texttt{Urg},p} \approx 0.126$ when the category is "7", $\alpha_{i:\texttt{Urg},p} \approx 0.155$ when the category is "8", $\alpha_{i:\texttt{Urg},p} \approx 0.172$ when the category is "9", and $\alpha_{i:\texttt{Urg},p} \approx 0.188$ when the category is "10".

3. `Jclin`. The physician indicates the maximum waiting time the patient should wait, in months. For a given patient p, the corresponding $\alpha_{i:\texttt{Jclin},p}$ value corresponds to $\alpha_{i:\texttt{Jclin},p} \approx 0.197$ when the `Jclin` category of patient p is "I", $\alpha_{i:\texttt{Jclin},p} \approx 0.175$ when the category is "II", $\alpha_{i:\texttt{Jclin},p} \approx 0.149$ when the category is "III", $\alpha_{i:\texttt{Jclin},p} \approx 0.121$ when the category is "IV", $\alpha_{i:\texttt{Jclin},p} \approx 0.09$ when the category is "V", $\alpha_{i:\texttt{Jclin},p} \approx 0.079$ when the category is "VI", $\alpha_{i:\texttt{Jclin},p} \approx 0.062$ when the category is "VII", $\alpha_{i:\texttt{Jclin},p} \approx 0.054$ when the category is "VIII", $\alpha_{i:\texttt{Jclin},p} \approx 0.045$ when the category is "IX", and $\alpha_{i:\texttt{Jclin},p} \approx 0.028$ when the category is "X".

4. `Tsuen`. For a given patient p, the corresponding $\alpha_{i:\texttt{Tsuen},p}$ value corresponds to $\alpha_{i:\texttt{Tsuen},p} \approx 0.05$ when the `Tsuen` category of patient p is "low", $\alpha_{i:\texttt{Tsuen},p} \approx 0.29$ when the category is "medium", and $\alpha_{i:\texttt{Tsuen},p} \approx 0.66$ when the category is "severe".

5. `Tlist`. Corresponds to the time the patient p has been on hold, in months. For a given patient p, the corresponding $\alpha_{i:\texttt{Tlist},p}$ value corresponds to $\alpha_{i:\texttt{Tlist},p} \approx 0.036$ when the `Tlist` category of patient p is "0–3", $\alpha_{i:\texttt{Tlist},p} \approx 0.052$ when the category is "4–6", $\alpha_{i:\texttt{Tlist},p} \approx 0.072$ when the category is "7–9", $\alpha_{i:\texttt{Tlist},p} \approx 0.092$ when the category is "10–12", $\alpha_{i:\texttt{Tlist},p} \approx 0.106$ when the category is "13–18", $\alpha_{i:\texttt{Tlist},p} \approx 0.112$ when the category is "19–24", $\alpha_{i:\texttt{Tlist},p} \approx 0.121$ when the category is "25–36", $\alpha_{i:\texttt{Tlist},p} \approx 0.128$ when the category is "37–48", $\alpha_{i:\texttt{Tlist},p} \approx 0.137$ when the category is "49–60", and $\alpha_{i:\texttt{Tlist},p} \approx 0.144$ when the category is "+60".

6. `Pmcx`. For a given patient p, the corresponding $\alpha_{i:\texttt{Pmcx},p}$ value corresponds to $\alpha_{i:\texttt{Pmcx},p} \approx 0.045$ when the `Pmcx` category of patient p is "low", $\alpha_{i:\texttt{Pmcx},p} \approx 0.33$ when the category is "medium", and $\alpha_{i:\texttt{Pmcx},p} \approx 0.625$ when the category is "high".

7. `Dest`. For a given patient p, the corresponding $\alpha_{i:\texttt{Dest},p}$ value corresponds to $\alpha_{i:\texttt{Dest},p} \approx 0$ when the `Dest` category of patient p is "NA", $\alpha_{i:\texttt{Dest},p} \approx 0.94$ when the category is "yes", and $\alpha_{i:\texttt{Dest},p} \approx 0.06$ when the category is "no".

8. `Com`. For a given patient p, the corresponding $\alpha_{i:\texttt{Com},p}$ value corresponds to $\alpha_{i:\texttt{Com},p} \approx 0.049$ when the `Com` category of patient p is "low", $\alpha_{i:\texttt{Com},p} \approx 0.353$ when the category is "medium", and $\alpha_{i:\texttt{Com},p} \approx 0.598$ when the category is "high".

9. `Lfam`. For a given patient p, the corresponding $\alpha_{i:\texttt{Lfam},p}$ value corresponds to $\alpha_{i:\texttt{Lfam},p} \approx 0.909$ when the `Lfam` category of patient p is "yes", and $\alpha_{i:\texttt{Lfam},p} \approx 0.091$ when the category is "no".

10. `Hanor`. For a given patient p, the corresponding $\alpha_{i:\texttt{Hanor},p}$ value corresponds to $\alpha_{i:\texttt{Hanor},p} \approx 0.056$ when the `Hanor` category of patient p is "no presence", $\alpha_{i:\texttt{Hanor},p} \approx 0.333$ when the category is "low presence", and $\alpha_{i:\texttt{Hanor},p} \approx 0.611$ when the category is "high presence".

11. `Opat`. For a given patient p, the corresponding $\alpha_{i:\texttt{Opat},p}$ value corresponds to $\alpha_{i:\texttt{Opat},p} \approx 0.068$ when the `Opat` category of patient p is "0" additional pathologies, $\alpha_{i:\texttt{Opat},p} \approx 0.151$ when the category is "I", $\alpha_{i:\texttt{Opat},p} \approx 0.212$ when the category is "II", $\alpha_{i:\texttt{Opat},p} \approx 0.253$ when the category is "III", and $\alpha_{i:\texttt{Opat},p} \approx 0.315$ when the category is "IV" .

12. `Diag`. For a given patient p, the corresponding $\alpha_{i:\texttt{Diag},p}$ value corresponds to $\alpha_{i:\texttt{Diag},p} \approx 0.076$ when the `Diag` diagnosis of patient p is "complicated otitis media", $\alpha_{i:\texttt{Diag},p} \approx 0.07$ when the diagnosis is "cholesteatoma of the ear", $\alpha_{i:\texttt{Diag},p} \approx 0.07$ when the diagnosis is "complicated chronic sinusitis", $\alpha_{i:\texttt{Diag},p} \approx 0.065$ when the diagnosis is "obstructive tonsil and apnea", $\alpha_{i:\texttt{Diag},p} \approx 0.064$ when the diagnosis is "otitis media with effusion", $\alpha_{i:\texttt{Diag},p} \approx 0.062$ when the diagnosis is "nasal polyp with apnea", $\alpha_{i:\texttt{Diag},p} \approx 0.061$ when the diagnosis is "obstructive sleep apnea", $\alpha_{i:\texttt{Diag},p} \approx 0.061$ when the diagnosis is "obstructed lacrimal obstruction", $\alpha_{i:\texttt{Diag},p} \approx 0.06$ when the diagnosis is "frontal mucocele", $\alpha_{i:\texttt{Diag},p} \approx 0.06$ when the diagnosis is "septodesk with apnea", $\alpha_{i:\texttt{Diag},p} \approx 0.052$ when the diagnosis is "simple chronic sinusitis", $\alpha_{i:\texttt{Diag},p} \approx 0.051$ when the diagnosis is "hypertrophy of tonsils and adenoids", $\alpha_{i:\texttt{Diag},p} \approx 0.046$ when the diagnosis is "recurrent or chronic tonsillitis", $\alpha_{i:\texttt{Diag},p} \approx 0.045$ when the diagnosis is "tympanic perforation", $\alpha_{i:\texttt{Diag},p} \approx 0.044$ when the diagnosis is "nasal polyp without apnea", $\alpha_{i:\texttt{Diag},p} \approx 0.041$ when the diagnosis is "tear ducts obstruction", $\alpha_{i:\texttt{Diag},p} \approx 0.038$

when the diagnosis is "septo-deviation without apnea", and $\alpha_{i:\texttt{Diag},p} \approx 0.035$ when the diagnosis is "rinodeviation".

13. `Olim`. For a given patient p, the corresponding $\alpha_{i:\texttt{Olim},p}$ value corresponds to $\alpha_{i:\texttt{Olim},p} \approx 0.049$ when the `Olim` category of patient p is "no", $\alpha_{i:\texttt{Olim},p} \approx 0.34$ when the category is "medium", and $\alpha_{i:\texttt{Olim},p} \approx 0.612$ when the category is "severe".

14. `Ncuid`. For a given patient p, the corresponding $\alpha_{i:\texttt{Ncuid},p}$ value corresponds to $\alpha_{i:\texttt{Ncuid},p} \approx 0.932$ when the `Ncuid` category of patient p is "yes", and $\alpha_{i:\texttt{Ncuid},p} \approx 0.068$ when the category is "no".

15. `Rcuid`. For a given patient p, the corresponding $\alpha_{i:\texttt{Rcuid},p}$ value corresponds to $\alpha_{i:\texttt{Rcuid},p} \approx 0.939$ when the `Rcuid` category of patient p is "yes", and $\alpha_{i:\texttt{Rcuid},p} \approx 0.061$ when the category is "no".

16. `Dolor`. For a given patient p, the corresponding $\alpha_{i:\texttt{Dolor},p}$ value corresponds to $\alpha_{i:\texttt{Dolor},p} \approx 0$ when the `Dolor` category of patient p is "0", $\alpha_{i:\texttt{Dolor},p} \approx 0.016$ when the category is "1", $\alpha_{i:\texttt{Dolor},p} \approx 0.032$ when the category is "2", $\alpha_{i:\texttt{Dolor},p} \approx 0.045$ when the category is "3", $\alpha_{i:\texttt{Dolor},p} \approx 0.08$ when the category is "4", $\alpha_{i:\texttt{Dolor},p} \approx 0.096$ when the category is "5", $\alpha_{i:\texttt{Dolor},p} \approx 0.110$ when the category is "6", $\alpha_{i:\texttt{Dolor},p} \approx 0.128$ when the category is "7", $\alpha_{i:\texttt{Dolor},p} \approx 0.147$ when the category is "8", $\alpha_{i:\texttt{Dolor},p} \approx 0.166$ when the category is "9", and $\alpha_{i:\texttt{Dolor},p} \approx 0.179$ when the category is "10".

17. `Dtrab`. For a given patient p, the corresponding $\alpha_{i:\texttt{Dtrab},p}$ value corresponds to $\alpha_{i:\texttt{Dtrab},p} \approx 0$ when the `Dtrab` category of patient p is "NA", $\alpha_{i:\texttt{Dtrab},p} \approx 0.929$ when the category is "yes", and $\alpha_{i:\texttt{Dtrab},p} \approx 0.071$ when the category is "no".

18. `Acc`. For a given patient p, the corresponding $\alpha_{i:\texttt{Acc},p}$ value corresponds to $\alpha_{i:\texttt{Acc},p} \approx 0.104$ when the `Acc` category of patient p is "urban", $\alpha_{i:\texttt{Acc},p} \approx 0.343$ when the category is "rural", and $\alpha_{i:\texttt{Acc},p} \approx 0.552$ when the category is "high rurality".

19. `Dtras`. For a given patient p, the corresponding $\alpha_{i:\texttt{Dtras},p}$ value corresponds to $\alpha_{i:\texttt{Dtras},p} \approx 0.875$ when the `Dtras` category of patient p is "yes", and $\alpha_{i:\texttt{Dtras},p} \approx 0.125$ when the category is "no".

20. `Ccrit`. For a given patient p, the corresponding $\alpha_{i:\texttt{Ccrit},p}$ value corresponds to $\alpha_{i:\texttt{Ccrit},p} \approx 0.652$ when the `Ccrit` category of patient p is "yes", and $\alpha_{i:\texttt{Ccrit},p} \approx 0.348$ when the category is "no".

Appendix C

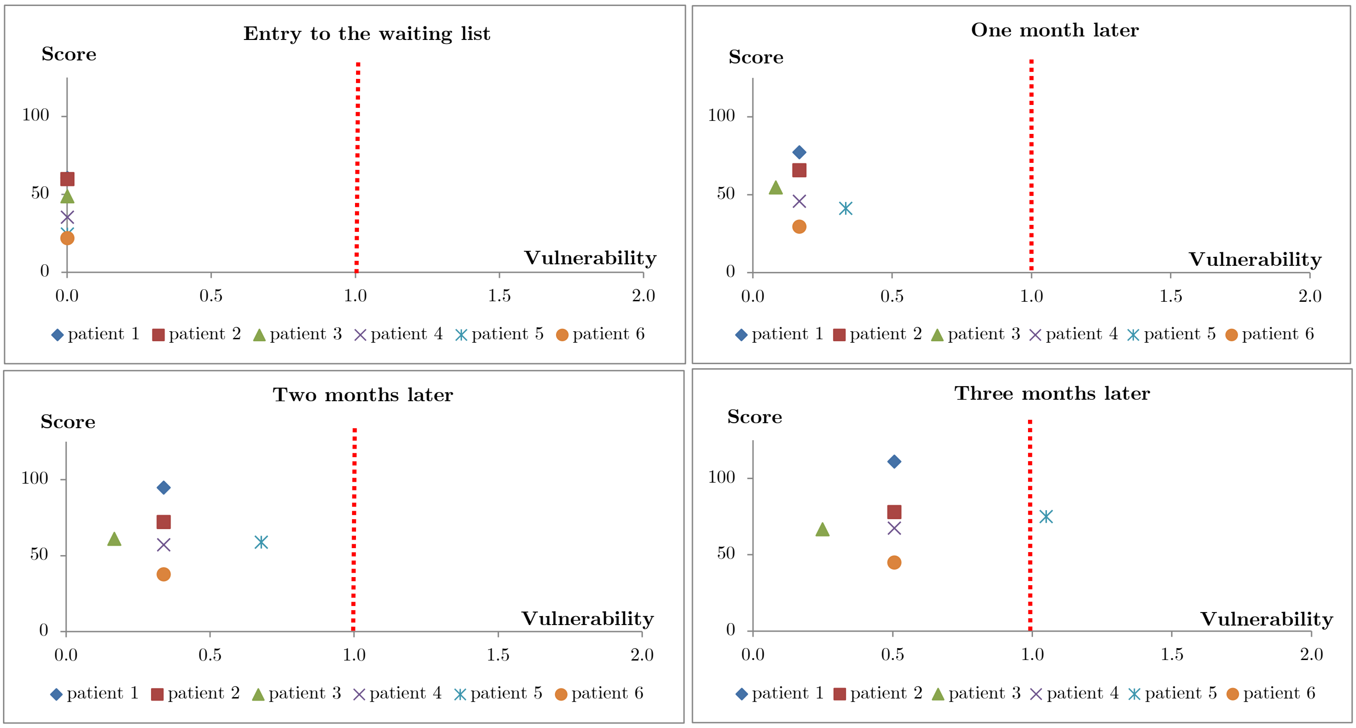

Figure A2. Evolution over time of the score and the vulnerability of six patients on the waiting list.

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