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Algorithmic Evaluations in Breast Cancer: the Case of Champalimaud Foundation

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Abstract

Algorithmic evaluations are increasingly used to make decisions thanks to the perception of objective measures of quality and performance. However, little is known about how the current evaluation methods change with ML algorithms and with what consequences for the actors and organizations being evaluated. We conducted an exploratory case study in the breast unit of the Champalimaud Foundation in Lisbon. Gioia methodology guided the collection and analysis of semi-structured interviews and archival data. Our results show that besides generating visible and direct changes (e.g., extraction and quantification of relevant criteria with systematic approaches), algorithmic evaluations trigger indirect and less visible dynamics (e.g., adding a new dimension - aesthetic score – in the evaluation of research units), which have profound implications on how institutions operate and how resources are allocated based on the ranking lists. We contribute to digital undertow and institutional displacement and human ML collaborations by explaining the processes through which the new methods are used in medical communities and their less visible yet impactful consequences.

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Keywords: *Machine Learning (ML); evaluation; aesthetics, breast cancer surgery, Gioia methodology*

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1. Introduction

The evaluations of actors are increasingly considered a trusted source of information thanks to the perception of objective measures of quality and performance [1]. They are particularly relevant for those services that encompass uncertain value [2] in several domains such as healthcare (e.g., surgery), education (e.g., university to enroll), tourism (hotel to book), culture (e.g., art) among others. The evaluations are elaborated by domain experts, who analyze the services along criteria and metrics established by national and internal institutions, and calculate a score that is used for creating ranking lists. External audiences (e.g., patients, students, tourists, future customers) consider such information when they form their perception of the service and make decisions such as to do a surgery with a specific doctor, to enroll in a high-ranking university, or to book a highly recommended hotel etc. In turn such decisions influence the resources, recognition, and opportunities (e.g., funds, economic incentives, accreditation schemes) of the actors or institutions that offer those services [3].

The current methods through which the evaluations are calculated present crucial limitations such as lack of systematic approaches, lack of evidence in the decision making and low agreement among the evaluators due to human inherent subjectivity. Machine Learning (ML) algorithms have the potential to offer innovative solutions to such concerns, however, this generates a shift from an exclusive dominance of humans towards machines [4]. In the near future, domain experts will evaluate and make decisions not only by drawing on their domain expertise and by communicating with other human experts in the field, but also by combining algorithms' analytical, predictive, and decision support capabilities [5]. Little is known about the emergence of human-ML collaborations and the combination of domain expertise with algorithmic evaluations. We addressed this gap by focusing on two primary research questions:

RQ1: How does evaluation change with ML algorithms?

RQ2: What outcomes do algorithmic evaluations generate for the actors and organisations being evaluated?

We conducted an exploratory qualitative case study [6] in the breast unit of the Champalimaud Foundation in Lisbon, Portugal. We collected semi-structured interviews and archival data from key actors that actively participated in the conceptualization and development of ML algorithms to improve the evaluation of aesthetic outcomes in breast cancer surgery. Goia methodology [7] guided our data analysis and interpretation. Our study contributes to the literature about the emergence of new human-ML collaborations and algorithmic evaluation.

In what follows, we present the research setting, the procedures we followed to collect and analyze semi-structured interviews and archival data. Next, we discuss our findings with a focus on the evaluation of aesthetic outcomes with and without ML algorithms and on building an evaluation equation for aesthetic outcomes. We conclude with limitations and future lines of research.

2. Research method

2.1. Research setting

We conducted an exploratory case study approach [6] at Champalimaud Foundation[2] in Lisbon, Portugal to investigate the role of ML algorithms in the evaluation of aesthetic outcomes [8]. This moment is particularly important as it can provide doctors and medical professionals more insights and evidence-based information for improving the breast cancer surgery, which can have positive impacts on patients' quality of life. Champalimaud Foundation is a worldwide leader in scientific and technological innovation, and it is continuously engaged with developing new standards of knowledge in the areas of neuroscience and cancer. We investigated in detail the breast cancer (BC) unit, which is one of the units of excellence in Europe and worldwide. In the BC unit, internationally renowned professionals with vast expertise and domain knowledge (such as medical oncologists, surgeons, plastic

[2] https://fchampalimaud.org/

surgeons, radio-oncologists, imaging experts, pathologists, specialized nurses, nuclear medicine experts, psycho-oncologists) conduct advanced biomedical research projects to move forward the current state of the art in the field. An interdisciplinary team meets weekly to make clinical decisions centered on patients' needs and their idiosyncratic characteristics to identify personalized treatments. The breast cancer unit is specialized in the diagnosis and treatment of breast disease both in early breast cancer and advanced breast cancer. For the purpose of our study, we are focusing on conservative surgery of early breast cancer. In addition, the BC unit develops intelligent medical system for the evaluation of the aesthetic outcomes of breast cancer conservative treatment [9]. In the last years, this involved the most advanced technologies that are currently available such as Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), and Augmented Reality (AR).

2.2. Data collection

In line with Gioia methodology [7], we collected semi-structured interviews and archival data in the breast cancer unit at the Champalimaud Foundation in Lisbon. An interview protocol to guide the data collection, which was constantly updated in line with the new information. We asked questions regarding the current limitations and the needs that drove the development process of algorithmic technologies, how they identified them, the procedures followed to develop new solutions with the support of ML algorithms. The second author introduced us to the breast cancer unit, organized the virtual meetings and the physical visit to the unit. From April 2022, we collected semi-structured interviews with key actors involved in the multidisciplinary projects such as breast surgeons, electrical engineers, PhD students in computer science that participated in the development of the algorithms used for the evaluation of aesthetic outcomes, assistant and associate professors in computer science, engineering, and practice (please see Table 1). All respondents provided their consent, the interviews were collected online and automatically transcribed with Teams. We also collected one in person follow-up interview with a breast surgeon, which was recorded with the mobile phone and later transcribed with Panopto.

Table 1. - Interviews by role of employees, length, and period

Role of interviewee	Date	Time (min)
Head, Breast surgeon	13/04/2022	98
Breast Surgeon	23/05/2022	49
Electrical engineer	28/06/2022	55
PhD in Computing & Machine Intelligence, biomedical engineer	04/07/2022	60
Assistant Professor in Computer Science and Engineering	26/07/2022	39
Associate Professor in Engineering and Machine Learning	24/10/2022	49
Associate Professor of Practice	27/10/2022	48

In addition, we collected archival data such as papers published by our respondents containing valuable technical information of the research projects, the technical side of the methods used to develop new algorithms. Then, we consulted the website of the foundation and of the breast cancer unit, and the news published by the foundation. Lastly, we also included some public presentations of our informants linked to the projects they are working on, which were retrieved from YouTube.

2.3. Data analysis

We analyzed the semi-structured interviews and the archival data in line with Gioia methodology [7]. NVivo software helped us to organize and group the codes. With open coding, we extracted most relevant aspects from the case study. We built on the terminologies used by our respondents (e.g., breast cancer conservative treatment, evaluation of aesthetic outcomes and the challenges they were experiencing during the evaluation phase). We followed our respondents' reasoning and logic based on which they make decision in the clinical practice. In this way, we identified one interesting research venue for further investigation, which is the role of advanced technologies in the evaluation of aesthetic outcomes of breast cancer conservative treatment. Next, we unpacked the procedures through which the domain experts performed the evaluation of aesthetic outcomes. We extracted the key phases they followed and focused on the way the multidisciplinary team developed new solutions to existing needs with the support of new technologies such as the development of new procedures for the collection of digital photographs or the development of ML algorithms for extracting new features from digital photographs and for combining them in innovative ways to get closer to the perception of the aesthetic outcomes with systematic approaches. Consequently, our informants talked about their projects for creating a link between the aesthetic outcomes and patients' quality of life.

3. Findings

3.1. The emergence of Machine Learning (ML) algorithms in the evaluation of breast cancer surgery

The uniqueness of the breast cancer conservative treatment (BCCT) relies on the fact that it aims to remove the cancer from the breast, to have high survival rates, to decrease the cancer recurrence but also to improve the aesthetic outcomes after the surgery [10]. The way the treated breast will look and be perceived by the patient after the surgery has a strong impact on patients' quality of life. For example, if the treated breast is asymmetric (e.g., very different from the non-treated breast such as it is smaller, or with the nipples located in different areas), or if the scar is big and very visible or the skin color is quite different – the patient will have a potential negative impact on the perception of her/his body, her/his psychological status as well as her/his social relations. Such post-operative deformities are difficult to treat, which cause patient dissatisfaction and poor quality of life. The BCCT technique is used to help patients overcome the cancer but also to make the most of their life after the surgery as the head breast surgeon mentioned:

> *"It's an opportunity (...) because it's a smile that you put on a patient's face."*

Oncologic outcomes of breast cancer conservative treatment are evaluated on objective dimensions (e.g., disease-free and survival rates) [11]. Whereas aesthetic outcomes are evaluated on less tangible dimensions (e.g., breast asymmetry, skin color, and scar visibility), which exhibit three main limitations. First, lack of systematic approaches and evidence in the decision-making process as the evaluation is performed through a visual inspection (eyeballing) of digital photographs before and after the surgery of the same patient as a professor of engineering and machine learning explained:

> *It (the evaluation) doesn't really bring the context, the country, the culture, the group where the patients live. That kind of knowledge is not integrated in the decision process of the aesthetic evaluation. The expectations and choices of patients are also not integrated. I think we are missing part of the information in this perception of what is the quality of life of the patients.*

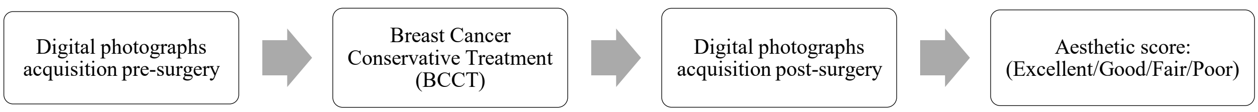

Figure 1 - Procedures followed for the evaluation of aesthetic outcomes with digital photographs

Second, there is a low interobserver agreement among two types of domain experts, who provide an aesthetic score using a four point Harris scale (Excellent/Good/Fair/Poor) (please see figure 1) [12]. (Excellent - treated breast nearly identical to untreated breast; good - treated breast slightly different from untreated; fair - treated breast clearly different from untreated but not seriously distorted; poor - treated breast seriously distorted [13]). Surgical oncologists tended to provide higher scores as they focused more on the cancer removal and survival rates. Instead, plastic surgeons tended to provide lower scores because they were more focused on the aesthetic outcomes and less on the oncological ones. Consequently, heterogeneous approaches for the evaluation and working practices proliferated and each of them provided different aesthetic outcomes. Third, there is lack of evidence on how the score was assigned and it was strictly linked to the evaluators/observers. Therefore, it was difficult to reproduce the evaluation of the same patients in different time points, or across patients in different time points within the same cancer units, or across patients in different time points from different cancer units located also in other countries but that perform similar surgery techniques due to inherent subjectivity of human decisions.

A multidisciplinary team in the breast cancer unit is developing a new methodology to support domain experts (doctors and their staff) during the evaluation of aesthetic outcomes of breast cancer conservative treatment [13], as a professor in engineering and machine learning said:

> *In the evaluation equation we are trying to bring more variables that are a bit more challenging to quantify and to understand what the impact on the aesthetic outcomes will be but that are important, the context of the patient both personal and the country where the patient is located.*

The new method combines cross-section of medical expert systems, soft computing, and machine learning to quantify dimensionless features of the breast in a more systematic way based on principles. Three main features are considered, which are breast asymmetry, skin color and scar visibility. In table 2, we provide a summary of the evaluation of aesthetic outcomes without ML learning algorithms (on the left column) and with the support of the ML algorithms (on the right column) along the most relevant variables (first column).

The aim of the project is to help domain experts to quantify the differences between treated and non-treated breasts grounded on principles used in the clinical practice that can be applied systematically on each case and be compared with other cases. The proposed method has been translated into a software named BCCT.core (Breast Cancer Conservation Treatment. cosmetic results)[3] which uses several ML algorithms and can be used by doctors and other authorized actors to evaluate the aesthetic outcomes of patients that went through breast cancer surgery. The method can be used in every cancer unit worldwide with simple procedures as follows. The software is installed in the unit in the PCs where the evaluation will be performed. The doctors or their staff collect digital photographs of patients before and after the surgery. Next, the evaluator opens the BCCT.core software, uploads the digital photographs in the software and runs it on them. The evaluator selects scale and reference points in the digital photograph and the software automatically calculates the before mentioned sub-dimensions and then it converts them into an overall objective classification of the aesthetic outcomes for that specific patient (please see figure 2). Each evaluation of the aesthetic outcomes is saved in a database managed by the breast cancer unit and can be visualized any time in the future for comparison with other cases or for future research according to patients' consent.

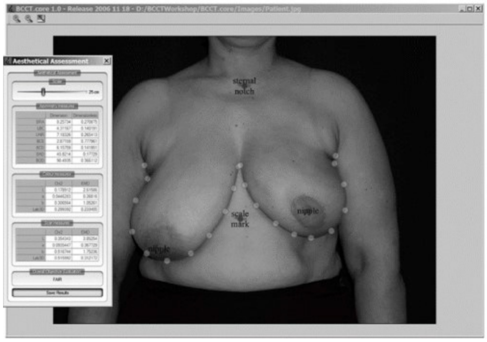

Figure 2 - Scale and reference points retrieved from [13]

3.2. Building algorithmic evaluations in breast cancer units

<u>Photo-robot for the acquisition of digital photographs</u>

The collection of the digital photographs and their quality is a core input in the evaluation formula as the software and its algorithms analyse them to provide an overall score. The collection of images has been until now a very expensive procedure due to the amount of time and human resources spent. Each patient is photographed before and after surgery in a standardized way using a conventional digital camera by the breast nurses. The pictures are then uploaded to a computer where all the images are stored and subsequently uploaded on the patient digital file. Although some standardization was followed (e.g., the position of the patient and the distance to the camera) the variability and quality of the photographs was heterogeneous. In addition, the evaluation process was not tracked,

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[3] https://www.inesctec.pt/en/technologies/bcct-core#content

and no measures of each feature and its sub-dimensions were stored limiting the comparison and the reproducibility of the evaluation. The multidisciplinary team in the breast cancer unit designed a new way of collecting the digital photographs. In collaboration with an international company that designs machines to capture photographs of different products for online sale the team developed a photo robot to automatically capture the photos with high professional standards and in the same way for each patient in order to decrease the variability between the pictures. Moreover, the process of picture transfer is automatic decreasing not only the human effort but also the pictures were acquired professionally with several backgrounds to highlight the main features as a surgeon explained:

> *"(…) people sell their things online and they have quite good pictures (…) some of them did not have any background, you immediately understand if they are pro/semi pro or amateur. I started to understand that I would like to have something that would not take so much time to take the photograph and they are taken in the same way with good quality."*

Quantification of dimensionless features with ML algorithms

The professional digital photographs are used to extract proxies for clinical variables through the extraction of measures that can be used for the evaluation of aesthetic outcomes. The team aims to quantify dimensionless features such as breast asymmetry, skin color, and scar visibility. To do so, it attempted to identify relevant sub-dimensions that better define the three features since there are no standard measures as a professor in engineering and machine learning explained:

> *There is no perfect one (measure) that we can computationally extract that really is the quantity of the interest that really captures the impact of the scar or the impact of the colour. We extracted several ones with proximations that we combine to provide the overall evaluation.*

Interestingly, the team identified and is continuing to further identify representative sub-dimensions that can be used as proxies for the evaluation of aesthetic outcomes. For example, the feature breast asymmetry can be measured with several sub-dimensions such as breast retraction assessment (BRA), lower breast contour (LBC), upward nipple retraction (UNR), breast compliance evaluation (BCE), breast contour difference (BCD), breast area difference (BAD), and breast overlap difference (BOD). Each dimensionless feature is automatically calculated by algorithms through a pattern classifier of representative sub-dimensions (please see Table 2). The team trained ML algorithms on the scores provided by a panel of experts to try to imitate domain experts' decisions. Based on this, the ML algorithms learn how to combine all of these individual aspects of quality to imitate as best as possible the perception of the overall quality delivered by the domain expert. During the experiments, several methods have been used such as support vector machines, linear and nonlinear models, decision trees to understand the logic behind the decisions, score cards that provided also good results in terms of transparency. Recently, the team considered to experiment with Deep Learning, which allows to improve the predictions but also to keep some transparency levels during the analysis.

The goal of quantifying dimensionless features requires substantial work in order to identify proxies that are closer to the perception of the aesthetic outcomes. In addition, the interdisciplinary team at the breast cancer unit aims to make a step further, which is to establish a scientific link between the overall perception of aesthetics and the quality of life of the patients as a professor in Computer Science and Engineering mentioned:

> *The integration of the information is more challenging to have the overall perception of the aesthetics and it is not yet consolidated. There is still a mismatch between computer evaluation of the overall quality and the domain experts' evaluation.*

Potential users of algorithmic evaluations

The proposed evaluation equation composed of the BCCT.core software and the ML algorithms can be adopted by several users as follows. Surgeons with different backgrounds can perform the evaluation of aesthetic outcomes of Breast Cancer Conservative Treatment with the support of ML algorithms. They will automatically receive the overall score that better represent the perception of aesthetic outcomes and quality of life. In addition, they will be able to quantify dimensionless features with their relative sub-dimensions in a more systematic way (please see Table 2, column with ML algorithms).

The software can be used by institutions to evaluate the quality of the services they are delivering. This can be an additional source of information that can be used to improve the practices done during patients journey in the institution as a professor in Computer Science and Engineering mentioned:

> *"Evaluation of the quality of the service in a statistical way is useful to see if everything is going on average or if the institution needs to improve the working practices."*

In addition, an independent user or entity can evaluate the performance of other breast cancer units with the support of the proposed software and ML algorithms. The team also aims to propose to the medical communities in breast cancer to add a new dimension in the evaluation and accreditation process of research centers as it is strictly linked to patients' quality of life.

Table 2 – Evaluation of aesthetic outcomes in Breast Cancer Conservative Treatment (BCCT): with and without ML algorithms

	Without ML algorithms	**With ML algorithms**
Aesthetic Score	Excellent/Good/Fair/Poor - Four point Harris scale [12]	
Actors	Performed by domain experts without any information systems support	Performed by domain experts with the support of the ML algorithms
Approach	Manual scores of aesthetic outcomes	Automatic scores of aesthetic outcomes
Technique	Eyeballing (visual inspection) of digital photograph	Cross-section of medical expert systems, soft computing, ML on digital photograph
Procedure	Sum of the individual (patients and domain experts) scores of subjective and objective individual indices	Automatic calculation of the key features, their sub-dimensions, and their conversion onto objective classification of the aesthetic outcomes once a scale and reference points are chosen by the domain experts
Features considered	Breast asymmetry (breast retraction assessment (BRA) index) Skin colour difference Scar visibility	Breast asymmetry calculated through sub-dimensions: • Breast retraction assessment (BRA), Lower breast contour (LBC), Upward nipple retraction (UNR), Breast compliance evaluation (BCE), Breast contour difference (BCD), Breast area difference (BAD), Breast overlap difference (BOD) Skin colour difference with 2 global measures of histograms: • 2 breast region masks on histograms, Computation of 3D colour histograms in each breast - 8 indices for global colour dissimilarity Scar visibility: Additional parameters extracted from digital photographs
Reproducibility	Low and Questionable (inherent subjectivity of human decisions)	High and more reliable assessments
Comparability	Uncertainty when comparing outcomes between and across studies	Automatic comparison within and across studies
Advantages	Lower or no investment in information systems development	Automated analysis of digital photographs Report automatically the numbers of each subdimension, save them in a dedicated database Convert automatically the sub-dimensions into an overall objective classification of the aesthetic outcomes High accuracy Prediction of aesthetic outcomes More systematic measures based on more principled approaches Obtain expert opinion in a more systematic manner
Limitations	Observer consensus of cosmetic outcome difficult to obtain Lack of general, consistent approaches	High costs for information systems development and implementation The projects are strictly linked to the availability of the research funds

4. Conclusions

With an exploratory case study [6] in the breast cancer unit at Champalimuad Foundation in Lisbon, Portugal, we investigated how the evaluation changes with the introduction of ML algorithms in breast cancer units and what consequences this brought to the actors and organizations that are being evaluated. The application of algorithmic evaluations on digital pictures in one breast cancer unit, besides generating visible and direct changes (e.g., extraction and quantification of relevant criteria with systematic approaches), triggers indirect and less visible dynamics (e.g., adding a new dimension - aesthetic score – in the evaluation of research units) that have profound implications on how institutions operate. For example, evaluation influences the way medical communities allocate resources based on the quality and performance of the services delivered (e.g., breast cancer surgery) within a time frame and more broadly how accreditation schemes are managed by domain experts.

Our paper makes three important theoretical contributions. First, it adds insights to the conceptualization of digital undertow and institutional displacement [3] by explaining the processes through which algorithmic evaluation unfolds in medical communities. Second, we contribute to the literature on the emergence of human-ML collaborations by shedding light on how domain experts (e.g., doctors) evaluate the quality and performance of services (breast cancer surgery) with additional source of information elaborated by ML algorithms (extraction and quantification of criteria with systematic approaches). Lastly, we illustrate how the evaluation of services is changing by providing counterintuitive insights to the literature on algorithmic evaluations [1].

While we followed robust and scientific approaches for this study, two main limitations emerged that call for future research. First, we interviewed the creators and leaders of such ambitious project in a breast cancer unit; however, the experience of other actors with different roles and backgrounds will provide more perspectives such as surgical oncologists, plastic surgeons to capture more notions about the way they evaluate the aesthetic outcomes, nurses, technicians that acquire and analyze digital pictures, patients and some experts from the accreditation schemes to share valuable information on the principles and practices followed. Second, we focused solely on the unit that developed and used the current and new methods for the evaluation of aesthetic outcomes. More research is necessary to better understand how other breast cancer units within the same medical community that are applying the procedures elaborated by the breast cancer unit in Champalimuad Foundation in Lisbon, Portugal.

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