# Accuracy of the Artificial Intelligence to Locate the Temporomandibular Disc in MRI

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**Article**

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## Abstract

Temporomandibular disorder (TMD) is a term used to describe the morphological and/or functional changes that affect the masticatory system. Internal derangements of the TMJ are among the most prevalent articular subtypes of TMD. TMD diagnoses are based on clinical and imaging examinations, mostly magnetic resonance imaging (MRI). Artificial intelligence (AI) has emerged as a method for optimizing determination of the position of the articular disc of the TMJ using MRI. This proof-of-concept study aimed to explore the reliability and accuracy of applying AI to optimize TMD diagnoses. This retrospective cross-sectional study comprised 459 images from 67 participants.. Neural networks and deep learning were developed. The study showed that the coefficient of agreement () between AI-analyzed MRI and TMJ MRI evaluated by specialist was 0.63. AI provided high reliability (84,6%) to locate the articular disc in MRI. Deep learning program revealed a sensitivity of 86.2% and specificity of 76.9% on the 1,000-step test. The 50,000-step test showed a sensitivity of 87.7% and specificity of 76.9%. ROC curve (AUC > 0.8) emphasized the high diagnostic accuracy. These findings demonstrated that AI is effective in optimizing the location of the TMJ disc through MRI.

## Introduction

The temporomandibular joint (TMJ) is considered the most complex and peculiar joint in the human body [1–3]. It represents a synovial joint with rotational movements in its lower compartment, and sliding of the disc-head complex of the mandible in its upper compartment. Therefore, TMJ is classified as a diarthrodial ginglymus joint [1].

For many years, clinicians have emphasized that the positioning of the TMJ disc is determined by the balance between its morphology, the intra-articular pressure, the condition of the TMJ ligaments, and the activity of the upper head of the lateral pterygoid muscle [1, 3]. Temporomandibular disorders (TMDs) are described as morphological and/or functional changes that affect the masticatory system, including the TMJ and masticatory muscles [4]. Clinically, TMD represents a heterogeneous group of disorders that affects the masticatory system, often characterized by pain and limited mouth opening [5]. Among the several subtypes of TMD, internal derangements are probably the most prevalent [6].

Internal derangement of the articular disc of the TMJ is defined as an abnormal positional and functional relationship between the fibrocartilaginous disc and articular surfaces [5]. Moreover, some authors have determined the parameters of the normal position of the articular disc, which is frequently defined as a normopositioned disc [6, 7]. Changes in these parameters are diagnosed through clinical evaluation, combined with complementary examinations. such as magnetic resonance imaging (MRI). MRI is the most relevant radiologic examination for determining the position of the fibrocartilaginous disc of the TMJ [5].

Due to its excellent tissue differentiation, MRI provides a detailed evaluation of the TMJ anatomy, and this characteristic is particularly related to its high spatial resolution [5]. Despite the accuracy of MRI in detecting the position of the TMJ disc, the interpretation of every TMJ imaging must always be considered with the corresponding clinical findings owing to the known difficulty in precisely determining the position of the TMJ disc even with MRI [7, 8].

The accurate interpretation of MRI images requires knowledge of the normal anatomy and an understanding of the normal and dysfunctional TMJ biomechanics [1]. Considering that the assessment of the articular disc of the TMJ through MRI is associated with a large variability, novel methods that enhance the detection of TMJ disc displacements through MRI are needed [1]. Artificial intelligence (AI) is a promising tool for locating and evaluating the TMJ disc through MRI.

AI is capable of analyzing complex medical data. Its potential to explore a meaningful relationship within a set of data can be used in the diagnosis, treatment, and outcome prediction in a wide range of clinical settings [8]. Deep learning, particularly artificial intelligence, can produce a wide range of technologies that affect our lives [8].

AI commonly refers to computational technologies that mimic or simulate processes supported by human intelligence. This includes reasoning, deep learning, adaptation, interaction, and sensory understanding [9]. The feasibility of using AI in medical and scientific research has grown rapidly in recent years. In healthcare, AI applications in medical imaging are likely to be significant.

Besides that, among the variety of AI algorithms available, the neural network-based deep learning approach has become prominent due to its effective capability for object recognition when applied to medical imaging [10]. In addition, the increase in computational power and the diffusion of open-source frameworks yielded the development of deep learning programs [10, 11].

The use of AI in medical radiology, particularly for diagnosis and prediction, has expanded considerably, producing impressive results [12]. For example, the diagnosis of TMJ osteoarthritis using cone beam computed tomography (CT) and AI has been recently reported by Mintz and Brodie (2019) [12]. It has been hypothesized that deep learning will be a part of clinical medicine and that AI-based platforms will improve the decision making of health professionals in the next few years [13–15]. Thus, this study aimed to evaluate the accuracy of an algorithm based on AI to determine the position of the TMJ disc through MRI.

# Materials And Methods

# Study design

This was a cross-sectional retrospective study. The study sample comprised 67 male and female subjects, without any distinction of ethnicity or social group. The participants were divided into two groups: 1) images with anterior TMJ disc displacement and 2) images without TMJ disc displacement.

The inclusion criteria are as follows:

- Age over 18 y, regardless of ethnicity or social group.
- MRI scans of the right and left TMJ, with the minimum quality necessary to individualize the anatomical structures of the TMJ and identify the position of the TMJ articular disc.

MRI images with artifacts affecting the determination of the position of the TMJ disc were excluded.

One TMD trained specialist with extensive knowledge of TMJ imaging determined the position of the TMJ articular disc in the images included in the study. Subsequently, the same images were analyzed by AI.

Data processing through AI was divided into two stages, a training phase and a testing phase. In the training phase, the image data were fed into the machine learning (ML) program. This process aimed to establish a learning pattern. The testing phase, image data were uploaded to the ML program. This procedure aimed to use the learning obtained in the training phase in order to assess whether the machine learning was accurated in acquiring the results. The outcome generated by the ML program was compared to the outcomes determined by the TMD specialist who initially evaluated each MRI. Based on this comparison, the sensitivity, specificity, and accuracy of the ML program for determining the diagnosis of each patient were obtained.

# MRI protocol

MRI exams were obtained from 1.5 tesla (T) magnetic field devices (GE). Each TMJ MRI was captured in the oblique sagittal plane, perpendicular to the axis of the mandibular head, in maximum habitual intercuspation (MHI). T1 and T2 weighted images, without contrast, were also performed.

# MRI evaluation

A total of 459 TMJ images from 67 participants were evaluated. Of the 459 images, 329 represented images with anterior displacement of the TMJ disc and 130 represented the absence of TMJ disc displacement.

The position of the TMJ disc was classified as follows:

A. TMJ disc displacement:

The TMJ disc was located anterior to the mandibular condyle in the closed-mouth position. For this analysis, a model based on the hands of the clock was used such that the center of the clock hands must coincide with the central region of the condyle. The TMJ disc is classified as normopositioned when its posterior band is located at the 12 o'clock position (11–13 h) of the clock [6].

B. Normopositioned TMJ disc:

A model based on the hands of a clock was also used. The posterior band of the TMJ disc was centered relative to the head of the mandible and located at the 12 o'clock position, with the mouth closed [6].

# Randomization

Simple randomization was performed to select the images from the MRI for further analysis. The randomization sequence was generated electronically using Microsoft® Excel (version 2019).

# Imaging evaluation parameters

A minimum of 10 images is typically recommended for training and at least 100 images are recommended for testing. In the current study, the images were separated into two categories and tested. The code used ensured that all tested images were always classified into one of the previously established categories (e.g., TMJ disc displacement vs. the absence of TMJ disc displacement). Deep learning tests were carried out with 1,000 and 50,000 steps.

Deep learning algorithms were built using Python, a programming language, and were implemented using the TensorFlow framework for deep learning.

# Statistical analysis

A coefficient agreement (κ) was achieved between the variables (expert evaluation x artificial intelligence program). ROC curve was performed emphasizing the diagnostic accuracy. The association between gender and the location of the TMJ disc was assessed using the chi-square test [14]. The level of statistical significance was set at 5%. SPSS version 28 (IBM®, Armonk, NY, USA) was used for all the statistical analyses.

## Results

In the present study, a total of 67 individuals were examined comprising 49 women (73% of the sample) and 18 men (27% of the sample), and a total of 459 TMJs images were included in the study.

A statistically significant association ($p < 0.05$) between the variables, “gender” and “position of the articular disc” was only found on the right side. A significantly higher proportion of women presented with anterior TMJ disc displacement. These results are shown in Fig. 1.

After the randomization process, 20% of the images were used for testing, totaling 91 images. Of those, 65 exhibited anterior TMJ disc displacement and 26 had a normopositioned TMJ disc.

After testing, the diagnostic results extracted from the AI program were compared to the results confirmed by the expert to determine the level of reliability. The kappa test was consistently greater than 0.63. Strong agreement and reliability were found in both the 1,000 step and 50,000 step tests ($p < 0.05$). The details are presented in Tables 1 and 2.

Table 1
Result of 1000-step test concordance analysis.

| | | **Displacement** | **Normal** | **Total** |
|---|---|---|---|---|
| Displacement | Count | 56 | 6 | 62 |
| | Percentage AI/1000 steps | 90,30% | 9,70% | 100,00% |
| | Expert Percentage | 86,20% | 23,10% | 68,10% |
| Normal | Count | 9 | 20 | 29 |
| | Percentage AI/1000 steps | 31,00% | 69,00% | 100,00% |
| | Expert Percentage | 13,80% | 76,90% | 31,90% |
| Total | Count | 65 | 26 | 91 |
| | *Percentage AI/1000 steps* | 71,40% | 28,60% | 100,00% |
| | *Expert Percentage* | 100,00% | 100,00% | 100,00% |

Table 2
Result of 50000-step test concordance analysis.

| | | **Displacement** | **Normal** | **Total** |
|---|---|---|---|---|
| Displacement | Count | 57 | 6 | 63 |
| | Percentage AI/50000 steps | 90,50% | 9,50% | 100,00% |
| | Expert Percentage | 87,70% | 23,10% | 69,20% |
| Normal | Count | 8 | 20 | 28 |
| | Percentage AI/50000 steps | 28,60% | 71,40% | 100,00% |
| | Expert Percentage | 12,30% | 76,90% | 30,80% |
| Total | Count | 65 | 26 | 91 |
| | *Percentage AI/50000 steps* | 71,40% | 28,60% | 100,00% |
| | Expert Percentage | 100,00% | 100,00% | 100,00% |

Sensitivity and specificity were also evaluated. The results revealed high sensitivity and moderate specificity. When we performed the analysis of agreement between the expert' classification and the results from the AI program, the 1,000-step test revealed 86.2% sensitivity and 76.9% specificity. In the 50,000-step test, the sensitivity and specificity were 87.7% and 76.9%, respectively. Figures 2 and 3 depict the ROC curve for deep learning test (AUC > 0,8) .

# Discussion

According to previous studies, the prevalence of pain related to TMD in the general population is approximately 5%. However, only 2% of those with presenting signs and/or symptoms of TMD seek treatment [16–18]. TMD may be the result of muscle hyperfunction or parafunction, with/without underlying primary or secondary degenerative changes within the TMJ. TMD encompasses several subtypes of articular and muscle disorders. Anterior disarrangement of the TMJ disc is one of the most prevalent TMD subtypes. Its diagnosis is based on a combination of clinical examination and medical imaging of the TMJ.

Several authors have described the use of different radiographic approaches for TMJ examination, including common radiographs, computed tomography (CT) scans, and MRI. TMJ MRI imaging is important in the diagnosis of disc displacements as it allows the direct visualization of the articular disc in both closed and open mouth positions [19–22]. An MRI of the TMJ allows the evaluation of the articular disc revealing its morphological characteristics and location relative to the mandibular condyle in both the open and closed mouth positions. The identification of the TMJ disc on MRI is crucial because the presence of a displaced disc is a significant sign of articular TMD [18]. Despite the sensitivity and specificity of MRI in detecting TMJ articular disc position, the results must always be considered together with the clinical findings [6, 20–22]. The present study combined clinical and MRI data to determine the position of the TMJ articular disc [18].

As per the clinical examinations and MRI examinations, the prevalence of TMD is higher in women. Moreover, a previous a systematic review with meta-analysis study revealed the gender distribution predominant for females (1161 females and 345 males) in patients with anterior disc displacement (ADD) of the temporomandibular joint (TMJ) [23]. Another study aimed to determine the association between the morphology of the joint cavity, joint spaces, and TMJ disc displacements, by evaluating the MRI of symptomatic patients. The results showed that a total of 113 joints (56.8%) presented with TMJ disc displacement [14].

The interpretation of the TMJ through MRI may be challenging, especially for non-specialists. Therefore, novel approaches to improve the accuracy of TMJ evaluations using MRI are needed. This study confirmed the feasibility of using AI in the diagnosis of TMD [24]. Moreover, these findings support the hypothesis that AI is useful as an effective tool to increase the sensitivity and specificity in the diagnosis of TMJ disc displacement. The use of AI on a large scale could speed up and improve the recognition of the different types of articular TMD [24].

Contemporary medicine faces the challenge of acquiring, analyzing, and applying a broad amount of knowledge needed to solve complex clinical problems. The development of AI in medical practice has been linked to the development of AI programs designed to assist clinicians in achieving a diagnosis, making therapeutic decisions, and predicting outcomes or prognoses [24]. This study reinforced the importance of applying AI in medicine.

A previous study developed an algorithm-derived neural network that enabled the classification of benign or malignant prostate neoplasms. This model, which was later validated in prospective studies, had a diagnostic accuracy of 90%, with a sensitivity of 81% and a specificity of 92% [24, 25]. In the present study, the sensitivity and specificity were tested, revealing the high accuracy in the identification of the TMJ disc position using AI. The 1,000-step revealed 86.2% sensitivity and 76.9% specificity, while the 50,000-step test revealed 87.7% sensitivity and 76.9% specificity. Moreover, the diagnostic accuracy was higher than 0.8.

This study highlights the application of AI in the diagnosis of TMD through imaging in combination with clinical examinations. The use of AI in the field of orofacial pain and TMD may optimize the time necessary for diagnosis. Machines can be easily trained to overcome issues with normal variants and imaging artifacts. Therefore, when correctly applied, AI may reduce the imprecision in valuating TMJ disorders using MRI. AI technology also permits the simultaneous evaluation of large amounts of data quickly and effortlessly [26]. In this way, computer vision models can help to reduce the time of notification of abnormal exams, signaling abnormalities at the time of the image. This would allow radiology departments to expedite the intervention of the referral clinical team [27].

Although AI has the potential to help solve important challenges in healthcare, it is important to note that the quality of the available dataset is a major limitation in the implementation of AI in healthcare systems [28]. Moreover, an important future challenge will be to ensure that AI is developed in a transparent and compatible mode, while stimulating innovations in the medical field. To achieve these goals and effectively utilize AI in medicine, an improved digital infrastructure within radiology departments may be required. Furthermore, new image reconstruction methods may be challenging, and new theoretical approaches will be further required [26].

# Conclusion

The current study showed that AI enhances the identification of the TMJ disc position through MRI. Additionally, it proved to be a reliable and accurate method for determining the positional shift of the TMJ disc. The greater the number of steps used to define the position of the disc, the greater the sensitivity, without changing the specificity. Thus, it is possible to establish the predictors of AI by optimizing the clinical diagnosis and treatment of TMJ disc displacement disorders.

# Declarations

## Ethical Considerations

This project was evaluated and approved by the ethics committee of Federal University of Rio de Janeiro (UFRJ), # # 49017321.8.0000.5257. This study was conducted according to the Declaration of Helsinki for human research. Besides that, based on the retrospective design of this study, the informed consent requirement was waived by the University Hospital Clementino Fraga Filho of Federal University of Rio de Janeiro (UFRJ) Research Ethics Committee.

## Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

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### Author's contributions

BSM and GQ conceived the study, collected the data, analyzed the data and led the writing.

ATO, NRF, EG, AD and MFD analyzed the data and drafted the manuscript.

### Declaration of conflicting interests

No conflict of interest to declare.

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# Figures

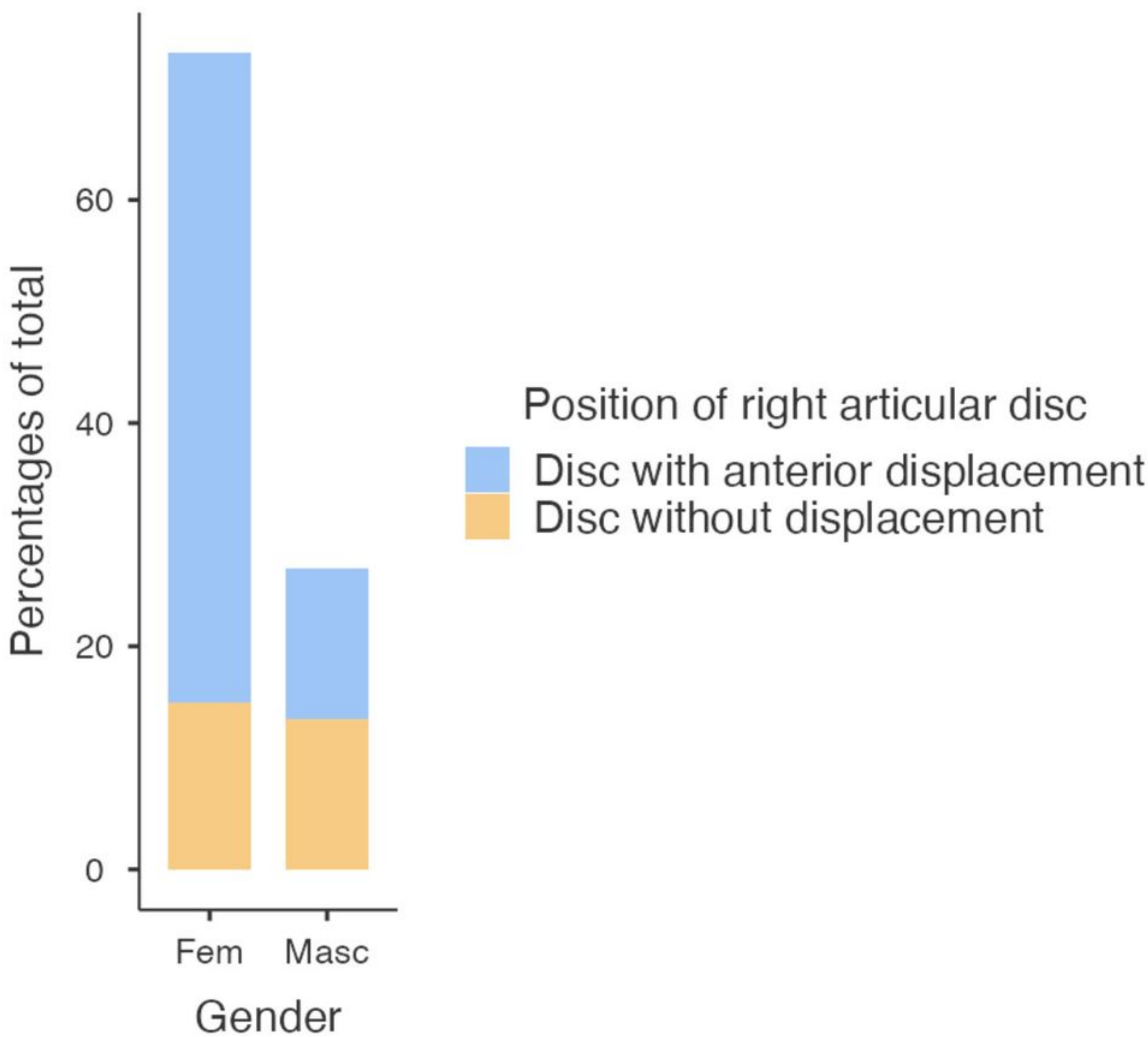



**Figure 1**

Distribution of the association between gender and right articular disc position.

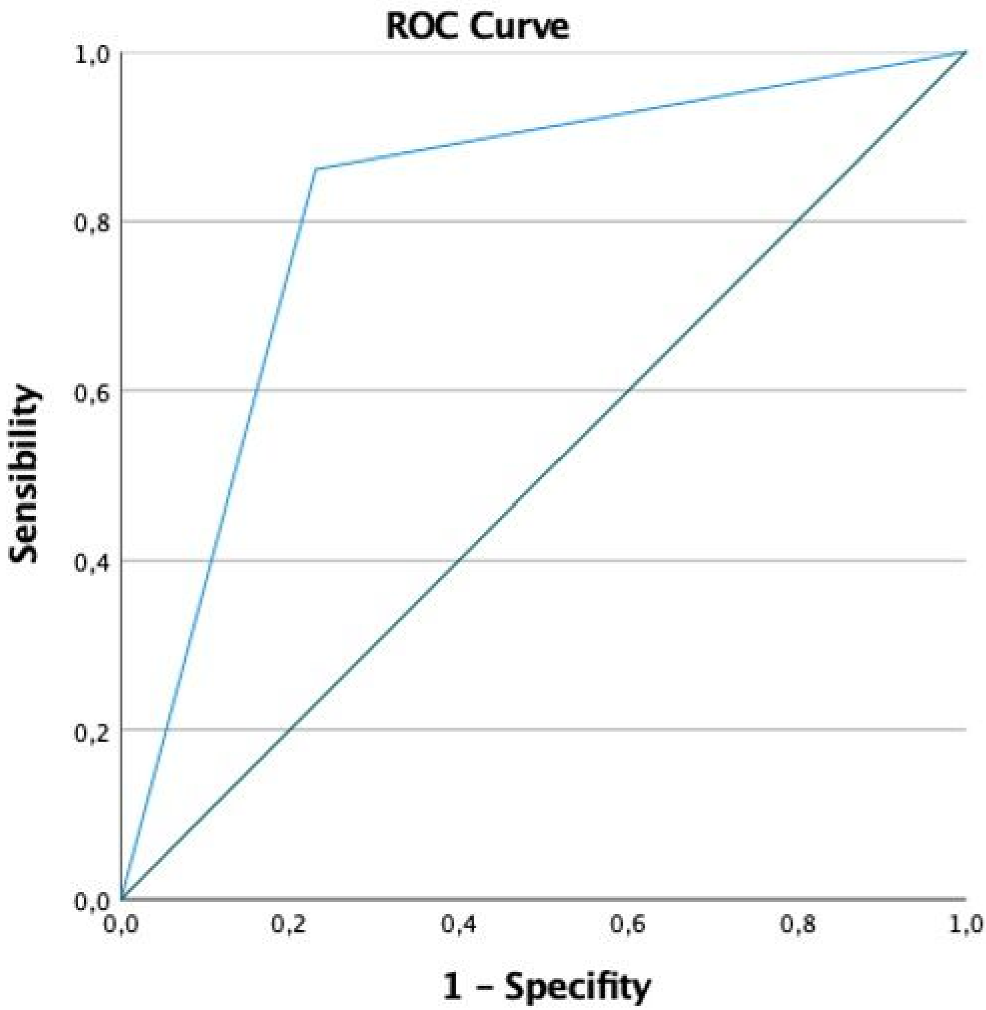
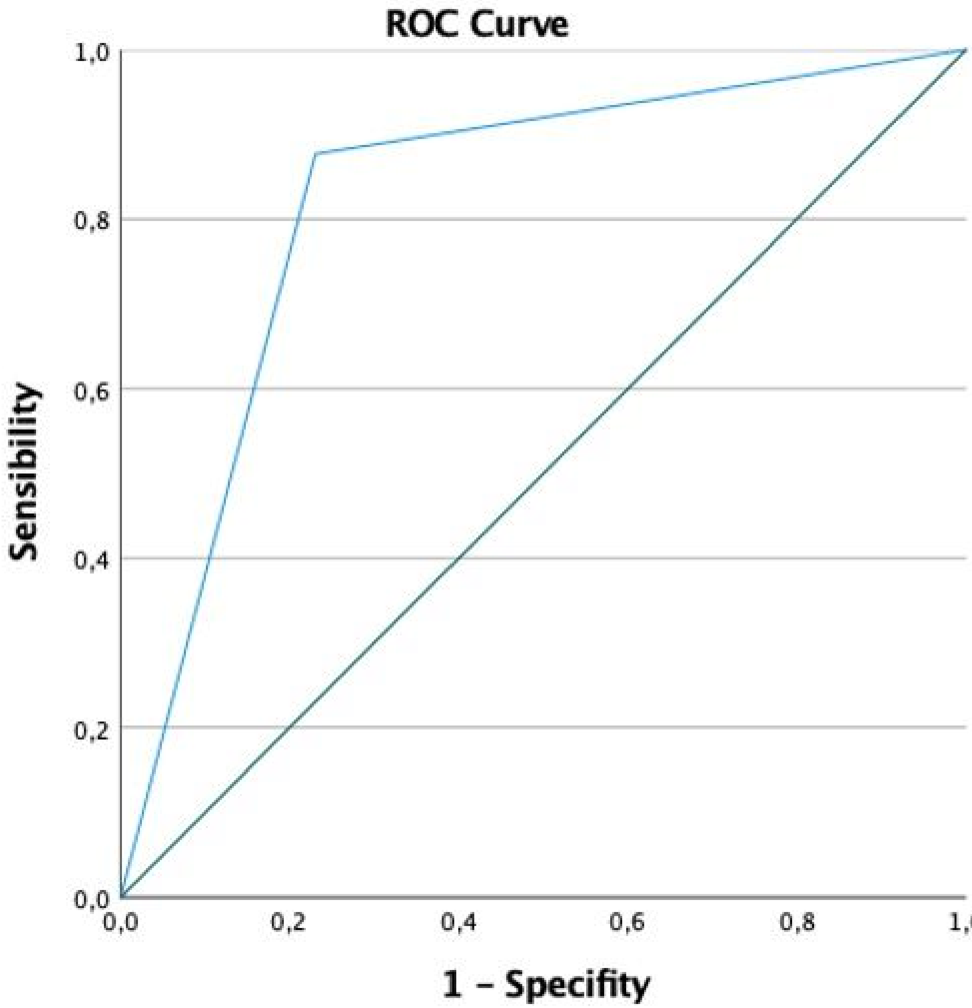



**Figure 2**

ROC curve showing the sensitivity and specificity of the 1000-step test.




## Figure 3

ROC curve showing the sensitivity and specificity of the 50000-step test.