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ORIGINAL ARTICLE

# Determination of probabilistic intersections related to acquired brain damage from the determination of a priori and a posteriori probabilities

## *Determinación de intersecciones probabilísticas relacionadas con daño cerebral adquirido a partir de la determinación de probabilidades a priori y a posteriori*

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## Abstract

**Background:** *The acquired brain damage is a common neurological disorder.* **Objective:** *Determine the probabilistic intersections of variables related to acquired brain damage from the determination of a priori and a posteriori probabilities.* **Method:** *Analytical retrospective study. A descriptive analysis was carried out, confidence intervals were calculated to obtain the mean and the proportion with $\alpha = 0.05$ considering the age of the patient and the diagnosis. An analysis of probabilistic intersection, a priori and a posteriori probability was performed considering diagnosis, sex and age decade; finally, chi squared was calculated.* **Results:** *736 patients were analyzed. The most frequent diagnosis was language disorder. The patients diagnosed with memory disorder were the youngest and those diagnosed with degenerative cognitive disorder the oldest. The probability that a patient with sequelae due to acquired brain damage arrives at the hospital, at the language pathology service, to be diagnosed with a language disorder and that this patient is also a man is 29.06%.* **Conclusions:** *The high prevalence of short and long-term disability generated by acquired brain damage highlights the importance of an early and timely detection and diagnosis so that it favors prompt and efficient specialized care.*

***Keywords:*** *Acquired brain damage. Acquired traumatic brain damage. Acquired non-traumatic brain damage. Language. Memory. Degenerative cognitive disorder.*

## Resumen

**Antecedentes:** *El daño cerebral adquirido es un trastorno neurológico común.* **Objetivo:** *Determinar las intersecciones probabilísticas de variables relacionadas con daño cerebral adquirido a partir de la determinación de probabilidades a priori y a posteriori.* **Método:** *Estudio retrospectivo analítico. Se realizó análisis descriptivo y se calcularon intervalos de confianza para la media y para la proporción con $\alpha = 0.05$ considerando la edad del paciente y el diagnóstico. Se realizó análisis de intersección probabilística, probabilidad a priori y a posteriori considerando el diagnóstico, el sexo y la década de edad; por último, se utilizó la prueba X2.* **Resultados:** *Se analizaron 736 pacientes. El diagnóstico más frecuente fue el trastorno del lenguaje. Los pacientes diagnosticados con trastorno de memoria fueron los más jóvenes y los diagnosticados con trastorno cognitivo degenerativo los más longevos. La probabilidad de que llegue al hospital, al servicio de patología de lenguaje, un paciente con secuelas por daño cerebral adquirido, sea diagnosticado con trastorno del lenguaje y sea hombre es del 29.06%.*

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**Conclusiones:** *La alta prevalencia de discapacidad a corto y largo plazo generada por el daño cerebral adquirido indica la importancia de la detección y el diagnóstico temprano y oportuno que favorezcan una pronta y eficiente atención especializada.*

***Palabras clave:*** *Daño cerebral adquirido. Daño cerebral adquirido traumático. Daño cerebral adquirido no traumático. Lenguaje. Memoria. Trastorno cognitivo degenerativo.*

## Introduction

Acquired brain injury (ABI) is considered the most common neurological disorder. It is speculated to be the leading cause of death and disability worldwide[1] and meets five criteria: 1) the injury affects part or all of the brain; 2) the clinical onset of the injury is acute (occurring within seconds or days); 3) one or more deficits can occur as a result of the injury, which are observable through clinical examination or diagnostic tests; 4) the deficit impairs functioning and quality of life, and 5) hereditary and degenerative diseases, as well as injuries occurring during the gestational and perinatal periods, are excluded[2]. The incidence varies depending on its etiology. Traumatic brain injuries (TBIs) are due to brain truma, have an annual occurrence worldwide of 200/100 000 people, cause secondary disability in 21% of the patients, and have a high impact on the health care system. On the other hand, non-traumatic ABI has a more heterogeneous etiology, and its incidence is variable. For example, stroke has an annual occurrence of 190/100 000, with secondary disability reported in 44% of the patient, and a high impact on the health care system as well. Anoxic encephalopathy is present in 20-30/100 000, causing disability in over 50% of the patients, and a medium impact on the health care system. Finally, primary tumors (5/100 000) and encephalitis (0.4/100 000) have disability rates over 50% and a low impact on the health care system[2].

ABI has significant consequences, including a high prevalence of disability within the first year and long-term effects that result in lifelong changes (memory, concentration, motor, sensory, cognitive, communication, or behavioral disorders)[1,3]. Furthermore, these sequelae have a negative impact on the ability to perform work and academic activities[4]. Regarding TBIs, it has been reported that 85% of recovery occurs within the first 6 months[5], while 5% to 15% of the patients will experience long-term disability or difficulties[6]. In the case of non-traumatic ABI, mainly due to a vascular event, a risk of recurrent stroke of nearly 20% has been determined within 5 years of the index event[7].

Intervention should be specialized, early, individualized, intensive, coordinated, and organized by a multidisciplinary team[8]. A significant part of care should be provided by specialists in the field of communication (phoniatrics specialist, audiology and otoneurology specialists, and speech therapists, or human communication therapists), along with physical therapy to reduce the impact of disability and facilitate reintegration into activities of daily living[9].

The aim of this study was to determine the probabilistic intersections of variables related to ABI based on the determination of prior and posterior probabilities.

## Method

This was a retrospective analytical study that analyzed information from the institutional database of the language pathology service at Instituto Nacional de Salud de México, Mexico City, Mexico. A total of 736 patients aged 13 and older were included, with information on sociodemographic and clinical data of the patients who sought medical attention due to ABI sequelae.

### *Variables*

The studied variables included gender, diagnosis, and the patient's age decade at the time of admission to the language pathology service.

### *Statistical analysis*

The statistical software package SPSS version 25 was used for the statistical analysis. An initial descriptive analysis was performed, calculating means and standard deviations for the age variable, as well as percentages and frequencies for the gender and diagnosis variables. Ninety-five percent confidence intervals (95%CI) were calculated for the age and diagnosis estimators, meaning the probability of event occurrence, in this case, to understand the range in which 95% of the studied population falls under the conditions of age and diagnosis. Probabilistic intersection analysis $P(A \cap B) = P(A) \cdot P(B)$ was performed as a basis

Table 1. Descriptive data of diagnosis and age of patients

| Diagnosis | n | % | Men | Women | Mean ± SD | Range | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| Language | 373 | 50.7 | 214 | 159 | 57.60 ± 16.355 | 82 | 13 | 95 |
| Speech | 77 | 10.5 | 55 | 22 | 46.16 ± 19.810 | 70 | 14 | 84 |
| Memory | 113 | 15.4 | 77 | 36 | 41.72 ± 18.380 | 69 | 13 | 82 |
| Language/Writing/Calculation | 4 | 0.5 | 3 | 1 | 62.75 ± 4.349 | 10 | 57 | 67 |
| Cognitive/Neurodegenerative | 99 | 13.5 | 29 | 70 | 72.80 ± 12.536 | 75 | 18 | 93 |
| Cognitive/fine motor | 11 | 1.5 | 7 | 4 | 52.55 ± 8.129 | 28 | 35 | 63 |
| Multiple | 59 | 8.0 | 39 | 20 | 43.27 ± 15.879 | 67 | 13 | 95 |

SD: standard deviation.

to obtain the prior probability P(B∩Ai), eg, the occurrence of an index event (ABI), and posterior probability P(Ai∩B), the occurrence of a subsequent event (diagnosis), using Bayes' theorem. This is relevant as it allows determining the dependence between 2 different events over time. Finally, the chi-square test was performed to determine whether there was a significant difference between the studied variables.

### *Ethical aspects*

The protocol was approved by the Center Research and Ethics Committee. All patients, or their parents or legal guardians signed an informed consent form authorizing the use of data anonymously.

## Results

The sample consisted of 736 patients with ABI sequelae, 424 of whom (57.6%) were men and 312 (42.4%), women. The mean age was 54.8 ± 19 years, with a minimum age of 13 years and a maximum of 95 years.

On the patients' diagnosis and age, it was found that the most common diagnosis was language disorder in 373 patients (50.7%), 214 of whom (57.4%) were men and 159 (42.6%), women, with a mean age of 57.6 ± 16.3 years (minimum age of 13 years and maximum age of 95 years). The second most common diagnosis was memory disorder, reported in 113 patients (15.4%), 77 of whom (68.1%) were men and 36 (31.9%), women, with a mean age of 41.7 ± 18.3 years (minimum age of 13 years and maximum of 82 years) (Table 1).

When the confidence intervals for the mean were analyzed with respect to the age of the patients, it was found that 95% of those diagnosed with cognitive/degenerative disorders were in the older age group, with 72.8 years (95%CI, 70.3-75.3), that is, ages ranged from 70 to 75 years, while 95% of the patients diagnosed with memory disorders were in an interval that included younger patients (41.4 years [95%CI, 37.8-45.1]), that is, ages ranged from 38 to 45 years. Furthermore, when analyzing confidence intervals regarding rates, it was found that the largest rate of the sample was in the language disorder diagnosis, at 50.7% (95%CI, 45.9-55.4), that is, from 46% to 55%, while the smallest rate was reported in patients diagnosed with language, writing, and calculation disorder, at 5.5% (95%CI, 0-11), that is, from 0% up to 11% (Table 2).

Probabilistic intersection analysis was performed based on the studied population to determine the posterior probability considering the baseline condition of ABI; therefore, the probability of the disease A (diagnosis) from occurring was calculated as long as the baseline condition occurred. It was found that the most frequent diagnosis was language disorder, followed by memory disorder, both in male patients. Thus, the probability that a patient with sequelae from ABI (n = 736) arriving at the hospital language pathology unit and being diagnosed with a language disorder (n = 373) is 373/736 = 0.5067, i.e., 50.67% (event A). Also, considering that the patient is a male (n = 214), the probability is 214/373 = 0.5737, i.e., 57.37% (event B). Therefore, $A \cap B$ = (0.5067) (0.5737) = 0.2906. Hence, the probability that a patient with ABI sequelae arrives at the hospital language pathology unit, is diagnosed with a language disorder, and is a male is 29.06%. Figure 1 shows that cognitive degenerative disorder was the only disorder in which the frequency was higher in women, at 70/99 = 0.7070, eg, 70.7%, with a probability of 9.5%.

**Table 2. Diagnosis and age decades following acquired brain injury**

| Decade of age | Language | Speech | Memory | Language/Writing/ Calculation | Cognitive/ Neurodegenerative | Cognitive/ Fine motor | Multiple |
|---|---|---|---|---|---|---|---|
| 10 to 19 | 6/373 = 0.016 | 7/77 = 0.0909 | 7/113 = 0.0619 | 0/4 = 0 | 2/99 = 0.0202 | 0/11 = 0 | 3/59 = 0.0508 |
| 20 to 29 | 18/373 = 0.0482 | 8/77 = 0.1038 | 28/113 = 0.2477 | 0/4 = 0 | 0/99 = 0 | 0/11 = 0 | 9/59 = 0.1525 |
| 30 to 39 | 34/373 = 0.0911 | 21/77 = 0.2727 | 28/113 = 0.2477 | 0/4 = 0 | 0/99 = 0 | 1/11 = 0.0909 | 13/59 = 0.2203 |
| 40 to 49 | 53/373 = 0.142 | 10/77 = 0.1298 | 14/113 = 0.1238 | 0/4 = 0 | 2/99 = 0.0202 | 2/11 = 0.1818 | 14/59 = 0.2372 |
| 50 to 59 | 82/373 = 0.2198 | 10/77 = 0.1298 | 15/113 = 0.1327 | 1/4 = 0.25 | 4/99 = 0.0404 | 5/11 = 0.4545 | 11/59 = 0.1864 |
| 60 to 69 | 84/373 = 0.2252 | 7/77 = 0.0909 | 6/113 = 0.053 | 27/99 = 0.2727 | 27/99 = 0.2727 | 3/11 = 0.2727 | 5/59 = 0.0847 |
| 70 to 79 | 65/373 = 0.1742 | 12/77 = 0.1558 | 12/113 = 0.1061 | 0/4 = 0 | 28/99 = 0.2828 | 0/11 = 0 | 2/59 = 0.0338 |
| 80 to 89 | 27/373 = 0.0723 | 2/77 = 0.0259 | 3/113 = 0.0265 | 0/4 = 0 | 32/99 = 0.3232 | 0/11 = 0 | 2/59 = 0.0338 |
| 90 to 99 | 4/373 = 0.0107 | 0/77 = 0 | 0/113 = 0 | 0/4 = 0 | 4/99 = 0.0404 | 0/11 = 0 | 0/59 = 0 |

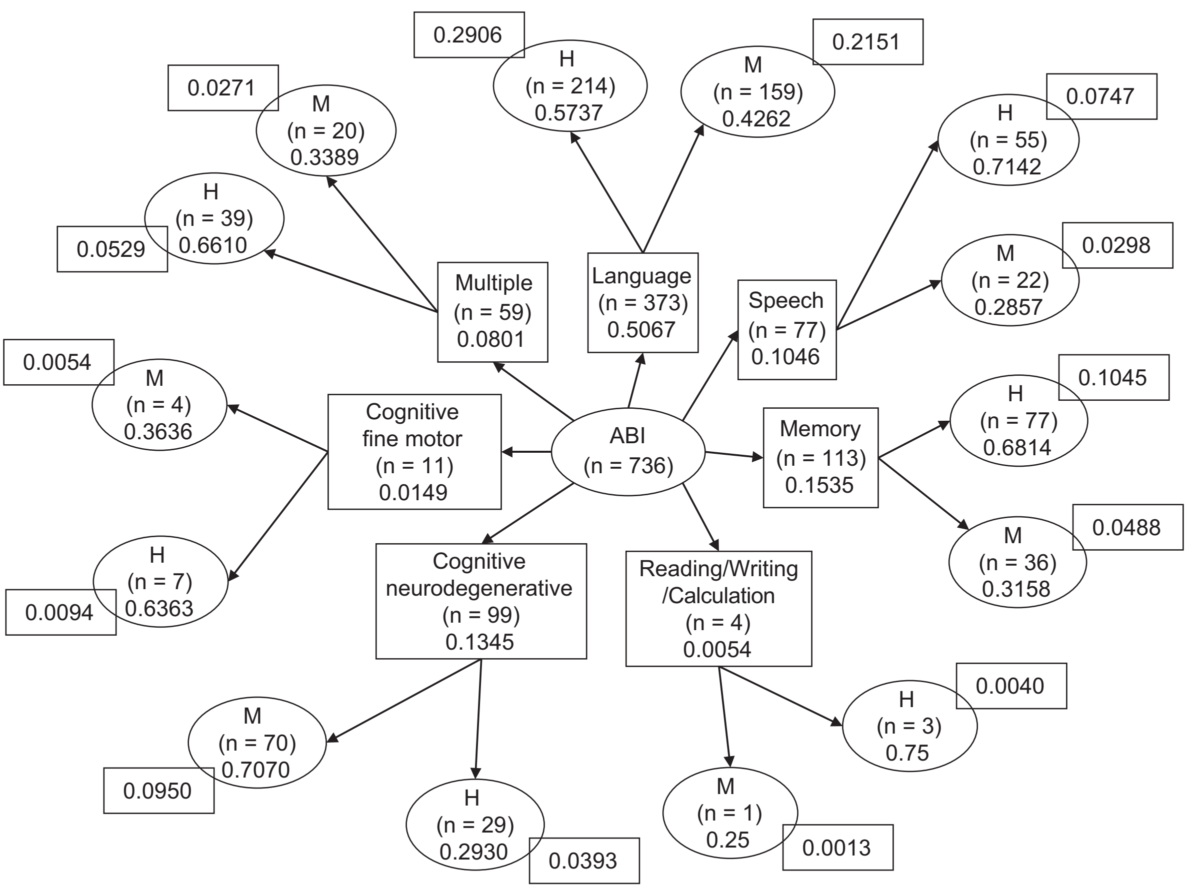


**Figure 1.** *Conditional probability diagram of diagnosis as a sequela of acquired brain injury (ABI). Radially displayed are all the posterior probabilities related to the diagnosis of the population with ABI sequelae seeking consultation for communication disorders, with the prior probability or baseline condition, in this case, ABI, located at the center. M: women; H: men.*

Probabilistic intersection was also performed to determine the probability of event occurrence, considering the baseline ABI condition and the patients' decades of age. It was found that the decades with the highest frequency of ABI sequelae were 60 to 69 years in women and 50 to 59 years in men.

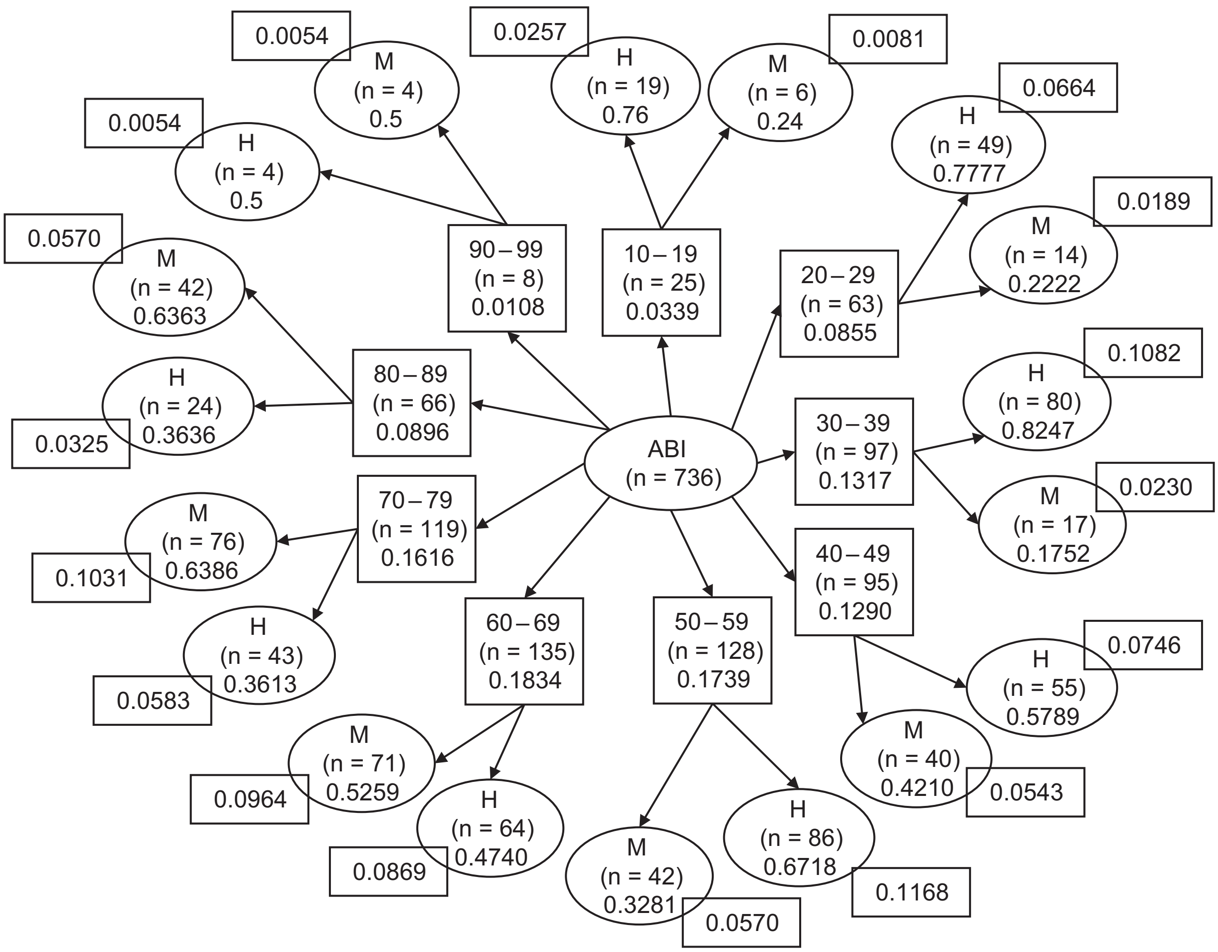


**Figure 2.** *Conditional probability diagram of the age decade at presentation of sequelae due to acquired brain injury (ABI). Radially displayed are all the posterior probabilities related to the age decades of the population with ABI sequelae seeking consultation for communication disorders, with the prior probability or baseline condition, in this case, ABI, located at the center. M: women; H: men.*

Therefore, the probability of a patient with ABI sequelae (n = 736) arriving at the hospital language pathology unit, and being between 60 and 69 years old (n = 135) is 135/736 = 0.1834, i.e., 18.34%. Considering that the patient is a female (n = 71), the probability is 71/135 = 0.5259, i.e., 52.59%. Therefore, $A \cap B$ = (0.1834) (0.5259) = 0.0964. Hence, the probability that a patient with ABI sequelae arrives at the hospital language pathology unit is between 60 and 69 years old and 9.64%. of being a female. Figure 2 illustrates that in the decades of 60 to 69 years, 70 to 79 years, and 80 to 89 years, women had the highest frequency of ABI sequelae, at 52.5%, 63.8%, and 63.3%, respectively, while in the decades of 10 to 19 years, 20 to 29 years, 30 to 39 years, 40 to 49 years, and 50 to 59 years, men had the highest frequency, at 76%, 77.7%, 82.5%, and 67.1%, respectively.

When calculating the chi-square test for the diagnosis and sex variables, a p value of 0.01 was obtained, indicating a significant difference, meaning a higher incidence of communication disorders as sequelae of ABI in men. Similarly, considering the variables of age decade and sex, a p value of 0.01 was obtained, that is, a significant difference in the different age decades of the patients with ABI sequelae in men. Both significances indicate that there is a relationship between patients' sex and diagnosis and the decade of age in which they develop ABI sequelae.

A contingency table was built with the diagnosis and age decade variables, finding that the decades with the highest frequency of language disorders were 50 to 59 years, at 21.9%, and 60 to 69 years, at 22.5%. Regarding speech disorders, the decade with the highest frequency was 30 to 38 years, at 27.2%. Regarding memory disorders, the decades with the highest frequency were 20 to 29 years and 30 to 39 years, both at 24.7%. For language, writing, and calculation disorders, the highest frequency was reported in the 60 to 69 years decade, at 75%. Cognitive degenerative disorders were most frequently diagnosed in the 80 to 89 years decade, at 32.3%, followed by the 70 to 79 years decade, at 28.2%, and the 60 to 69 years decade, at 27.2%. Cognitive disorders along with fine motor skills were most frequently found in the 50 to 59 years decade, at 45.4%. Multiple disorders were more common in the 40 to 49 years decade, at 23.7%, and the 30 to 39 years decade, at 22% (Table 2).

Considering the diagnosis and the patient's age decade variables, the chi-square test was calculated with a 99% confidence interval, and a significant difference was established with a p value of 0.01, indicating a relationship between the diagnosis and the decade of age at which it occurs.

## Discussion

This study provides information to understand the characteristics of the patients who suffered ABI and presented cognitive and communication sequelae. It also provides insights into the probabilistic findings of variables related to this type of brain damage in a cohort of the patients treated at Instituto Nacional de Salud in Mexico. Considering the patients' sex, it was found that men were more widely affected, representing 57.6% of the sample compared to 42.4% of women, with a difference of 15.2%. Data reported in the scientific medical literature currently available show a similar trend, reaching 73% among men[8,10]. However, we should mention that this trend has been reported to be reversed in patients with acquired injuries in sports activities that predispose to concussion, with a ratio of 2 women for every man[11].

The most common diagnosis was language disorder, present in 373 patients (50.7%). This result is corroborated by the confidence interval for the proportion, where the highest frequency was found to be within the range of 45.9% to 55.4%. It also showed a posterior probability of language disorder in men of 29.06%. Finally, the contingency table shows that the decades of 50 to 59 years and 60 to 69 years are the ages where this diagnosis is most frequently established as a sequel of ABI. The main cause of language disorders reported in the literature is stroke[12], which is considered to be the 3rd leading cause of disability-adjusted life years worldwide, with an overall incidence rate ranging from 76 to 119 per 100 000 population[13]. Additionally, considering the age at which it occurs more frequently, which is consistent with our results, it is assumed that chronic degenerative diseases (hypertension, hyperlipidemia, diabetes mellitus, metabolic syndrome), habits (smoking, alcoholism, sedentary lifestyle, high-risk diet, malnutrition), and other conditions (psychosocial stress, sleep apnea, hormone replacement therapy, migraines, depression, and work-related stress) play a significant role too[7,14]. However, we should mention that cardiovascular factors, especially hypertension, are the most influential, with a 6-fold higher risk when systolic blood pressure is high and up to 12 times higher when diastolic blood pressure stays high[15]. Diabetes mellitus presents a risk 1.5 times higher, tobacco consumption 1.3 times higher, and metabolic syndrome 23 times higher, along with an increased risk due to obesity proportional to the body mass index[14]. The medical literature states that 85% of stroke-related deaths occur in individuals older than 60 years. However, there is a high incidence predominantly in men aged 45 to 64 years[14,16]. It has been suggested that women have a neuroprotective factor related to hormonal issues[10].

The second most frequently diagnosed disorder was memory impairment, found in 113 patients (15.4%). We should mention the confidence interval for the mean age obtained, which indicates that patients with this condition tend to be younger, specifically between 37.8 to 45.1 years old. The age decades where the highest proportion of patients are diagnosed with memory impairment are 20 to 29 years and 30 to 39 years, each accounting for 24.7%. We should also mention that men received this diagnosis more frequently (68.1%) compared to women (31.9%). These findings lead us to consider what has been reported in the literature, which establishes that memory disorders are common in patients who have previously experienced traumatic brain injuries (TBIs). This has been reported as a side effect in nearly 43.4% of the patients with mild TBIs, 41.1% of the patients with moderate TBIs, and 44.2% of the patients with severe TBIs[17]. The literature also mentions that the most frequent sequelae of TBIs are primarily cognitive, with memory impairment accounting for 40% to 60% of the cases, followed by changes to executive functions, attention, motor skills, speech, and language[4,18]. Risk factors for these disorders include alcohol and drug consumption. In fact, it has been reported that over 50% of the patients who sustained a TBI were intoxicated at the time of the injury. Additionally, they have a double risk of recurrence due to trauma over an approximate period of 2 years[19]. Furthermore, patients with a history of alcohol or drug abuse show more significant brain damage, including less gray matter, increased hippocampal damage, and ventricular enlargement[20].

Regarding the gender of the patients, results are consistent with international and national statistics. TBI has an incidence rate of 349/100 000 people worldwide. When considering gender, this rate is 195/100 000 for women and significantly higher at 388/100 000 for men. Also, a decreased risk has been reported in men as they age, possibly due to reduced risk behaviors as they get older[10]. In Mexico, TBI is the 4th leading cause of death, with a male-to-female ratio of 3 to 1. It primarily affects individuals aged 15 to 45 years, being car crashes the main cause, particularly in individuals younger than 25 years. This explains the confidence interval for the mean age, indicating that patients with memory disorders tend to be younger[21,22].

One noteworthy finding is related to the diagnosis of neurodegenerative cognitive disorders. According to the confidence interval for the mean age, patients diagnosed with this disorder tend to be older, with an age range from 70.3 to 75.2 years. The decades with the highest diagnosis rates are 60 to 69 years (27.2%), 70 to 79 years (28.2%), and 80 to 89 years (32.3%). Additionally, this disorder is more frequently diagnosed in women (70.7%), with a posterior probability intersection of 9.5%. It is a fact that population aging is a global trend, leading to the development of age-related conditions. The World Health Organization (WHO) defines aging as a physiological process due to the accumulation of molecular and cellular damage over time, leading to gradual changes in physical and mental skills, as well as an increased risk of illness or death. Internal and external variables also play a key role in shaping a complex chain of comorbidities in this process[23]. Several studies have presented crucial information related to age-dependent functional, biochemical, and structural brain changes at both micro and macro levels, affecting the performance and execution of skills in older adults[24-26]. Therefore, an increase in neurodegenerative cognitive disorders is expected, with a rising trend in the coming years. The results also highlight that in this disorder, women were more frequently diagnosed. A literature review can explain this phenomenon, as there is a tendency toward longer life expectancy in women, with approximately a 6-year difference compared to men in Mexico. Furthermore, there is a phenomenon known as the "feminization of aging," where greater longevity is observed in women, with 124 women for every 100 men aging 80 years and older[27]. On the other hand, we should mention that after the age of 65, TBIs increase in frequency, mainly due to an increase in falls as a consequence of aging[12,28]. This is related to a decrease in motor skills, vertigo-related events associated with vestibular system degeneration, and a reduction in appendicular muscle mass. Additionally, the complexity of cases will be greater due to comorbidity and pre-existing cognitive disorders[29].

Finally, regarding age, diagnosis, and the gender of the patients, it was found that men were diagnosed more frequently between the ages of 10 and 59. The decade with the highest rate of diagnoses for men was between 30 and 39 years, with a posterior probability of 82.5%. In contrast, for women, the most frequent diagnoses occurred between the ages of 60 and 89, with each decade having a posterior probability of 63%. Building on the previously discussed points, it is possible that TBIs are a significant factor for younger men, while strokes play a more significant role in middle-aged men. For women, strokes, along with the feminization of aging, contribute to a higher incidence rate, especially after the age of 60.

## Conclusions

Based on these results, we can infer the following regarding this sample: The probability that a patient with ABI sequelae receives a diagnosis of speech disorder, or memory impairment is higher in men compared to women; the probability that a patient with ABI sequelae receives a diagnosis of neurodegenerative cognitive disorder is higher in women compared to men; the probability that a patient with ABI sequelae is between 60 and 89 years old is higher in women compared to men, and the probability that a patient with ABI sequelae is between 10 and 59 years old is higher in men compared to women.

Given the high prevalence of short- and long-term disabilities resulting from ABI, early detection and timely diagnosis are crucial for providing efficient specialized care.

Age-related cognitive problems are beginning to impact health care statistics, which emphasizes the importance of prevention through informative campaigns and the implementation of strategies for healthy aging, as well as the creation and implementation of cognitive stimulation programs.

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None declared.

## Conflicts of interest

None declared.

## Ethical disclosures

**Protection of human and animal subjects.** The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki).

**Confidentiality of data.** The authors declare that they have followed the protocols of their work center on the publication of patient data.

**Right to privacy and informed consent.** The authors have obtained approval from the Ethics Committee for analysis and publication of routinely acquired clinical data and informed consent was not required for this retrospective observational study.

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