applied sciences

MDPI

Article

A Technological Framework to Support Asthma Patient Adherence Using Pictograms

Rosa Figueroa [1,*], Carla Taramasco [2,*], María Elena Lagos [3], Felipe Martínez [4], Carla Rimassa [5], Julio Godoy [6], Esteban Pino [1], Jean Navarrete [7], Jose Pinto [1], Gabriela Nazar [8], Cristhian Pérez [9] and Daniel Herrera [5]

1 Department of Electrical Engineering, Universidad de Concepción, Concepción 4070409, Chile; epino@biomedica.udec.cl (E.P.); jose.pinto@biomedica.udec.cl (J.P.)
2 School of Engineering, Andres Bello University, Viña del Mar 2531015, Chile
3 Department of Nursing and Public Health, Universidad de Concepcion, Concepción 4070409, Chile; mariaelagos@udec.cl
4 Faculty of Medicine, Andres Bello University, Viña del Mar 2531015, Chile; ranoih@gmail.com
5 Faculty of Medicine, University of Valparaíso, Valparaíso 2340000, Chile; carla.rimassa@uv.cl (C.R.); daniel.herrera@uv.cl (D.H.)
6 Department of Computer Science, Universidad de Concepción, Concepción 4070409, Chile; jugodoy@inf.udec.cl
7 Department of Industrial Engineering, Universidad de Concepción, Concepción 4070409, Chile; jnavarretec@udec.cl
8 Department of Psychology, Universidad de Concepción, Concepción 4070409, Chile; gnazar@udec.cl
9 Department of Medical Education, Universidad de Concepción, Concepción 4070409, Chile; cperezv@udec.cl
* Correspondence: rosa.figueroa@biomedica.udec.cl (R.F.); carla.taramasco@unab.cl (C.T.)

Abstract: Background: Low comprehension and adherence to medical treatment among the elderly directly and negatively affect their health. Many elderly patients forget medical instructions immediately after their appointments, misunderstand them, or fail to recall them altogether. Some identified causes include the short time slots allocated for appointments in the public health system in Chile, the complex terminology used by healthcare professionals, and the stress experienced by patients during appointments. One approach to improving patients' adherence to medical treatment is to combine written and oral instructions with graphical elements such as pictograms. However, several challenges arise due to the ambiguity of natural language and the need for pictograms to accurately represent various medication combinations, doses, and frequencies. Objective: This study introduces SIMAP (System for Integrating Medical Instructions with Pictograms), a technological framework aimed at enhancing adherence among asthma patients through the delivery of pictograms via a computational system. SIMAP utilizes a collaborative and user-centered methodology, involving health professionals and patients in the construction and validation of its components. Methods: The technological framework presented in this study is composed of three parts. The first two are medical indications and pictograms related to the treatment of the disease. Both components were developed through a comprehensive and iterative methodology that incorporates both qualitative and quantitative approaches. This methodology includes the utilization of focus groups, interviews, paper and online surveys, as well as expert validation, ensuring a robust and thorough development. The core of SIMAP is the technological component that leveraged artificial intelligence methods for natural language processing to analyze, tokenize, and associate words and their context to a set of one or more pictograms, addressing issues such as the ambiguity in the text, the cultural factor that involves many ways of expressing the same indication, and typographical errors in the indications. Results: Firstly, we successfully validated 18 clinical indications along with their respective pictograms. Some of the pictograms were redesigned based on the validation results. However, in the final validation, the comprehension percentages of the pictograms exceeded 70%. Furthermore, we developed a software called SIMAP, which translates medical indications into previously validated pictograms. Our proposed software, SIMAP, achieves a correct mapping rate of 96.69%. Conclusions: SIMAP demonstrates great potential as a technological component for supplementing medical instructions with pictograms when tested in a laboratory setting. The use of artificial intelligence for natural language processing can successfully map medical instructions, both structured and unstructured,

check for updates

Citation: Figueroa, R.; Taramasco, C.; Lagos, M.E.; Martínez, F.; Rimassa, C.; Godoy, J.; Pino, E.; Navarrete, J.; Pinto, J.; Nazar, G.; et al. A Technological Framework to Support Asthma Patient Adherence Using Pictograms. *Appl. Sci.* **2024**, *14*, 6410. https://doi.org/10.3390/app14156410

Academic Editor: Chilukuri K. Mohan

Received: 20 June 2024
Revised: 11 July 2024
Accepted: 18 July 2024
Published: 23 July 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

into pictograms. This integration of textual instructions and pictograms holds promise for enhancing the comprehension and adherence of elderly patients to their medical indications, thereby improving their long-term health.

Keywords: natural language processing; machine learning; pictograms; tokenization; n-gram

1. Introduction

Technologies such as artificial intelligence and natural language processing have demonstrated significant promise in healthcare applications. Examples include utilizing machine learning techniques to identify latent diseases in X-ray images, predict patient outcomes, and provide treatment recommendations [1–3]. However, their widespread adoption is hindered by healthcare professionals' limited understanding of their potential and the scarcity of human resources knowledgeable in AI and machine learning. Additionally, a lack of interdisciplinary collaboration impedes the direct application of these technologies in healthcare [4].

One area where technology can be applied in healthcare is supporting strategies to manage chronic diseases. In recent times, chronic diseases have experienced an increase globally due to longer life expectancy, sedentary lifestyles, and air pollution. This rise has led to a greater demand for health services [5,6]. Asthma is a chronic condition considered a severe public health problem, affecting around 200 million people globally [7]. People who have asthma and do not adhere to their treatment experience a progressive decrease in their quality of life. Patients who adhere to inhaler treatment and a proper application technique exhibit better symptom control [8]. Adherence to treatment in people with chronic diseases is around 50%; however, in people with asthma, this percentage is even lower, as low as 22% [9]. Therefore, healthcare professionals must promote medical indications comprehension among these patients, which is not trivial. Recent studies indicate that 78% of patients do not recall medical instructions, 40% to 80% of communicated information is immediately forgotten, and 50% of retained information might be incorrect [10]. Consequently, developing tools that can support healthcare professionals in patient education and patients in understanding and remembering medical instructions is essential. In this context, the use of pictograms associated with medical instructions has shown promise in aiding individuals with low health literacy in adhering to medical treatment [11]. However, before evaluating this positive effect, a proper software framework must be developed to accurately translate instructions from natural language into pictograms or pictogram sequences. This task is non-trivial due to variations in how health professionals convey their instructions—some use medication abbreviations, while others use special lexical structures to indicate dosage, posing challenges for developing accurate mapping rules.

The literature on the automated translation of text to images is currently dominated by methods based on neural networks, specifically Generative Adversarial Networks (GANs) [12–14]. However, these neural network-based methods require vast amounts of data, which are not always readily available, to create an accurate model. In the case of pictograms, the literature is not as extensive.

For instance, Picto, a tool that transforms text to pictograms and vice versa, utilizes two sets of pictograms, Beta and Sclera, in conjunction with WordNet to construct a lexical–semantic database for automatically associating pictograms with text [15]. Another work in this line is Pictogrammar, an adaptive and augmentative pictogram-based communication system designed for individuals with autism spectrum disorder to assist them in generating messages [16]. Pictogrammar employs Pictontology, a custom-built ontology of multimedia resources based on 621 SupO (Simple Upper Ontology) terms linked to pictograms, along with the attributes and properties of each resource. This model produces restrictions that facilitate the addition of new concepts into categories, as well as the suggestion of new pictograms based on the context (predictive semantic grammar).

In this context, Glyph stands out as one of the pioneering tools used to transform text into pictograms in the healthcare field, serving as the basis for various articles [17,18]. Glyph employs a database of medical terms where each pictogram and its corresponding label are linked to a graphical (atomic or composite) or semantic (disease, device, etc.) category. To accurately identify information related to medicines, Glyph utilizes a database available in DailyMed. Plain-text indications are segmented into semantic units for pictogram classification and labeled in categories that facilitate the concatenation of images (weight, composite or atomic units, frequency of medicine doses, negation, daytime of the dose). To compose the image, the authors use a rule engine based on grammatical patterns obtained from clinical indications of a cardiology unit. Finally, Glyph's performance was evaluated in a study by Hill et al., revealing that participants who received discharge instructions with Glyph-generated pictograms recalled 35% more of their discharge instructions at discharge than those who received standard discharge instructions. Additionally, participants who received discharge instructions with pictograms reported higher satisfaction with their understanding of the instructions one week after discharge compared to those who received standard discharge instructions [18].

In the article by Figueroa et al., a study is described to test physicians' perception of the worthiness of developing a system for complementing medical indications with pictograms. The authors applied an expert judgment survey to medical professionals in Concepción, Chile, consisting of 66 questions seeking opinions on whether the medical instruction pictogram pairs were "unnecessary", "useful", or "essential". Results showed that 22 of the pairs of indications–pictograms were considered "essential", 11 were considered "useful", and none were considered "unnecessary" [19].

In Heyns' 2019 study, the effectiveness of using pictograms to complement medical indications in primary healthcare facilities in Cape Town, South Africa, was examined. The author found that the use of pictograms was beneficial in aiding the understanding of clinical information in low-literate patient populations and across languages. Specifically, the author noted that a large font size, bold text, and white space positively impacted the recognition of important text in the indication. Furthermore, the understanding of medical indications was enhanced with a verbal explanation and when pictograms were designed in collaboration with the target population [20].

On the other hand, Rungsriwattana et al. present a randomized controlled study conducted in chronic patients in a primary health care center in Thailand, indicating that medication adherence with the use of pictograms was significantly higher than in the control group [21]. In their article, Leong et al. present the findings of a randomized clinical trial conducted in patients with a chronic disease. The study revealed that 77% of participants reported improved understanding of medication instructions with the use of pictograms, 67% preferred pictograms over written instructions for receiving their medication instructions, and 93% felt that pictograms should be utilized on medication labels [22].

In a recent systematic review of the effectiveness of pictograms in healthcare settings, Menon et al. found that all included studies concluded that pictograms had a positive impact on enhancing patient adherence to medical treatment and helped decrease dosing errors. They further found that pictograms had a positive impact on adherence to treatments in patients with low health literacy levels compared to written or oral interventions [23].

In this study, we propose a technological framework to support adherence in asthma patients using pictograms. This framework is called SIMAP (automatic system to complement medical indications with pictograms). SIMAP used a user-centered methodology for the construction and validation of each of its components. The framework consists of three primary elements: a collection of clinical recommendations for treating asthma, a set of pictograms to accompany these clinical recommendations, and an algorithm designed to use natural language processing to automatically enhance the clinical instructions for asthma treatment with pictograms of dosage, types of drugs, and frequency of use. Accordingly, the main contributions of this work can be summarized as follows:

- A generalizable methodology for validating health pictograms based on international standards.
- An algorithm to process medical text from electronic systems into pictograms.
- A technology that supports standardization in delivering medical indications for bronchial asthma in primary health to support the understanding of such indications.
- A database of pictograms to support medical indications for bronchial asthma that are validated for relevance and comprehension.

The rest of this article is organized as follows: Section 2 describes the materials and methods used to build the SIMAP system. Section 3 describes the results of medical indication collection methodology, validation of pictograms, and results related to the SIMAP algorithm. Sections 4 and 5 present an analysis of the performance of the SIMAP algorithm and a discussion of the state of development of the SIMAP system and future work.

2. Materials and Methods

2.1. SIMAP: System for Automatic Association of Medical Indications with Pictograms

SIMAP is a system designed to enhance understanding and aid retention of medical indications for individuals with bronchial asthma [15,24]. SIMAP has three core components: (i) a collection of clinical indications for asthma treatment, (ii) a set of pictograms to complement the clinical indications for asthma treatment, and (iii) an algorithm that automatically supplements clinical indications for asthma treatment with pictograms (Figure 1). The following sections explain the methodologies applied to create each of the components mentioned above.

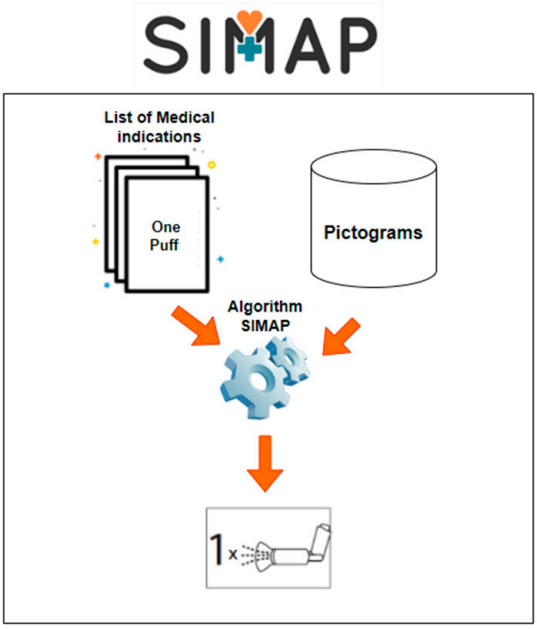


Figure 1. Core components of SIMAP.

2.2. Methodology for Collecting and Validating Medical Instructions and Pictograms for the Care of Patients with Asthma

We employed a user-centered methodology involving the collection of medical instructions and pictograms through focus groups or individual interviews with health professionals specialized in asthma care. The data collection, indication validation, and pictogram selection process took place in February 2021.

2.2.1. Collection of Clinical Recommendations for Treating Asthma

SIMAP requires, as one of its core components, a comprehensive set of natural language instructions tailored to guide patients in the effective management of bronchial

asthma. Therefore, this stage is dedicated to the identification and validation of a collection of medical indications expressed in natural language, extracted from a Family Health Center. This process entailed a qualitative study employing an exploratory approach and a descriptive scope. Given the initial project constraints imposed by COVID-19, sampling was determined based on accessibility. As a result, a total of eight focus groups were conducted across eight primary healthcare centers. Through these sessions, we formulated a comprehensive set of 13 recommendations for patients concerning the management and treatment of bronchial asthma. This process involved identifying the most used indications and exploring the challenges patients face in understanding and adhering to them. After identifying a concise set of indications, our focus shifted to incorporating a range of lexical variables, including synonyms, to broaden the linguistic expressions associated with the collected indications. This approach is aimed to facilitate their subsequent recognition by computational algorithms.

2.2.2. Pictogram Validation Process

In response to the challenges presented by the COVID-19 pandemic, we implemented a two-stage pictogram validation process.

First validation process: In this stage, we employed a paper-based selection and evaluation tool in the form of a booklet. This booklet included the pictograms, their respective alternatives, and a comment section to facilitate the process. The booklet was applied during meetings with clinicians and patients conducted at the Family Health Centers. To ensure a thorough qualitative assessment, during this meeting, we also conducted a focus group session upon completing the pictogram selection and validation process. This session enabled us to collect insights from both individual and collective perspectives on the pictograms, facilitating any necessary adjustments or revisions for a comprehensive evaluation.

Second validation process: In this stage, we devised an instrument comprising 18 pictograms associated with medical indications with the aim of testing the correspondence between medical indications and pictograms. This instrument adhered to ISO 9186 guidelines and consisted of two sections [25–27]. The initial section collected information about the sociodemographic and occupational background of the experts, covering aspects such as age, gender, health center, profession, working hours in ARU (Asthma Respiratory Unit), and specialization courses in the field.

The subsequent section aimed to ascertain whether the presented pictogram corresponded to the medical indication, providing two response choices: (a) It matches indicating that the pictogram accurately represented the indication, or (b) it does not fit signifying that the pictogram did not accurately represent the indication. Each question was followed by an open-response box to allow for suggestions and comments regarding the pictogram. This instrument was completed by professionals from the ARUs, including kinesiologists, physicians, nurses, nursing technicians, and pharmaceutical chemists. Each expert was tasked with determining whether the pictogram accurately represented the linked medical indication.

The assessment of the pictograms was expressed in terms of the percentage of experts who deemed the pictogram to adequately represent the medical indication.

2.2.3. Assessment Process for Patients' Comprehension of Pictograms

After the sets of medical indication–pictogram pairs were validated by the experts in the ARU rooms, the validation of pictogram comprehension by patients attending the participating ARU rooms began. This process consisted of two stages. The first stage aimed to understand what patients perceived when confronted with each pictogram. In the second stage, a group of kinesiologists with expertise in managing bronchial asthma determined whether the patients understood the pictograms by analyzing their responses. Since the results for some of the pictograms were inconclusive, the process was repeated only for those pictograms that did not achieve an adequate level of comprehension.

2.3. Questionnaire to Assess the Comprehension of Pictograms among Patients with Bronchial Asthma and Users of Family Health Centers

In this stage, we developed an instrument to collect what patients perceived when confronted with each pictogram adhering to ISO 9186 guidelines. The questionnaire encompassed the following sections:

- Informed consent.
- Presentation of the study.
- Section for sociodemographic information: gender (male, female, other), age (years), educational level (elementary school incomplete, elementary school complete, high school incomplete, high school complete, technical complete, technical incomplete, university incomplete, university complete, postgraduate), current activity (full-time worker, part-time worker), community of residence, name of the health center, and region.
- Section for the participant's health history: name of the disease, approximate date of diagnosis, diagnosis of other chronic diseases, and presence of asthma attacks in the last 6 months.
- General instructions for answering the questionnaire.
- Presentation of each pictogram with a text box for the answer (Figure 2).
- Acknowledgments

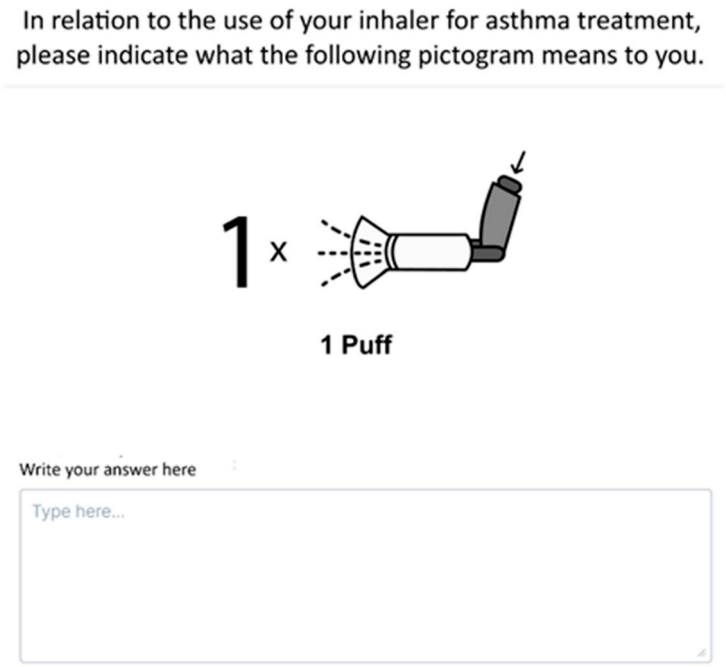


Figure 2. Example of a question designed to assess comprehension of a pictogram.

This version of the questionnaire underwent a cognitive interview with bronchial asthma patients selected for convenience. The cognitive interview is a valuable tool for analyzing the cognitive mechanisms underlying the questionnaire response process. It involves a series of questions administered in a controlled environment, utilizing a small sample from the target population. The primary objective is to assess comprehension of instructions, memory retention, appropriateness of response options, response time, social desirability, sensitivity, and various other cognitive and motivational factors involved in comprehending and responding to questionnaires.

This process led to the development of a questionnaire designed to evaluate the comprehension of pictograms in patients with bronchial asthma who use Family Health Centers (Version 2).

2.4. Evaluation Process of Pictogram Comprehension by Users Diagnosed with Bronchial Asthma

During this phase, we evaluated the comprehension level of the proposed pictograms among patients diagnosed with bronchial asthma. Users of the ARUs from health centers participating in the project were invited to participate, based on the following inclusion and exclusion criteria.

Inclusion Criteria

- Adults aged 18–65 years that have been diagnosed with bronchial asthma.
- Have internet access and a cell phone, computer, or another electronic device.
- Provide an email address or telephone number for contact purposes.
- Manage or have support for the use of the Internet.

Exclusion Criteria

- Presence of obstructive bronchial conditions other than bronchial asthma, such as chronic obstructive pulmonary disease (COPD) or mixed states.
- Presence of psychiatric pathology.
- Diagnosis of dementia.
- History of problematic alcohol consumption.
- History of substance abuse.
- The presence of significant ophthalmologic conditions that may hinder the proper visualization of images.
- Visual and/or hearing impairment.

The sample size adhered to ISO 9186-1 guidelines, recommending a minimum of 50 participants for the evaluation of pictogram comprehension. These participants were distributed across the municipalities of Hualpén, Talcahuano, San Antonio, and Valparaíso.

For data collection, we utilized the instrument Questionnaire for Evaluating Pictogram Comprehension Among Patients with Bronchial Asthma, Users of Family Health Centers, Version 2.

2.4.1. First Evaluation of Pictogram Comprehension by External Expert Judgement

In this phase, we assessed the comprehension of pictograms by users with the assistance of two external experts, both kinesiologists. They evaluated the responses of 50 users (24 from the Valparaíso Region and 26 from the Biobío Region) for each of the 18 pictograms and reported their level of understanding.

To conduct this assessment, we created an Excel-based evaluation matrix, including:

- Instructions for the evaluator;
- The medical indication;
- The associated pictogram;
- The participant's response;
- A field for the expert judge's evaluation.

Each evaluator independently determined whether, in their opinion, the participant's response corresponded to the medical indication conveyed by the pictogram. They used two response categories:

- The pictogram is adequately understood;
- The pictogram is not adequately understood.

2.4.2. Second Evaluation Process of Pictogram Comprehension by Users Diagnosed with Bronchial Asthma

Building upon the findings from prior stages, specific pictograms underwent a redesign process. Subsequently, we developed a condensed version of the original instrument, focusing solely on the reevaluation of six pictograms. This revised instrument included the following components:

- Introduction to the study;
- Response instructions;

- Two examples demonstrating responses using previously validated pictograms;
- Presentation of the six pictograms with corresponding evaluation prompts and acknowledgments.

Sixteen patients diagnosed with bronchial asthma, as well as users of the health centers participating in the project and meeting the study's inclusion criteria, took part in the study. Among these 16 patients, 8 evaluated the pictograms between 1 January and 13 January 2020, while the remaining 8 assessed the pictograms between 21 January and 31 January 2021.

2.4.3. Second Evaluation of Pictogram Comprehension by External Expert Judgement

Similar to the previous stage, participants' responses were independently assessed by two external evaluators to gauge the level of comprehension of the six pictograms.

As in the initial evaluation round, evaluators used an assessment matrix to independently determine whether the participant's response aligned with the medical indication conveyed by the pictogram. They employed two response categories:

- The pictogram is clearly understood;
- The pictogram is not adequately understood.

This stage featured two rounds of comprehension evaluation. The first occurred between 13 and 19 January, while the second took place between 31 January and 3 February 2022.

2.5. Methodology for the Development of the Computational Platform

In this work, we propose a software framework called SIMAP to automatically associate medical indications with sequences of pictograms. The general design of our SIMAP framework is shown in Figure 3. The SIMAP algorithm consists of several steps that transform medical instructions written in natural language into sequences of pictograms. The process begins with the input text, which can be either structured (with a predefined format) or unstructured (free natural language), and this characteristic will determine the type of processing to be carried out. Afterwards, the input text is cleaned and tokenized. Finally, the processed medical indication is searched in the pictogram dictionary to retrieve the best match. This approach allows for handling the variability in the wording of medical instructions, including abbreviations and typographical errors, thereby improving the system's accuracy and usability.

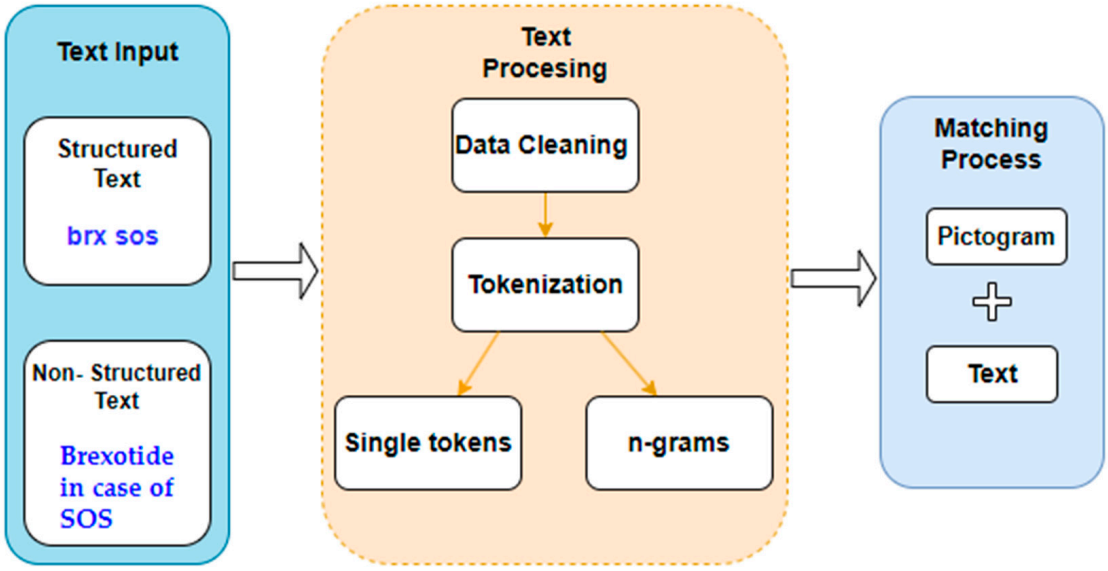


Figure 3. Diagram of the components that integrate the SIMAP algorithm.

2.5.1. Input Text

The algorithm processes plain text instructions as input, which may be either structured or unstructured. Table 1 provides illustrative examples of input formats.

Table 1. Example text before pre-process.

Structured	Unstructured
(brm 1-1 + brx sos, brd 2-2-2)	"Use bromide one puff every 12 h + brexotide in case of emergency, berodual 2 puff every 8 h"
BUD 2-0-2	Budesonide every eight hours two puffs
dsl lrt brm 1-1-1-1	Desloratadine loratadine bromide => one puff every 6 h

2.5.2. Data Cleaning

Due to the nature of the text, there may be more than one prompt per text input. Indications can be separated by plus sign (+), comma (,), dot (.), and new line(s). After identifying the sub-prompts, the text is cleaned of possible punctuation and unwanted characters, as illustrated in Table 2.

Table 2. List of unwanted characters.

!	"	#	$	%	&	}
'	(	)	*	+	,	~
-	.	/	:	;	<	|
=	>	?	@	[	\	{
]	^	_	`			

After identifying the sub-indications, the sample texts are as follows (see Table 3).

Table 3. Input text after cleaning process.

Structured	Unstructured
• brm 11	• Use bromide one puff every 12 h
• brx sos	• Brexotide in case of emergency
• brd 222	• Berodual 2 puffs every 8 h
• BUD 202	• Budesonide every eight hours two puffs
• dsl 1111	• Desloratadine one puff every 6 h
• lrt 1111	• Loratadine one puff every 6 h
• brm 1111	• Bromide one puff every 6 h

2.5.3. Extracting Tokens from Text

After cleaning the input, it is necessary to extract tokens that will be used later to find a matching pictogram. In this step, tokenization is carried differently on a structured or non-structured input. Tokenization is a process that involves dividing text into a list of single tokens (words or other text unit); if the tokens are grouped together in a sequence of words, then they are called n-grams. (see Table 4).

- Structured text: The professionals at ARU tend to employ a numerical structure to convey information about the use of medicines to patients, as detailed in the Data Collection section. In this context, the indication is modeled into individual tokens. Subsequently, for each token obtained, a mapping is created using a dictionary of pictograms. In this dictionary, each key corresponds to a drug or instruction, while the values encompass all possible ways of writing the drug or instruction (e.g., Key: brexotide, values = brexotide, brex, bxt). The algorithm can identify indications with the described format.

Table 4. Input text as structured and unstructured text.

Structured (Tokenization)	Unstructured (n-Gram)
• ['brm', '11'] • ['brx', 'sos'] • ['brd', '222']	*Use bromide one puff every 12 h* (a) ['use bromide one', 'bromide one puff', 'one puff every', 'puff every 12', 'every 12 h'] (b) ['use bromide', 'bromide one', 'one puff', 'puff every', 'every 12', '12 h'] (c) ['use', 'bromide', 'one', 'puff', 'every', '12', 'hours'] *Brexotide in case of emergency* (a) ['brexotide in case', 'in case of', 'case of emergency'] (b) ['brexotide in', 'in case', 'case of', 'of emergency'] (c) ["brexotide', 'in', 'case', 'of', 'emergency'] *Berodual 2 puffs every 8 h* (a) ['berodual 2 puffs', '2 puffs every', 'puffs every 8', 'every 8 h'] (b) ['berodual 2', '2 puffs', 'puffs every', 'every 8, '8 h'] (c) ['berodual', '2', 'puffs', 'every', '8', 'hours']
• ['bud', '202']	*Budesonide every eight hours two puffs* (a) ['Budesonide every eight', 'every eight hours', 'eight hours two', 'hours two puffs'] (b) ['Budesonide every', 'every eight', 'eight hours', 'hours two', 'two puffs'] (c) ['Budesonide', 'every', 'eight', 'hours', 'two', 'puffs']
• ['dsl', '1111'] • ['lrt', '1111'] • ['brm', '1111']	*Desloratadine one puff every 6 h* (a) ['Desloratadine one puff', 'one puff every', 'puff every 6', 'every 6 h'] (b) ['Desloratadine one', 'one puff', 'puff every', 'every 6', '6 h'] (c) ['Desloratadine', 'one', 'puff', 'every', '6', 'hours'] *Loratadine one puff every 6 h* (a) ['loratadine one puff', 'one puff every', 'puff every 6', 'every 6 h'] (b) ['loratadine one', 'one puff', 'puff every', 'every 6', '6 h'] (c) ['loratadine', 'one', 'puff', 'every', '6', 'hours']

Unstructured Text: For this input, the algorithm tokenizes the text. Then, sequences of consecutive tokens are grouped to model the input as n-grams. N-grams are better at identifying more complex indications in the free text [28]. This algorithm represents the text into trigrams, bigrams, and unigrams. After this representation, a mapping is performed for each n-gram using a dictionary of pictograms.

2.5.4. Matching in Pictogram Dictionary

Finally, the algorithm delivers a list of pictograms associated with each indication (see Table 5).

Table 5. Input and final output example.

Input	Output
BUD 202	['budesonida', 'c-12-h.png', '2-puff.png']
(brm 1-1 + brx sos, brd 2-2-2)	[['bromuro', 'uso-diario.png', 'c-12-h.png', '1-puff.png'], [brexotide, 's-o-s.png'], ['bromuro', 'uso-diario.png', 'c-8-h.png', '1-puff.png']]
use fluticasone one puff every 6 h + salbutamol use in case of emergency 2 puff, prednisone 1 puff every 12 h	[['fluticasone', 'uso-diario.png', 'c-6-h.png', '1-puff.png'], ['salbutamol', 's-o-s.png', '2-puff.png'], ['prednisone', 'c-12-h.png', '1-puff.png']]

2.5.5. Data Collection

SIMAP processes text input indications collected in the previous stages. These indications primarily focus on reminding patients to adhere to their pharmacological treatment. The treatment specifications include information on the drug, its frequency of use, and the administered dose. The health center follows a standardized set of words and codes to structure these indications, aiming to enhance patient comprehension.

Structured indication: Compound of medication + frequency of use and dose.

1. Medication: A list of medications for the treatment of asthma.
   - Brexotide
   - Budesonide
   - Loratadine
   - Theophylline
   - Salmeterol
   - Fluticasone
   - Salbutamol
   - Desloratadine
   - Bromide
   - Prednisone
   - Berodual
2. Frequency of use and dose: numerical code as shown in the following table (see Table 6).

Table 6. Frequency of use and dose example.

Code	Indication
1-1	one dose every 12 h
1-1-1	one dose every 8 h
1-1-1-1	one dose every 6 h
2-2	two doses every 12 h
2-2-2	two doses every 8 h
2-2-2-2	two doses every 6 h

2.5.6. NLP Tools and Methods for Structured Text

In this case, the tokenization method was used to divide the raw text into small chunks of words or phrases, known as tokens. If the text is divided into words, it is referred to as 'word tokenization', and if it is divided into phrases, it is termed 'phrase tokenization'. For example, given the input text: 'Tokenization is one of the first steps in any NLP pipeline. Tokenization is nothing but splitting the raw text into small chunks of words or sentences, called tokens', the resulting tokens would be as shown in Table 7.

Table 7. Word tokenization.

Tokenization	is	one	of	the	first	step
In	any	NLP	pipeline	Tokenization	is	nothing
but	splitting	the	raw	text	into	small
chunks	of	words	or	sentences	called	tokens

2.5.7. NLP Tools and Methods for Non-Structured Text

In the case of unstructured text, we employ n-grams, which are sequences of characters or words extracted from text. N-grams can be divided into two categories: (1) character based and (2) word based. A word-based n-gram is a set of n consecutive words extracted from a sentence. For instance, consider the sentence 'The cow jumps over the moon'. If $N = 2$ (known as bigrams), then the n-grams would be as shown in Table 8.

Table 8. Bigram list.

the cow	cow jumps	jumps over
over the	the moon	

If N = 3, the n-grams would be (see Table 9):

Table 9. trigram list.

the cow jumps	cow jumps over
jumps over the	over the moon

When N = 2, this is called a bigram, and when N = 3, this is called a trigram.

If X = Num of words in a given sentence K, the number of n-grams for sentence K would be:

$$Ngrams_K = X - (N - 1)$$

3. Results

3.1. Validation of the Medical Indications and Pictograms

The validation process involved healthcare professionals affiliated with the Asthma Respiratory Unit (ARU) in various CESFAMs (Community Healthcare Centers) across the Valparaíso and Biobío regions. The participants comprised a diverse range of expertise, including kinesiologists, physicians, nurses, nursing technicians, and pharmaceutical chemists. In total, six separate validation processes were conducted, each taking place at a distinct CESFAM in the Valparaíso and Biobío regions. In the first stage, 22 ARU professionals participated, with 15 from the Valparaíso region and 7 from the Concepción region. The distribution of participants per center is presented in Table 10.

Table 10. Distribution of participants per health center.

Region	Commune	CESFAM	Professionals
Valparaíso	San Antonio	CESFAM Manuel Bustos	5
	Valparaíso	CESFAM Quebrada Verde	0
		CESFAM Marcelo Mena	2
		CESFAM Barón	4
		CESFAM Esperanza	4
Bío Bío	Hualpén	CESFAM Hualpencillo	3
		CESFAM Talcahuano Sur	4
		CESFAM Leocan Portus	0
		CESFAM La Floresta	0
Total number of participants in the validation			22

Based on our methodology, a set of 13 medical indications for asthma treatment and inhaler use was selected and prioritized through focus group analysis.

- Indication 1: One puff.
- Indication 2: Two puffs.
- Indication 3: Every eight hours.
- Indication 4: Every twelve hours.
- Indication 5: Always use an aerocamera.
- Indication 6: Shake the inhaler vertically for one minute.
- Indication 7: Remove the cap of the inhaler.
- Indication 8: Insert inhaler into the air chamber.
- Indication 9: Adjust the air chamber to the face.
- Indication 10: Press the inhaler.

- Indication 11: Breathe into the air chamber and perform a puff.
- Indication 12: Hold your breath for 10 s.
- Indication 13: Breathe out through the nose.

Pictograms, representing both general and complementary indications for the use of inhalers in asthma treatment, were constructed using qualitative analysis and guidance from ISO 9186 and the ONCE Foundation [29–32]. Figure 4 displays the initial set of 13 pictograms designed based on indications to enhance treatment and adherence to bronchial asthma.

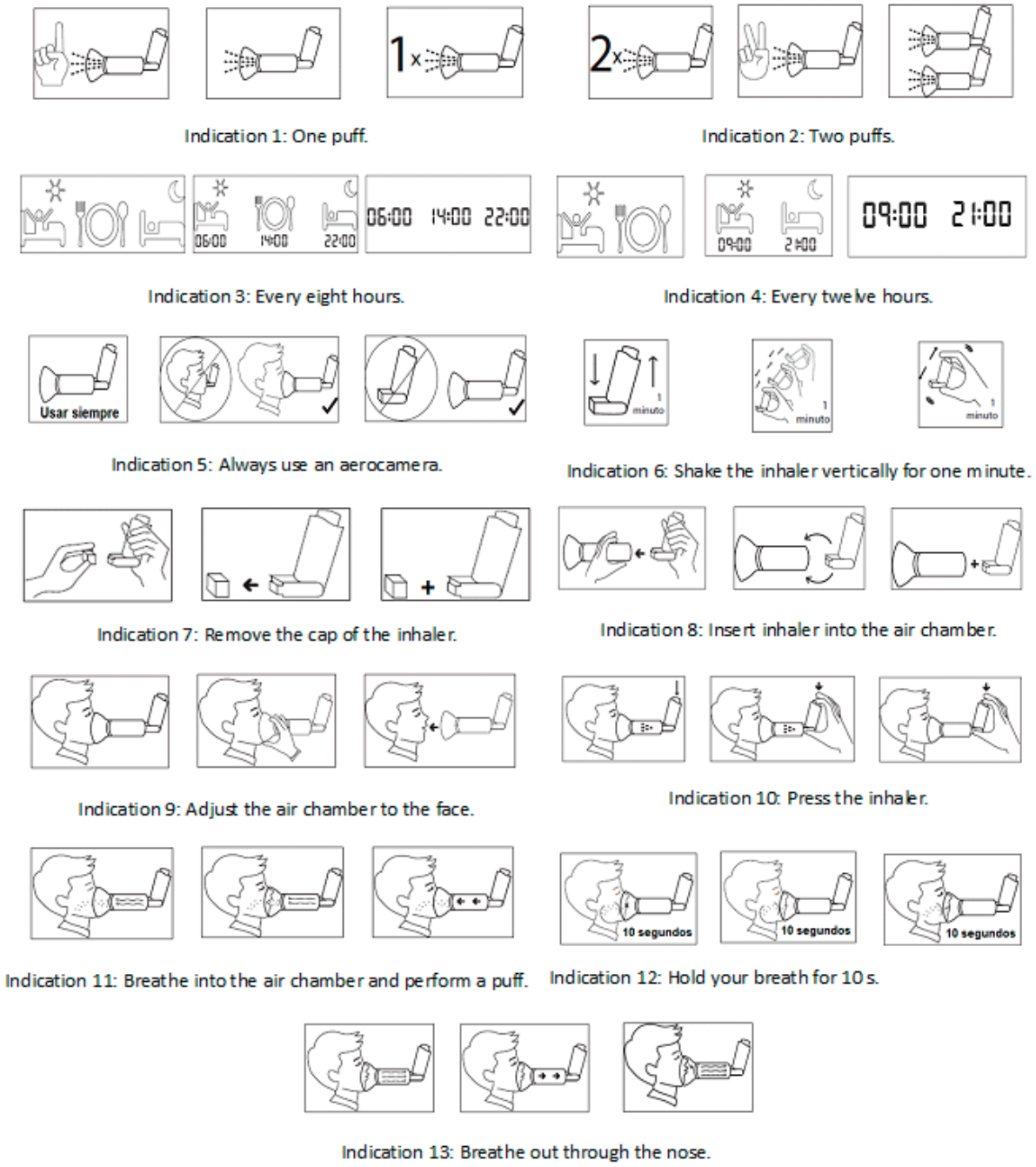


Figure 4. First pictograms designed for the 13 medical indications for asthma treatment and inhaler use. For each indication, 3 pictogram options are included.

3.2. First Stage of Adaptation and Design of Pictograms for Medical Indications

Table 11 presents a comprehensive quantitative overview of the results obtained in the pictogram selection process. In a broader perspective, the indications showcase success rates in the chosen alternatives surpassing 67% across 10 indications, while 2 indications fall within the range of 60% to 66%. Notably, only one indication, labeled as number 13, registers a success rate below 50%. Moving forward, Table 12 exhibits the finalized pictograms selected from the survey, accompanied by proposed design enhancements. Further refinement was guided by professionals' valuable feedback, derived from qualitative analysis of the focus groups and the observations section of the instrument. This insightful feedback prompted the consideration of incorporating five new medical indications, each complemented by a corresponding pictogram, as outlined in Table 13.

Table 11. Results in % of pictogram selection by ARU professionals.

Indication	Total Valid Answers	Total Answers	Percentage "A" in Valid Answers	Percentage "B" in Valid Answers	Percentage "C" in Valid Answers	Percentage "A" in Total Answers	Percentage "B" in Total Answers
1	21	22	33%	0%	67%	32%	0%
2	21	22	62%	29%	10%	59%	27%
3	22	22	23%	68%	9%	23%	68%
4	22	22	18%	73%	9%	18%	73%
5	22	22	14%	86%	0%	14%	86%
6	22	22	0%	82%	18%	0%	82%
7	20	22	75%	25%	0%	68%	23%
8	22	22	95%	0%	5%	95%	0%
9	22	22	23%	64%	14%	23%	64%
10	22	22	0%	82%	18%	0%	82%
11	18	22	6%	72%	22%	5%	59%
12	20	22	45%	35%	20%	41%	32%
13	18	22	6%	11%	83%	5%	9%

Table 12. Selection and suggested modifications with pictograms.

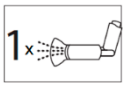
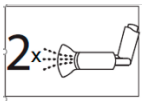
Indication	Selected Pictogram Alternative	Suggested Corrections
One puff		It is only suggested to include the text of the indication.
Two puffs		A recommendation has been made to consider including the phrase 'wait one minute between inhalations.
Every eight hours		The time notations at the bottom of the images may pose issues because individuals do not all wake up at the same hour. To address this, it would be beneficial to have the flexibility to customize these times according to each patient while maintaining the daily frequency. Therefore, a suggestion is to incorporate blank spaces in the time slots, allowing for individualized time entries for each patient.

Table 12. *Cont.*

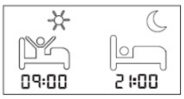
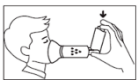
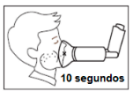
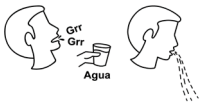
Indication	Selected Pictogram Alternative	Suggested Corrections
Every twelve hours		Same suggestion as indication 4
Always use an aerocamera		It is only suggested to include the text of the indication.
Shake the inhaler vertically for one minute		The numbers could be larger, and the image sharper. Additionally, '1 minute' should be aligned in a sentence.
Remove the cap of the inhaler		The arrow from Alternative B could be included between the cap and the inhaler in Alternative A.
Insert inhaler into the air chamber		Consider adding a socket or insertion slot to the air-chamber in Alternative A. This may make Alternative A more comprehensive than originally anticipated.
Adjust the air chamber to the face		The indication should use "cover" instead of "fit", and for the nose and mouth, it should specify "face". So, the revised indication would be: "Cover the nose and mouth with the air chamber".
Press the inhaler		The indications should state 'Press the inhaler once'. To accommodate this, you can add the phrase 'press once' to pictogram B.
Breathe into the air chamber and perform a puff		Include a hand and date image on the inhaler in Alternative B to illustrate the puff application process, similar to indication 10.
Hold your breath for 10 s		A suggestion is to modify the indication from 'hold' to 'hold your breath for 10 seconds'. Additionally, you can enhance the clarity of the instruction by including the phrase 'hold 10 seconds' below the image, within the box. To accommodate patients with varying literacy levels, consider replacing or complementing the word 'seconds' with an image depicting a clock to enhance understanding.
Breathe out through the nose		In Alternative C, replace the wavy arrows with straight arrows for a clearer depiction. For practitioners who believe that the application involves blowing air through the nose, consider adding an 'X' over the mouth, as in 'Alternative A' in instruction 12. Please note that for some practitioners, the distinction between blowing through the mouth or nose is significant.

Table 13. Aggregated indications derived from the analysis of focus group results.

Indication	Pictogram	Reason for Adding the Indication
Using the inhaler in a crisis		Indication for bronchodilator use.
Use in inhaler every day		Guidance for the utilization of regular corticosteroid inhaler therapy.
Use 4 times a day every 6 h		Some patients require bronchodilator treatment every 6 h.
Rinsing the mouth		Practitioners recommend incorporating mouthwash or mouth rinsing after corticosteroid use to prevent fungal growth.
Washing the air chamber		Professionals recommend including the cleaning of the air chamber as a vital instruction.

3.3. Second Validation Process of Pictograms to Support Clinical Indications for Patients with Bronchial Asthma, by ARU Professionals

Table 14 offers an overview of the participants' characteristics in this stage of the study. In contrast, Table 15 provides a comprehensive analysis of the validation results for pictogram designs, considering the recommendations outlined in Section 2 of this report. The findings indicate that all pictograms demonstrate a compatibility score exceeding 70% with the medical indications, except for pictogram 3, which exhibits a compatibility score of 65.3%. It is important to note that these results reflect the outcomes of the evaluation conducted in both participating regions, namely BioBío and Valparaiso.

Table 14. Characterization of participating professionals by region (*N* = 32).

		Biobío	Valparaíso
Gender	Female	8	15
	Male	6	2
Age(mean)		34.93 (7.97)	36.50 (8.39)
Educational level	Complete technician	0	3
	Full university education	12	9
	Postgraduate	02	5
ARU experience (years)		5.46 (5.87)	6.17 (6.46)
Role in ARU	Physician	6	2
	Kinesiologist	5	9
	Nurse	3	2
	Pharmacy	0	1
	Pharmaceutical Chemist	0	1
	Other	0	3

Table 15. Results of validation set medical indication to pictogram by ARU professionals.

Indication–Pictogram	Frequency of Compatibility between Pictograms and Medical Indications in Both Regions (*N* = 32)	Average Percentage (%) of Compatibility between Pictograms and Medical Indications in Both Regions (*N* = 32)
1	32	100
2	28	87.5
3	21	65.3
4	30	93.8
5	30	93.8
6	26	81.3
7	27	84.4
8	28	87.5
9	30	93.8
10	32	100
11	26	81.3
12	31	96.9
13	31	96.9
14	23	71.9
15	28	87.5
16	29	90.63
17	30	93.8
18	28	87.5

3.4. First Evaluation of Pictogram Comprehension by External Expert Judgement

During this phase, the comprehension of pictograms by users was assessed with input from two external experts, both kinesiologists. These experts evaluated the responses of 50 users (24 from the Valparaíso region and 26 from the Biobío region) for each of the 18 pictograms, reporting their respective levels of understanding. Following the evaluation of all pictograms by these two experts, the inter-rater agreement coefficient was determined using the Kappa index. The resulting findings are presented below, in Table 16. This evaluation took place from 8 to 15 November 2021. After both experts assessed all the pictograms, we calculated the inter-evaluator agreement coefficient using the Kappa index. We determined an optimal level of comprehension as achieved when at least 67% of the participants demonstrated a clear understanding of the pictogram. This was supported by a substantial inter-judge agreement exceeding 0.60, indicating a 'moderate' level according to the Kappa index.

Table 16. Evaluation of pictograms by expert judgment.

Pictogram	% Comprehension	Agreement YES (*N* = 50)	Agreement NO (*N* = 50)	Disagreement (*N* = 50)	Kappa Index	Strength of Inter-judge Concordance	Observations
1	84	42	7	1	0.92	Almost Perfect	Accepted
2	62	31	8	11	0.45	Moderate	Third Expert
3	52	26	21	3	0.87	Almost Perfect	Redesign
4	88	44	2	4	0.46	Moderate	Accepted
5	84	42	5	3	0.74	Substantial	Accepted
6	68	34	12	4	0.8	Substantial	Accepted
7	78	39	8	3	0.81	Almost Perfect	Accepted
8	86	43	4	3	0.69	Substantial	Accepted
9	96	48	2	0	1	Almost Perfect	Accepted
10	86	43	3	4	0.56	Moderate	Accepted
11	84	42	4	4	0.63	Substantial	Accepted
12	52	26	23	1	0.96	Almost Perfect	Redesign

Table 16. *Cont.*

Pictogram	% Comprehension	Agreement YES (*N* = 50)	Agreement NO (*N* = 50)	Disagreement (*N* = 50)	Kappa Index	Strength of Inter-judge Concordance	Observations
13	64	32	13	5	0.77	Substantial	Third Expert
14	68	34	16	0	1	Perfect	Accepted, minor changes s
15	42	21	18	11	0.58	Moderate	Third Expert
16	68	34	16	0	1	Perfect	Accepted, minor changes
17	76	38	8	4	0.75	Substantial	Accepted
18	84	42	3	5	0.49	Moderate	Accepted

Table 16 indicates that 11 out of the 18 pictograms successfully met these criteria. Pictograms 2 and 15 showed a low level of comprehension without strong agreement among the evaluators, leading us to refer them for evaluation by a third external judge, independent of the project team. Pictogram 13 achieved an understanding rate of 64%, approaching the project's defined threshold, and demonstrated substantial agreement among evaluators. However, as it fell just short of the desired comprehension level, we decided to subject it to evaluation by a third judge. Pictograms 4, 10, and 18 showed moderate agreement strength. Despite this, they exhibited a high degree of agreement between judges, aligning with the limitation reported by the Kappa index. Recognizing this limitation and considering the strong evidence of comprehension, the project team resolved to approve pictograms 4, 10, and 18. The outcomes of the assessment conducted by the third judge were integrated into the existing evaluations provided by the two prior judges. Subsequently, both comprehension scores and the Kappa index values were averaged to yield the consolidated results, as presented in Table 17.

Table 17. Summary of review results by third evaluating judge.

	Average Comprehension	Average Kappa	Strength of Inter-judge Concordance
Pict2	69.33	0.48	Moderate
Pict13	67.33	0.37	Low
Pict15	49.33	0.57	Moderate

The third evaluation emphasized the necessity for redesign, especially for pictogram 13, owing to its insufficient comprehension. As a result, the redesigned pictograms underwent a new comprehension review process involving ARU users.

3.5. Second Evaluation of Pictogram Comprehension by External Expert Judgement

Building on the outcomes of the previous stage, it was concluded that redesign was essential for pictograms 3, 12, 13, 14, 15, and 16. Table 18 below presents the original renditions alongside the proposed modifications.

Two external evaluators independently assessed participants' responses, rating the level of understanding for all six pictograms. Upon concluding the second phase of data collection, which involved a total of 16 patients, the inter-evaluator agreement coefficient was calculated using the Kappa index. It is noteworthy that all pictograms demonstrated a level of understanding surpassing the 87% threshold. Consequently, these pictograms are considered validated, and the comprehensive results can be found in Table 19.

Table 18. Pictograms subject to redesign.

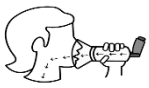
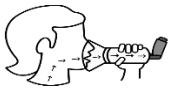
Pictogram	Initial Version	Modification Requested
3		Remove '2 puffs under 60 s' and include the word 'wait' beneath the stopwatch.
12		Use a solid line, not a dotted line, and emphasize that the nose and mouth are covered. Provide two options, one correct and one incorrect. Display only the profile to highlight the adjustment to the nose and mouth.
13		Shade the area of the mouth covered by the aerocamera.
14		Shade the area of the mouth covered by the aerocamera.
15		Remove "X" from the mouth and show closed lips.
16		Shade the area of the mouth covered by the aerocamera.

Table 19. Second evaluation of pictogram comprehension by external expert judgement.

Pictogram	% Comprehension	Sample Size	Agreement YES (N = 50)	Agreement NO (N = 50)	Disagreement (N = 50)	Kappa Index	Strength of Inter-Judge Concordance	Observations
3	87.5	16	14	1	1	0.94	Almost perfect	Validated
12	87.5	16	14	0	2	0.87	Almost perfect	Validated
13	81.25	16	13	2	0	1	Perfect	Validated
14	93.75	16	15	1	0	1	Perfect	Validated
15	87.5	8	7	0	1	0.87	Almost perfect	Validated
16	87.5	16	14	2	0	1	Perfect	Validated

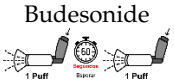
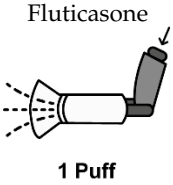
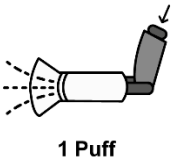
3.6. SIMAP Algorithm Results

In the context of the SIMAP application, we conducted an evaluation of 18 pictograms. Out of these, 11 pictograms related to inhalation techniques were excluded due to their specific indications. Among the remaining selection, we identified seven pictograms that correlated with both usage frequency and dosage information. Upon analyzing the provided indication data, a discernible pattern emerged, linking certain character combinations to their corresponding pictograms. The algorithm is proficient in mapping these character combinations and correctly associating them with the respective pictograms. Moreover, it exhibits the ability to comprehend natural language and establish accurate pictogram associations.

It is important to note that the proposed solution operates within the constraints of the input data domain and the predefined output pictograms. Consequently, it cannot establish associations with pictograms beyond those that have been officially approved.

With this curated list of pictograms, SIMAP becomes capable of linking medical indications to visual representations, as illustrated in Table 20.

Table 20. Input and Output obtained from the system.

Input	Output
BUD 202	Budesonide 
(brd 2-2-2)	berodual 
use fluticasone one puff every 6 h + salbutamol in case of emergency 2 puffs, prednisone 1 puff every 12 h	Fluticasone  salbutamol  prednisona 

We conducted three comprehensive evaluations to ascertain the effectiveness of SIMAP in accurately associating medical indications with pictograms that faithfully convey their intended meanings.

For the first evaluation, we used a dataset meticulously collected by researchers and personnel from the SIMAP project at the Universidad de Concepción and the Universidad de Valparaíso. This dataset consisted of a total of 242 medical instructions. Impressively, SIMAP successfully mapped 234 of these instructions to their respective sets of pictograms, achieving a commendable 96.69% accuracy rate in translation. The eight instances where SIMAP did not generate pictograms corresponded to instructions that did not prescribe any treatment (e.g., "sin-tratamiento").

In our second evaluation, we aimed to assess the robustness of SIMAP's mapping algorithm. Specifically, we sought to determine how well SIMAP performed when confronted with typographical errors introduced into medical indications by health professionals or their assistants. These errors could potentially result in the failure to generate pictograms. For this assessment, we intentionally introduced random errors into the medical indications and measured the accuracy of translation in the resulting erroneous indications. We assigned a probability to each character in the text that referred to the prescribed medicine for the patient's treatment, indicating the likelihood of it being replaced by another random letter. For instance, "BUD 2-0-2" could be altered to "ByD 2-0-2".

To ensure the credibility of our findings and to mitigate the influence of randomness, we conducted this experiment multiple times for each probability value. Subsequently, we report the average results in Table 21, providing a more robust assessment of SIMAP's performance under these challenging conditions.

Table 21. Correct translation rate for different error probabilities per text character.

% Error per Character	Correct Translation Rate
1%	96.5%
5%	95.3%
10%	91%
20%	78.3%
30%	61.9%
40%	41.9%
50%	28.3%

Table 21 provides valuable insights into SIMAP's performance, illustrating its capability to accurately map erroneous medical indications to the correct pictogram. SIMAP achieves an accuracy rate of nearly 80% when, on average, one out of every five characters contains an error in its writing. However, as the error rate escalates, the correct translation rate experiences a notable decline. Even when approximately half of the characters contain errors, SIMAP still manages to correctly map nearly 30% of the indications.

In our third and final evaluation, we expanded upon the second evaluation by broadening the scope of potential typos to encompass all characters within the medical indications, not just those indicating the medicine to be administered. This extended evaluation allowed for the possibility of spaces, lines, and numbers being replaced by random letters with specific probabilities. To maintain robustness and mitigate the influence of random errors, we conducted each experiment 10 times, providing a more comprehensive view of SIMAP's performance, as detailed in Table 22.

Table 22. Correct translation rate for different error probabilities per each character.

% Error per Character	Correct Translation Rate
1%	96.4%
5%	93.8%
10%	84.5%
20%	62.9%
30%	40.2%
40%	22.5%
50%	11.5%

The outcomes presented in Table 22 align with our expectations, clearly indicating that SIMAP's proficiency in accurately mapping indications to pictograms diminishes as the number of errors in the indications increases. Nevertheless, it is noteworthy that SIMAP can still achieve an 85% accuracy rate in correct translations when there is an average 10% chance of each character being erroneous.

These findings underscore SIMAP's capacity to effectively enhance medical indications with pictograms that faithfully represent their intended meaning. However, we must emphasize the importance of maintaining a standardized input format for instructions when employing SIMAP for mapping to pictograms. As evidenced by the results, SIMAP exhibits robustness against typos up to a certain threshold. Beyond that threshold, when indications contain a substantial number of typos, the algorithm faces significant challenges in producing the correct corresponding pictogram(s).

4. Discussion

In this research, we introduce SIMAP, a technological framework designed to promote adherence among asthma patients through the utilization of pictograms. This framework was built using a user-centered methodology. Its components are a collection of clinical recommendations for treating asthma, a set of pictograms to accompany these clinical recommendations, and an algorithm designed to use natural language processing to automatically enhance the clinical instructions for asthma treatment.

The methodology to validate both the medical indications and pictograms is intended to aid in the treatment of patients with bronchial asthma. Our observations revealed that most of the pictograms were readily comprehended by the patients upon initial presentation. However, those pictograms that posed challenges in terms of understanding were subjected to redesign and subsequent validation. Through this iterative process, we successfully validated a total of 18 pictograms, which subsequently served as the foundation for the algorithm's design.

On the other hand, the algorithm to automatically associate medical indications with pictograms maps medical indications to sequences of previously validated pictograms. In crafting this algorithm, we harness natural language processing tools to meticulously analyze and standardize textual data, streamlining its correlation with one of the 18 available pictograms. These pictograms indicate the dosage, type of medicine, and its frequency in a dataset of medical indications, achieving a 96% correct translation rate.

One of the main challenges in achieving a high accuracy rate (96%) in the assignment of medical indications to pictograms was the variability in the way healthcare professionals wrote the indications. This variability included the use of abbreviations and specific terminology that the model did not easily recognize, creating difficulties in correctly interpreting and mapping the instructions to the corresponding pictograms. To overcome this challenge, an exhaustive analysis of common medical indications in asthma treatment was conducted, with the active participation of healthcare professionals to validate and document the various forms of expression. Additionally, a natural language processing (NLP) algorithm was developed to analyze, tokenize, and map words and their context to pictograms, handling both structured and unstructured text. Specific pictogram dictionaries were created that included multiple variants of writing for each medication or instruction, improving mapping accuracy through tokenization and n-gram techniques. Iterative validation and refinement processes, in collaboration with healthcare professionals and patients, allowed continuous adjustment and improvement of the system, ensuring that the indications were clearly represented through the pictograms. The combination of these approaches was key to overcoming the challenges associated with variability in the writing of indications and achieving a high accuracy rate.

Although SIMAP was designed to complement medical indications for patients with bronchial asthma, the pictograms related to the inhaler technique could be adapted to other respiratory pathologies and the frequency pictograms, such as every 8 h, could be adapted to other pathologies. SIMAP methodologies could also be adapted to other chronic conditions to support patient education and self-management. The selection of which chronic condition to address first depends on local contextual factors such as, for example, disease prevalence, lack of adherence to treatment, the potential impact of education strategies on quality of life, and willingness of the health team to work on innovations in healthcare, among others. Regardless of the chronic condition selected, the methodology for collecting medical indications and validating pictograms should be applied to ensure that the pictograms used are helpful and understood by patients.

One drawback of SIMAP is its reliance on validated indications to generate pictograms. However, it currently employs basic NLP techniques for preprocessing these indications. Looking ahead, our goal is to harness the power of artificial intelligence to enable users to input a wide range of indications, with the algorithm accurately producing the corresponding pictogram.

5. Conclusions

Our successful implementation of a development and validation strategy has yielded a robust framework, laying the foundation for substantial progress. All medical instructions and pictograms comprising SIMAP were validated for both their correspondence and comprehension by the patients. Likewise, the SIMAP algorithm has demonstrated an impressive accuracy rate of approximately 96% when tested on medical indications extracted from a clinical dataset. Consequently, we firmly believe that this framework holds

immense potential for significantly improving the treatment of asthma patients, thereby promising enhanced healthcare outcomes.

In our future endeavors, we aim to expand our pictogram database, with a specific emphasis on enriching resources for asthma patients. We also will conduct feasibility assessments to explore the potential inclusion of other medical conditions, such as diabetes, within the scope of our project. SIMAP was developed as a proof of concept with medical indications and pictograms related to the treatment of bronchial asthma, so the product achieved is a pilot system only evaluated at the laboratory level in terms of its accuracy. The following steps evaluate the system in a relevant environment to prove its effectiveness in controlling bronchial asthma. On the other hand, plans also include generating a massification and scalability strategy that allows, in collaboration with health centers, other universities, and even other countries, to add medical indications and pictograms for other chronic pathologies or health conditions. As for the future development of the SIMAP algorithm, it is planned to explore the implementation of advanced techniques such as word embeddings and more sophisticated language models to improve the accuracy and robustness of the system. Using embeddings such as Word2Vec, GloVe, or BERT can provide a better semantic representation of words and phrases in medical indications, which could significantly improve the algorithm's ability to handle variations in natural language. In addition, incorporating transformer-based models, such as GPT-3 or BERT, can increase the understanding and processing of unstructured medical texts. These advanced techniques will allow the algorithm to learn from large volumes of textual data and continuously improve its performance using deep learning. It is also planned to use transfer learning techniques to adapt the algorithm to different medical specialties, ensuring its applicability to a broader range of medical conditions. These enhancements will not only increase the accuracy of the mapping of indications to pictograms but will also facilitate the scalability of the system and its integration into various clinical contexts.

Finally, we plan to incorporate SIMAP into mobile applications for patients, aiming to facilitate treatment adherence by providing information through various means.

Author Contributions: Conceptualization, R.F., C.T., M.E.L., J.G., and C.R.; Methodology, R.F., C.T., M.E.L., F.M., C.R., J.N., J.G., E.P., G.N., J.P., C.P., and D.H.; Writing—original draft preparation, R.F., M.E.L., and J.P.; Writing—review and editing, C.T., F.M., C.R., J.G., J.N., E.P., G.N., and J.P.; Supervision, R.F. and C.T.; Funding acquisition, R.F. and C.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidad de Concepción grant number 219.092.053-M, FONDEF, ANID (National Research and Development Agency, Chile, Funder URL https://anid.cl/, accessed on 17 July 2024), grant number ID19I10120 (RLFI, CT, ML, CR, JG, EP, JN, JP, FM, GN), the National Center on Health Information Systems (CTI230006 CENS), and the Millennium Nucleus on Sociomedicine, grant ANID–MILENIO–NCS2021_013 (CT, RLFI, ML). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by two ethics committees: the Ethics Committee of Talcahuano's Health Service (resolution 174, 23 December 2019), and the Ethics Committee of the Metropolitan East Health Service (12 November 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy restrictions.

Acknowledgments: The authors would like to thank the Universidad de Concepción, FONDEF, the National Center on Health Information Systems, and the Millennium Nucleus on Sociomedicine for supporting the authors of this work. The authors would like to thank the health management boards and family health centers participating in this study in Valparaíso, San Antonio, Hualpén y Talcahuano. This recognition extends particularly to the health teams dealing with asthma respiratory units (Salas ERA).

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

References

1. Shelmerdine, S.C.; Martin, H.; Shirodkar, K.; Shamshuddin, S.; Weir-McCall, J.R. Can artificial intelligence pass the Fellowship of the Royal College of Radiologists examination? Multi-reader diagnostic accuracy study. *BMJ* **2022**, *379*, e072826. [CrossRef]
2. Hilton, C.B.; Milinovich, A.; Felix, C.; Vakharia, N.; Crone, T.; Donovan, C.; Proctor, A.; Nazha, A. Personalized predictions of patient outcomes during and after hospitalization using artificial intelligence. *npj Digit. Med.* **2020**, *3*, 51. [CrossRef]
3. Nilsen, P.; Reed, J.; Nair, M.; Savage, C.; Macrae, C.; Barlow, J.; Svedberg, P.; Larsson, I.; Lundgren, L.; Nygren, J. Realizing the potential of artificial intelligence in healthcare: Learning from intervention, innovation, implementation and improvement sciences. *Front. Health Serv.* **2022**, *2*, 961475. [CrossRef]
4. Pucchio, A.; Papa, J.D.; de Moraes, F.Y. Artificial intelligence in the medical profession: Ready or not, here AI comes. *Clinics* **2022**, *77*, 100010. [CrossRef] [PubMed]
5. Fuller, R.; Landrigan, P.J.; Balakrishnan, K.; Bathan, G.; Bose-O'Reilly, S.; Brauer, M.; Caravanos, J.; Chiles, T.; Cohen, A.; Corra, L.; et al. Pollution and health: A progress update. *Lancet Planet. Health* **2022**, *6*, e535–e547. [CrossRef] [PubMed]
6. Park, J.H.; Moon, J.H.; Kim, H.J.; Kong, M.H.; Oh, Y.H. Sedentary Lifestyle: Overview of Updated Evidence of Potential Health Risks. *Korean J. Fam. Med.* **2020**, *41*, 365–373. [CrossRef] [PubMed]
7. The Lancet. Global Burden of Disease. Global Health Metrics. Asthma-Level 3 Cause [Internet]. 2020, Volume 396, pp. 108–109. Available online: https://www.thelancet.com/gbd/summaries (accessed on 9 July 2024).
8. Mäkelä, M.J.; Backer, V.; Hedegaard, M.; Larsson, K. Adherence to inhaled therapies, health outcomes and costs in patients with asthma and COPD. *Respir. Med.* **2013**, *107*, 1481–1490. [CrossRef]
9. Granda, P.; Villamañán, E.; Carpio, C.; Laorden, D.; Sobrino, C.; Herrero, A.; Quirce, S.; Alvarez-Sala, R. Adherence to inhalers in patients with severe asthma treated with anti-interleukin-5 biologics. *Farm. Hosp.* **2022**, *46*, 203–207. [CrossRef] [PubMed]
10. Aslam, A.M.; Kennedy, J.; Seghol, H.; Khisty, N.; Nicols, T.A.; Adie, S. A randomized controlled trial of patient recall after detailed written consent versus standard verbal consent in adults with routine orthopaedic trauma. *Bone Jt. Open* **2023**, *4*, 104–109. [CrossRef] [PubMed]
11. Merks, P.; Cameron, J.; Bilmin, K.; Świeczkowski, D.; Chmielewska-Ignatowicz, T.; Harężlak, T.; Białoszewska, K.; Sola, K.F.; Jaguszewski, M.J.; Vaillancourt, R. Medication Adherence and the Role of Pictograms in Medication Counselling of Chronic Patients: A Review. *Front. Pharmacol.* **2021**, *12*, 582200. [CrossRef] [PubMed]
12. Ramzan, S.; Iqbal, M.M.; Kalsum, T. Text-to-Image Generation Using Deep Learning. *Eng. Proc.* **2022**, *20*, 16. [CrossRef]
13. Ku, H.; Lee, M. TextControlGAN: Text-to-Image Synthesis with Controllable Generative Adversarial Networks. *Appl. Sci.* **2023**, *13*, 5098. [CrossRef]
14. Zhou, R.; Jiang, C.; Xu, Q. A survey on generative adversarial network-based text-to-image synthesis. *Neurocomputing* **2021**, *451*, 316–336. [CrossRef]
15. Norré, M.; Vandeghinste, V.; Bouillon, P.; François, T. (Eds.) Extending a text-to-pictograph system to French and to Arasaac. In Proceedings of the International Conference on Recent Advances in Natural Language Processing (RANLP 2021), Online, 1–3 September 2021.
16. Ben Mesmia, F.; Mouhoub, M. A Web-Based Communication Tool for Arabic-Speaking Newcomers to Canada. In Proceedings of the 14th International Conference on Advances in Computer-Human Interactions, Nice, France, 18–22 July 2021.
17. Mutal, J.; Bouillon, P.; Norré, M.; Gerlach, J.; Ormaechea-Grijalba, L. (Eds.) A Neural Machine Translation Approach to Translate Text to Pictographs in a Medical Speech Translation System-The BabelDr Use Case. In Proceedings of the 15th Biennial Conference of the Association for Machine Translation in the Americas, Orlando, FL, USA, 12–16 September 2022; Volume 1: Research Track.
18. Schubbe, D.; Cohen, S.; Yen, R.W.; Muijsenbergh, M.V.; Scalia, P.; Saunders, C.H.; Durand, M.-A. Does pictorial health information improve health behaviours and other outcomes? A systematic review protocol. *BMJ Open* **2018**, *8*, e023300. [CrossRef] [PubMed]
19. Figueroa, R.; Taramasco, C.; Flores, C.; Ortiz, L.; Vásquez-Venegas, C.; Salas, P.; Zeng-Treilter, Q. A Physician's Perspective on the Incorporation of Pictograms as a Supplement to Medical Instructions in Chile: A Pilot Study. *IRBM* **2023**, *44*, 100712. [CrossRef]
20. Heyns, J.; van Huyssteen, M.; Bheekie, A. The effectiveness of using text and pictograms on oral rehydration, dry-mixture sachet labels. *Afr. J. Prim. Health Care Fam. Med.* **2021**, *13*, a2646. [CrossRef] [PubMed]
21. Rungsriwattana, V.; Ngamchaliew, P.; Buathong, N. Effects of Pharmaceutical Pictograms on Medication Adherence in Elderly Patients with Chronic Diseases at Primary Health Care Center in Hat Yai, Songkhla. *J. Med. Assoc. Thail.* **2021**, *104*, 482–488.
22. Leong, M.; Tam, V.; Xu, T.; Peters, M. Understanding medication schedules: Do pictograms help? *J. Patient Saf.* **2018**, *14*, e19–e24. [CrossRef] [PubMed]
23. Menon, D.D.; Joy, J.M.; Paul, A.; Reddy, S.A.; Raj, E.A.; Krishnan, J.B.; Vilakkathala, R. Effectiveness of pictograms in patients or caregivers in healthcare settings: A systematic review. *J. Pharm. Health Serv. Res.* **2021**, *12*, 607–614. [CrossRef]
24. International Organization for Standardization ISO 9186-3. Graphical Symbols—Test Methods—Part 3: Method for Testing Symbol Referent Association. Available online: https://www.iso.org/standard/59882.html (accessed on 12 January 2024).
25. *ISO 9186-1:2014*; Graphical Symbols—Test Methods—Part 1: Method for Testing Comprehensibility. International Organization for Standardization (ISO): Geneva, Switzerland, 2014.
26. *ISO 9186-2:2008*; Graphical Symbols—Test Methods—Part 2: Method for Testing Perceptual Quality. International Organization for Standardization (ISO): Geneva, Switzerland, 2008.

27. *ISO 9186-3:2014*; Graphical Symbols—Test Methods—Part 3: Method for Testing Symbol Referent Association. International Organization for Standardization (ISO): Geneva, Switzerland, 2014.
28. Maipradit, R.; Hata, H.; Matsumoto, K. Sentiment classification using N-gram inverse document frequency and automated machine learning. *IEEE Softw.* **2019**, *36*, 65–70. [CrossRef]
29. Espinoza-Navarro, O.; Rivera-Gutiérrez, S. Ética y Jurisprudencia Administrativa de los Derechos de los Sujetos de Investigación en Pandemia (COVID-19): Función de los Comités Éticos Científicos: Chile. *Int. J. Morphol.* **2021**, *39*, 785–788. [CrossRef]
30. Venegas, C.P.V. Desarrollo De Algoritmo Para Asociación Automática De Pictogramas a Indicaciones Médicas. Doctoral Dissertation, Universidad de Concepción, Concepción, Chile, 2017.
31. Hopewell, S.; Boutron, I.; Chan, A.-W.; Collins, G.S.; de Beyer, J.A.; Hróbjartsson, A.; Nejstgaard, C.H.; Østengaard, L.; Schulz, K.F.; Tunn, R.; et al. An update to SPIRIT and CONSORT reporting guidelines to enhance transparency in randomized trials. *Nat. Med.* **2022**, *28*, 1740–1743. [CrossRef] [PubMed]
32. CMEIS Recommendations for Scientific Ethical Committees (Cecs) in the Review of Research Protocols in the Context of Pandemic by COVID-19—6 June 2020. Available online: https://www.uta.cl/wp-content/uploads/2020/06/ProtocoloCECc.pdf (accessed on 14 January 2024).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.