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Asociación Colombiana de Medicina Física y Rehabilitación

Original research

Characterization of physiological changes in residual limb volume in transtibial amputees

Caracterización de los cambios en el volumen del muñón en pacientes con amputación transtibial

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Abstract

Introduction. Amputations are events that can have physical, psychological, and occupational consequences on individuals. In Colombia, these represent an important cause of physical limitation and are mainly associated with armed conflict.
Objectives. To characterize changes in stump volume in a group of patients with transtibial amputations who began the prosthetic fitting process at a hospital in Bogotá D.C. (Colombia); to identify possible factors associated with these changes and their time or occurrence; and to establish specific times for measuring the stump volume during the prosthetic adaptation process.
Methods. A prospective study was conducted with a series of cases that included adult patients (>18 years) diagnosed with transtibial amputation and who began the prosthetic fitting process at the Prosthetics and Amputee Service of the Central Military Hospital *(Hospital Militar Central)* of Bogotá D.C. between January 2022 and June 2023. The personal data of the participants, who were assessed on four occasions in which their stump length and circumference were measured and 3D scanned to calculate the stump volume, were recorded. A descriptive analysis was performed using the R statistical software. The data are described using absolute and relative frequencies for qualitative variables, and measures of central tendency and dispersion for quantitative variables.
Results. A total of 20 participants were included, all men, with a mean age of 34.66 years. 95% of the amputations were caused by an improvised explosive device, 75% were in the left leg and 60% had cylindrical morphology. A significant association was found between the time of use of the prosthesis and the activity level of the patient. It will be observed that changes in the volume, length and circumference of the stump do not follow a uniform pattern and vary between individuals; However, in the stumps of bulbous morphology, only reductions in volume were observed, without an increase in measurements. No significant associations were found between sociodemographic characteristics of the participants and changes in stump volume.
Conclusion. No sociodemographic factor or condition was identified as having a significant effect on stump volume changes. In addition, it was not possible to establish specific variability values or predict when changes in the stump volume will occur; therefore, it was not possible to establish specific times to perform measurement of the stump.

Keywords. Amputation , prosthesis and implants, amputation stumps, leg trauma.

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Resumen

Introducción. Las amputaciones son eventos que pueden tener consecuencias físicas, psicológicas y laborales en las personas. En Colombia, estas representan una causa importante de limitación física y se asocian principalmente al conflicto armado.

Objetivos. Caracterizar los cambios en el volumen del muñón de un grupo de pacientes con amputación transtibial que iniciaron proceso de protetización en un hospital de Bogotá D.C. (Colombia); identificar los posibles factores asociados a estos cambios y el momento de ocurrencia, y establecer tiempos específicos para la realización de la medición del volumen del muñón durante el proceso de adaptación protésica.

Métodos. Se realizó un estudio prospectivo con una serie de casos que incluyó a pacientes adultos (>18 años) con diagnóstico de amputación transtibial y que iniciaron proceso de protetización en el Servicio de Prótesis y Amputados del Hospital Militar Central de Bogotá D.C. entre enero de 2022 y junio de 2023. Se registraron los datos personales de los participantes, quienes fueron valorados en cuatro oportunidades en las que se les realizó medición de longitud y circunferencias al muñón y escaneo 3D para calcular el volumen del muñón. Se realizó un análisis descriptivo mediante el programa estadístico R. Los datos se describen usando frecuencias absolutas y relativas para las variables cualitativas, y medidas de tendencia central y dispersión para las cuantitativas.

Resultados. Se incluyeron 20 participantes, todos hombres, con una edad media de 34,66 años. 95% de las amputaciones fueron causadas por un artefacto explosivo improvisado, 75% eran en la pierna izquierda y 60% tenían morfología cilíndrica. Se encontró una asociación significativa entre el tiempo de uso de la prótesis y el nivel de actividad del paciente. Se observó que los cambios en el volumen, la longitud y la circunferencia del muñón no siguen un patrón uniforme y varían entre individuos; sin embargo, en los muñones de morfología bulbosa solo se observaron reducciones de volumen, sin aumento en las medidas. No se encontraron asociaciones significativas entre las características sociodemográficas de los participantes y los cambios de volumen del muñón.

Conclusión. No se identificó un factor o una condición sociodemográfica que tenga un efecto significativo en los cambios de volumen del muñón. Además, no fue posible establecer valores específicos de variabilidad ni predecir cuándo ocurrirán cambios en el volumen del muñón; por lo tanto, no fue posible establecer momentos específicos para realizar mediciones al muñón.

Palabras clave. Amputación, prótesis e implantes, muñones de amputación, traumatismos de la pierna.

Introduction

According to the World Health Organization (WHO), approximately 16% of the world's population, that is, 1,3 billion people, have a significant disability, and this figure is increasing due to the rise in chronic non-communicable diseases and population aging.[1] Amputations are devastating events in a person's life that can have physical, psychological, and occupational consequences.[2]

In Colombia, amputations represent a major cause of physical limitation and are mainly associated with the armed conflict. According to the Office of the High Commissioner for Peace, since 1990 there have been 12,409 victims of anti-personnel mines in the country, with 55.2% of the incidents concentrated in five departments: Antioquia, Meta, Nariño, Caquetá and Norte de Santander.[3-5]

The decision to perform an amputation seeks to improve the patient's health condition, maximizing his/her independence and possibility of walking recovery,[5,6] and results in a complex process, especially when the amputation is due to ischemic or vascular causes, tumors, infection or deformity[7]. The levels of amputation in the lower limb vary and include: ankle disarticulation, transtibial, knee disarticulation, transfemoral and hip disarticulation.[8,9] For an amputation to be considered successful, the resulting stump must meet the following specific characteristics: Elastic skin, painless scar, stable bone and balanced muscles to facilitate prosthetic adaptation.[10,11]

A transtibial prosthesis has five main components: interface, socket, suspension system, pylon and prosthetic foot,[7,12,13] and for its design, sociodemographic and clinical factors such as weight, age, stump condition, associated pathologies and level of physical activity of the patient must also be taken into account.

Changes in the volume of the stump are more frequent during the first 12 to 18 months post-amputation and are caused by physiological mechanisms such as blood accumulation,

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vasodilation and modifications in interstitial fluids.[14,15] These changes can be measured through different methods such as: immersion in water, mathematical calculations, ultrasound, medical imaging, bioimpedance and CAD/CAM systems, the latter being the most reliable method.

Scientific literature highlights that the functionality of the prosthesis is the most relevant factor for the user, above aesthetic or weight considerations.[6,16]

Taking into account the foregoing, the objectives of the present study were to characterize the changes that occur in the stump volume of a group of patients diagnosed with transtibial amputation who started their prosthetic fitting process in a tertiary care hospital in Bogotá D.C. (Colombia); to identify the possible factors associated with the appearance of these changes and the time of occurrence, and establish specific times for the measurement of the stump volume during the prosthetic adaptation process, which could ultimately reduce economic costs to the healthcare system.

Methods

Type of study and study population

A prospective observational case series study was conducted. The sample selection was non-probabilistic for convenience and all adult patients (>18 years) with transtibial amputation who began their prosthetic fitting process at the prosthesis and amputee service of the Hospital Militar Central (Central Military Hospital) of Bogotá D.C. between January 2022 and July 2023, and who signed the informed consent, were considered. Patients who had open wounds, who did not use prostheses, or who interrupted the prosthetic process were excluded.

The minimum sample size was calculated using the Epidat 4.2 software for a correlation of 0.60 between the time of use of prostheses and the volume change, with a confidence level of 95% and a power of 80% in a two-tailed analysis, estimating a minimum of 20 subjects.

Procedures

Data collection was conducted in the walking room of the service, where patients were informed of the study objectives and asked to sign the informed consent. The sociodemographic data of the participants were recorded in a Microsoft Excel database and the RODIN M4D Scan system was used with a computer-aided design (CAD/CAM) program to measure the volume of the stump; manual measurements were taken and the stump was scanned with the patient in a sitting position (Figure 1). Volume measurements were performed at four points: 1) at the beginning of the prosthetic fitting process, 2) at the beginning of the use of the test (check) socket, 3) one month after the start of use of the test socket and 4) three months after the use of the definitive prosthesis. The units used were cubic decimeters (dm^3) for volume and centimeters (cm) for length and circumferences.

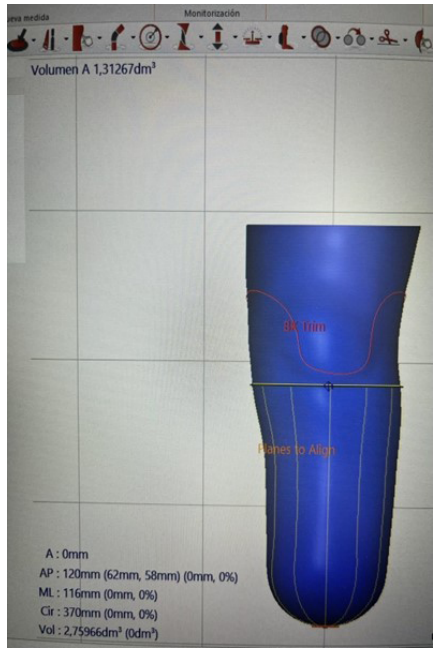

Figure 1. Calculation of the stump volume using the CAD/CAM program.
Source: Image obtained during the study.

Variables

The study included variables of a quantitative and qualitative nature, with nominal and ratio levels

of measurement. Sociodemographic, clinical, and functional characteristics were assessed, including age, gender, body mass index (BMI), laterality, reason for amputation, comorbidities, use of prosthesis, type of socket muscle strength, morphology, stump volume, as well as activity level, and daily duration of physical activity.

Statistical analysis

To minimize errors, the information was reviewed by a second evaluator and a detailed statistical analysis was used. The data are described using absolute and relative frequencies for the qualitative variables, and measures of central tendency and dispersion for the quantitative variables. The distribution of the data was verified with the Shapiro-Wilk test, and confirmatory analyses included Chi2, Fisher's exact test, paired T test, and Wilcoxon signed-rank test. The correlations were calculated with Pearson and Spearman coefficients.

The analysis was conducted using the Stata 14 and SPSS V22 programs, with a confidence level of 95%.

Results

22 patients were recruited to participate in the study; however, two of them were excluded because they discontinued the prosthetic fitting process due to medical complications, so the final sample consisted of 20 participants.

All participants were men (100%) and 55% were in the age range of 26 to 35 years, with a mean age of 34.66±13.38 years. The minimum age recorded was 20 years, while the maximum age was 86 years.

95% (n=19) of the participants had undergone transtibial amputation as a result of trauma caused by an explosive device; these patients had a K3 activity level. The remaining percentage (5%), which corresponds to an elderly person, suffered amputation as a consequence o f a peripheral vascular disease and has a K1 functional level.

Regarding the laterality of the amputations, 15 (75%) cases were on the left side and 5 (25%) on the right side. With respect to the morphology of the stump, it was found that the most common was cylindrical, present in 12 (60%) patients, followed by bulbous and conical, with three patients each (30%); on the contrary, the least common was the quadrangular, registered in only two (10%) participants.

Muscle strength in all patients was within normal parameters, with an equal distribution between levels 4 and 5 on the Daniels scale, occurring in a 50/50 ratio.

The BMI showed that 60% of the participants had a normal weight and 40% were overweight, with an average weight of 70 kg. Only two participants (10%) reported a history of arterial hypertension, the rest (80%) did not report any diseases other than those related to the amputation.

Table 1 presents the sociodemographic and clinical characteristics of the participants, and Table 2 presents the volumes and the differences in their volumes.

Table 1. Sociodemographic and clinical characteristics of the sample.

Variable	Category	Absolute frequency (n)	Relative frequency (%)
Gender	Male	20	100
	Female	0	0
Body mass index	Normal weight	12	60
	Overweight	8	40
Cause of the amputation	Traumatic	19	95
	Medical	1	5
Laterality of amputation	Left	15	75
	Right	5	25
Medical history	Arterial hypertension	2	10
	Without other antecedents	18	90
Average body weight		70 kg	

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Table 2. Volumes and volume differences.

	Vol 1	Vol 2	Vol 3	Vol 4	Volume difference 2-1	Volume difference 3-2	Volume difference 4-2
Mean	1.26	1.22	1.15	1.03	0.04	0.07	-0.17
Median	1.15	1.28	1.18	1.02	-0.01	0.06	-0.14
Minimum value	0.48	0.33	0.57	0.42	-0.46	-0.29	-0.61
Maximum value	2.13	2.02	1.73	1.54	0.62	0.35	0.70
Standard deviation	0.49	0.46	0.35	0.33	0.24	0.17	0.31
Q1	0.94	0.84	0.85	0.81	-0.11	0.03	-0.46
Q3	1.73	1.57	1.41	1.39	0.17	0.14	-0.04
Mean reduction					0.24	0.13	0.24
Mean increase					0.13	0.13	0.27

Vol: volume; Q1: First quartile; Q3: Third quartile.
Note: negative values indicate an increase in the measurement of the volume of the stump.
Source: own elaboration.

The mean reduction in volume before starting to use the prosthesis, compared to the time spent performing physical activity, was greater in the group that practices physical activity three times a week for more than 75 minutes, with a value of 0.19 and a ratio of 2 to 1 in cubic decimeters with respect to those who practice physical activity for less than 50 minutes; however, it is likely that there were no significant differences between the time spent performing physical activity and the difference in volume during the time prior to the start of use of the prescribed prosthesis because the p-value was 0.35.

The median difference in stump volume during the first month of prosthesis use was 0.08 dm^3 for those who did not perform physical activity, and 0.04 dm^3 for those who did.

The difference in stump volume in the first month after starting to use the prosthesis and the time of use during the day showed an average of 0.04 dm^3 for those who used it for less than six hours a day, while for those who exceeded that time it was 0.09 dm^3.

When comparing the morphology of the stump with the volume changes prior to the start of the use of the prosthesis, it was observed that there were no significant differences between any of the categories according to the results of the Wilcoxon sign rank test and the Holm adjustment method, with a p-value=0.42 for the bulbous morphology vs. the cylindrical and a p-value=1.00 for the others.

Similarly, during the monitoring of volume changes, a p-value=1 was obtained in all categories.

In addition, it was observed that those who used the prosthesis for more than 4.1 hours a day did not have reductions greater than 0.35 dm^3 and that those who used it for more than 6.1 hours a day had a maximum volume increase of 0.08 dm^3.

The Pearson/Spearman correlation for the time of use of the prosthesis and the volume differences were all weak, with a positive correlation of 0.150 for volume difference 3-2 and negative correlations of -0.148 for volume differences 4-3 and of -0.084 for volume differences 4-2.

The differences observed in the stump volume during the time when the patients already had and used the prosthesis had a p-value in the Wilcoxon test of 0.000414, which contrasts with the values obtained between the multiple volume differences (2-1, 3-2 and 4-2) and the BMI, physical activity and occupational activity (Table 3), which suggests that there is no statistically significant difference between them.

When analyzing the differences in stump volume between the measurements taken, it was evident that the BMI showed variations of 0.15 between the first and second measurement, 0.79 between the second and third, and 0.85 between the second and fourth. Regarding the physical activity, the difference were of 0.31 between the second and third and 0.57 between

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the second and fourth. For the occupational activity, differences of 0.82 were registered between the first and second measurements, 0.37 between the second and third, and 0.76 between the second and fourth. A positive correlation was observed between the initial volume and that registered before the use of the prosthesis (0.92) and at one month of use (0.94), although this was weaker at four months (0.69). In contrast, the difference in volume before the use of the prosthesis had a negative correlation at one month (-0.51) and four months (-0.04) (Figure 2).

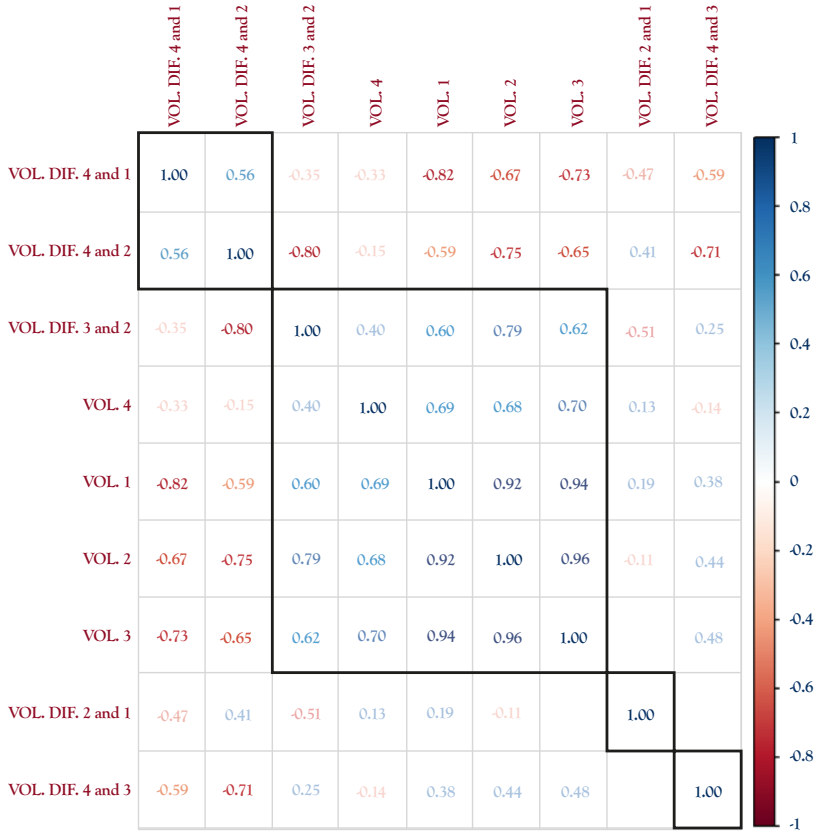

Figure 2. Correlation of volumes.
Source: own elaboration.

Table 3. Correlations of stump volumes in the different measurements.

	Vol 1	Vol 2	Vol dif 2-1	Vol 3	Vol dif 3-2	Vol 4	Vol dif 4-1	Vol dif 4-3	Vol dif 4-2
Vol1		0.0000	0.0955	0.0000	0.0388	0.0001	0.0002	0.1845	0.0344
Vol 2	0.0000		0.6125	0.0000	0.0000	0.0003	0.0079	0.0919	0.0008
Vol dif 2-1	0.0955	0.6125		0.7390	0.0267	0.5145	0.0649	0.6673	0.1443
Vol 3	0.0000	0.0000	0.7390		0.0179	0.0000	0.0041	0.0799	0.0083
Vol dif 3-2	0.0388	0.0000	0.0267	0.0179		0.0885	0.1914	0.3370	0.0006
Vol 4	0.0001	0.0003	0.5145	0.0000	0.0885		0.6142	0.2367	0.9848
Vol dif 4-1	0.0002	0.0079	0.0649	0.0041	0.1914	0.6142		0.0002	0.0004
Vol dif 4-3	0.1845	0.0919	0.6673	0.0799	0.3370	0.2367	0.0002		0.0000
Vol dif 4-2	0.0344	0.0008	0.1443	0.0083	0.0006	0.9848	0.0004	0.0000	

Vol: volume; Dif: difference.
Source: own elaboration.

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The mean variability of the stump volumes throughout the study was higher in terms of increase, which ranged between 2.5% (0.021 dm^3) and 28% (0.26 dm3), that in terms of reduction, which ranged between 0.7% (0.008 dm^3) and 25% (0.25 dm^3) (Figure 3). The mean volumes progressively decreased in each measuremet; however, these differences were not significant since it was observed that the confidence intervals are intersected. The foregoing was confirmed with the p-value matrix, in which, when comparing all volumes, a p-value=1 was obtained.

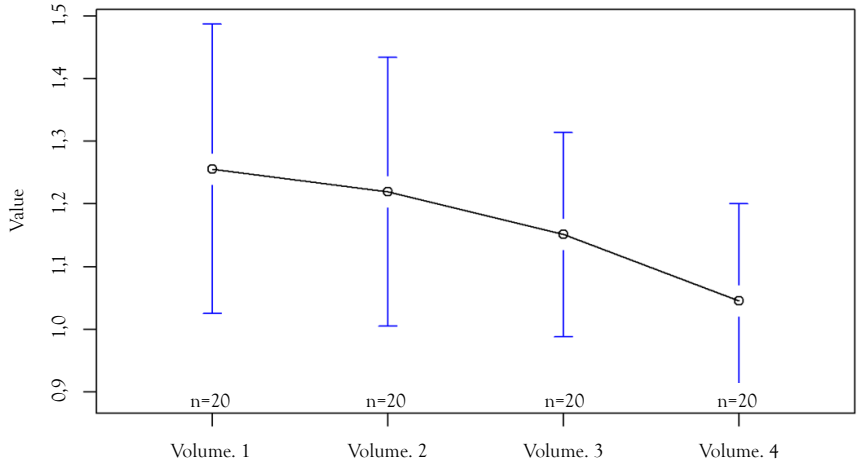

Figure 3. Variability of mean volumes.
Source: own elaboration.

When averaging the stump volume measurements over the follow-up period, it was found that by the end of the study only three participants had an increase in their stump volume.

The results of the Shapiro Wilk test (0.21 to 0.83) showed that the values of the stump volume presented a normal distribution for each and every one of the measurements; the same occurred with the difference in volumes 2-1 and 3-2 (0.39-0.85).

Discussion

The measurement of the stump volume at different times after transtibial amputation has shown fluctuations both diurnal and in the short and long term, variations that are influenced by multiple physiological and functional factors. The main purpose of this study was to characterize these volumetric changes and their possible relationship with sociodemographic variables. Although the specific literature on this phenomenon remains limited, previous studies[17,18] have documented volume variations between 2.4% and 35%, values that partially approach the findings of the present study, in which variations between 0.7% and 28% were found.

For the measurement of the volume of the stump, the CAD/CAM system with optical scanner was used, a technique recognized for its high repeatability and precision,[15] which reinforces the reliability of the results. Positive correlations were identified between the initial stump volume and the measurements after the use of the prosthesis, although these decreased over time. This behavior coincides with research such as that conducted by Sanders *et al.*,[13] who have reported greater fluctuations in the initial stages of prosthetic use.

Regarding the characteristics of the sample, there was a total predominance of male participants and amputations of traumatic origin, which is consistent with what has been reported in population studies of amputation in conflict contexts conducted in Colombia.[4,9] However, the low heterogeneity of the cohort limits the generalization of the results. Another relevant finding was the association between the morphology of the stump and volumetric changes: bulbous stumps showed more consistent reductions, without increases, which has also been reported in the literature on socket adaptation.[11]

Regarding the BMI and the physical activity level, no statistically significant associations were observed. Nevertheless, the literature supports the role of exercise in the regulation of body weight and overall health.[19] In line with the above, the present study found that those who engaged in regular physical activity and had occupational activity showed greater volume reductions, suggesting a possible functional relationship.[20] Similarly, participants who wore the prosthesis for more than 4.1 hours per day also reported a more significant reduction in volume, which is consistent with studies that have documented tissue adaptations based on prolonged use of the device.[13,21]

It is noteworthy that participants who did not perform physical activity prior to the use of the prosthesis also presented significant reductions in volume. This raises questions about other potentially influential factors such as the use of bandages or liners, which have also been linked to volumetric variations.[13,20]

Neither the length nor the circumference of the stump showed a uniform pattern during the measurements. The literature indicates that variables such as mechanical load during gait can alter the distribution of fluids and, therefore, the stump volume.[14] Even though the variability at the time of scanning could have introduced biases—for example, due to physical activity performed before the measurement—this bias was minimized by having a single trained operator for all measurements.[22]

Overall, the results obtained in this study allow us to conclude that variability of the stump volume is a natural and multifactorial biological phenomenon.[23,24] Although the statistical correlations were significant, they cannot be assumed as direct causal relationships. In this regard, it is recommended to increase the sample size and conduct more robust longitudinal studies to clarify the real influence of clinical and sociodemographic factors on changes in the stump volume in patients with transtibial amputation.[25]

This study reveals a well-documented reality: in Colombia, a considerable number of transtibial amputations occur as a result of trauma caused by improvised explosive devices.[25] This underscores the urgent need to address the reduction of violence stemming from armed conflicts and to confront the consequences that these actors generate.

The main strength of this study is the longer follow-up of the sample (up to 311 days) compared to other reports that do not exceed 160 days.[18,26]

Conclusions

In the present study, a significant association was found between the time of use of the prosthesis and the level of activity (K levels). As for the changes in the stump (volume, length, and circumferences), these do not present uniform values nor do they follow a predictable pattern. The bulbous morphology of the stump showed only volume reductions, although the lack of homogeneity of the sample suggests the need for additional studies to assess its statistical significance.[27]

No significant associations were found between the sociodemographic characteristics and the volume changes, possibly due to sample heterogeneity or outliers.[27] However, the relationship between physical activity and reduction in the stump volume requires further research, considering its positive impact on the body composition and its potential influence on the adipose tissue distribution.[28]

In conclusion, no sociodemographic factor with a significant effect on stump volume changes was identified. Nor can specific values of variability be anticipated or established in these changes. In addition, although changes are most noticeable shortly after amputation, it is not possible to determine specific times to make measurements, since variations in volume are inevitable and constant.[29]

Authors' contribution

Conceptualization: Miguel Ángel Gutiérrez Ramirez was responsible for the initial research idea that gave rise to the study, while Jaclin Patricia Gaviria Moreno developed and conceptually structured this idea, formulating the central theoretical and clinical aspects, as well as the necessary changes for its methodological and scientific evolution.

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Content and data curation: Jaclin Patricia Gaviria Moreno was responsible for the search, selection and rigorous organization of the scientific information relevant to the development of the study. This process included the identification of reliable sources in the academic literature, as well as the verification of their validity and relevance. In addition, this author carried out data curation, which included the annotation and auditing of databases, debugging of redundant information, correction of inconsistencies from primary sources, and implementation of computational procedures to ensure the quality and reuse of the data collected during the research.

Formal analysis of the data: Jaclin Patricia Gaviria Moreno was in charge of the application of statistical techniques for the processing and analysis of the data obtained during the study. Her work included the selection of appropriate methods to evaluate changes in the volume of the stump, the rigorous treatment of the variables recorded and the quantitative interpretation of the results, ensuring the validity and soundness of the analysis performed.

Investigation: Jaclin Patricia Gaviria Moreno was responsible for the direct execution of the research work, including the implementation of the procedures and the systematic collection of the clinical data necessary for the study. Their work ensured the rigorous and ethical collection of the empirical evidence on which the analysis of the study is based.

Methodology: Jaclin Patricia Gaviria Moreno was responsible for the design and development of the methodology of the study. Her contribution included the development of the experimental approach, the definition of the measurement criteria and the structuring of the statistical models used for the analysis of the data, guaranteeing the scientific validity of the study design.

Project management: Jaclin Patricia Gaviria Moreno assumed the management and general coordination of the study. He was responsible for the planning, organization and monitoring of research activities, ensuring compliance with the objectives, schedules and ethical guidelines established.

Material resources: The measurement materials, access to patients, clinical instrumentation, and computing resources necessary for the execution of the study were provided by the Central Military Hospital. Jaclin Patricia Gaviria Moreno was in charge of the direct supervision of the use and management of these resources, ensuring their proper implementation during the research process.

Supervision: Miguel Ángel Gutiérrez Ramirez was in charge of the overall supervision of the study. His work included strategic guidance, methodological accompaniment, as well as tutoring.

Validation: Jaclin Patricia Gaviria Moreno was responsible for verifying the consistency and reproducibility of the data obtained in the study. This work included quality control of the procedures applied, review of the intermediate and final results, and confirmation of the methodological consistency that supports the validity of the findings.

Visualization: Jaclin Patricia Gaviria Moreno was responsible for the preparation, creation, and visual presentation of the study data. This included the elaboration of tables, graphs and explanatory diagrams that facilitated the interpretation of the results and their adequate communication in the final manuscript.

Writing-original draft: Jaclin Patricia Gaviria Moreno was responsible for the preparation of the initial draft of the study manuscript. This task included the comprehensive writing of the scientific text and its corresponding translation, ensuring the clarity and coherence of the content for its submission for publication.

Writing - review and editing: Jaclin Patricia Gaviria Moreno was responsible for the technical and scientific editing of the manuscript, incorporating the adjustments of style, conceptual precision and format required for its final presentation. Miguel Ángel Gutiérrez participated in the critical review of the content.

Ethical considerations

The study followed the ethical principles for biomedical research on human subjects set out in the Declaration of Helsinki[30] and the scientific, technical and administrative standards for health research of Resolution 8430 of 1993 of the Ministry of Health of Colombia.[31] Furthermore, it was approved by the Research Ethics Committee of the Hospital Militar Central and the informed consent of each of the participants was obtained.

Conflict of interest

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References

1. Organización Mundial de la Salud (OMS). Discapacidad. Ginebra: OMS; 2023 [cited June 30, 2025]. Available at: https://www.who.int/es/news-room/fact-sheets/detail/disability-and-health.

2. Dillingham TR, Pezzin LE, MacKenzie EJ. Limb amputation and limb deficiency: epidemiology and recent trends in the United States. South Med J. 2002;95(8):875-83. Available at: https://doi.org/10.1097/00007611-200208000-00018.

3. Colombia. Ministerio de Salud y Protección Social (Minsalud). Guía de práctica clínica para el diagnóstico y tratamiento preoperatorio, intraoperatorio y postoperatorio de la persona amputada, la prescripción de la prótesis y la rehabilitación integral. Guía No. 55. Bogotá D.C.: Minsalud; 2015.

4. Colombia. Dirección para la Acción Integral contra Minas Antipersonal. Datos abiertos. Registro de información de afectación por MAP y MUSE e intervención. Fecha de corte: 31 de enero de 2024. Bogotá D.C.: Acción Contra Minas; 2024 [cited June 19, 2025]. Available at: https://www.accioncontraminas.gov.co/Estadisticas.

5. Esquenazi A, DiGiacomo R. Rehabilitation after amputation. J Am Podiatr Med Assoc. 2001;91(1):13-22. Disponible en: https://doi.org/10.7547/87507315-91-1-13.

6. Gallagher P, MacLachlan M. Development and psychometric evaluation of the Trinity Amputation and Prosthesis Experience Scales (TAPES). Rehabilitation Psychology. 2000;45(2):130-154. Available at: https://doi.org/10.1037/0090-5550.45.2.130.

7. Fortington LV, Geertzen JH, van Netten JJ, Postema K, Rommers GM, Dijkstra PU. Short and long term mortality rates after a lower limb amputation. Eur J Vasc Endovasc Surg. 2013;46(1):124-31. Available at: https://doi.org/10.1016/j.ejvs.2013.03.024.

8. Burger H, Marincek C. Return to work after lower limb amputation. Disabil Rehabil. 2007;29(17):1323-9. Available at: https://doi.org/10.1080/09638280701320797.

9. Colombia. Dirección para la Acción Integral contra Minas Antipersonal. Situación víctimas minas antipersonal en Colombia. Bogotá D.C.: Acción Contra Minas; 2023.

10. Gailey R, Allen K, Castles J, Kucharik J, Roeder M. Review of secondary physical conditions associated with lower-limb amputation and long-term prosthesis use. J Rehabil Res Dev. 2008;45(1):15-29. Available at: https://doi.org/10.1682/jrrd.2006.11.0147.

11. Larsen BG, McLean JB, Allyn KJ, Brzostowski JT, Garbini JL, Sanders JE. How do transtibial residual limbs adjust to intermittent incremental socket volume changes? Prosthet Orthot Int. 2019;43(5):528-39. Available at: https://doi.org/10.1177/0309364619864771.

12. Chui KK, Jorge M, Yen SC, Lusardi MM. Orthotics and prosthetics in rehabilitation. 4th ed. St. Louis: Elsevier; 2020.

13. Sanders JE, Youngblood RT, Hafner BJ, Ciol MA, Allyn KJ, Gardner D, *et al.* Residual limb fluid volume change and volume accommodation: relationships to activity and self-report outcomes in people with trans-tibial amputation. Prosthet Orthot Int. 2018;42(4):415-27. Available at: https://doi.org/10.1177/0309364617752983.

14. Sanders JE, Fatone S. Residual limb volume change: systematic review of measurement and management. J Rehabil Res Dev. 2011;48(8):949-86. Available at: https://doi.org/10.1682/jrrd.2010.09.0189.

15. Kofman R, Beekman AM, Emmelot CH, Geertzen JHB, Dijkstra PU. Measurement properties and usability of non-contact scanners for measuring transtibial residual limb volume. Prosthet Orthot Int. 2018;42(3):280-7. Available at: https://doi.org/10.1177/0309364617736088.

16. Resnik L, Borgia M. Reliability of outcome measures for people with lower-limb amputations: distinguishing true change from statistical error. Phys Ther. 2011;91(4):555-65. Available at: https://doi.org/10.2522/ptj.20100287.

17. Tantua AT, Geertzen JH, van den Dungen JJ, Breek JK, Dijkstra PU. Reduction of residual limb volume in people with transtibial amputation. J Rehabil Res Dev. 2014;51(7):1119-26. Available at: https://doi.org/10.1682/JRRD.2013.11.0243.

18. Zachariah SG, Saxena R, Fergason JR, Sanders JE. Shape and volume change in the transtibial residuum over the short term: preliminary investigation of six subjects. J Rehabil Res Dev. 2004;41(5):683-94. Available at: https://doi.org/10.1682/jrrd.2003.10.0153.

19. Murphy D. Fundamentals of amputation care and prosthetics. New York: Demos Medical; 2013.

20. Kelly BM, Spires MC, Restrepo JA. Orthotic and prosthetic prescriptions for today and tomorrow. Phys Med Rehabil Clin N Am. 2007;18(4):785-858. Available at: https://doi.org/10.1016/j. pmr.2007.08.001.

21. McLean JB, Redd CB, Larsen BG, Garbini JL, Brzostowski JT, Hafner BJ, *et al*. Socket size adjustments in people with transtibial amputation: effects on residual limb fluid volume and limb-socket distance. Clin Biomech (Bristol). 2019;63:161-71. Disponible en: https://doi.org/10.1016/j.clinbio- mech.2019.02.022.

22. Lindner HYN, Nätterlund BS, Hermansson LMN. Upper Limb Prosthetic Outcome Measures: Review and Content Comparison Based on International Classification of Functioning, Disability and Health. Prosthet Orthot Int. 2010;34(2):109-128. Available at: https://doi.org/10.3109/030936410037769 76.

23. Board WJ, Street GM, Caspers C. A comparison of trans-tibial amputee suction and vacuum socket conditions. Prosthet Orthot Int. 2001;25(3):202-209.

24. Laferrier JZ, Gailey R. Advances in lower-limb prosthetic technology. Phys Med Rehabil Clin N Am. 2010;21(1):87-110. Available at: https://doi.org/10.1016/j.pmr.2009.08.003.

25. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, Travison TG, Brookmeyer R. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Arch Phys Med Rehabil. 2008;89(3):422-429. Available at: https://doi.org/10.1016/j.apmr.2007.11.005.

26. Parvizi J, Kim GK. Amputation of the lower limb. In: Parvizi J, editor. High yield orthopaedics. Philadelphia: Elsevier; 2010. p. 17-19.

27. Pirouzi G, Abu Osman NA, Eshraghi A, Ali S, Gholizadeh H, Wan Abas WA. Review of the socket design and interface pressure measurement for transtibial prosthesis. ScientificWorld Journal. 2014;2014:849073. Available at: https://doi.org/10.1155/2014/849073.

28. Cutson TM, Bongiorni DR. Rehabilitation of the older lower limb amputee: a brief review. J Am Geriatr Soc. 1996;44(11):1388-1393. Available at: https://doi.org/10.1111/j.1532-5415.1996.tb01415.x.

29. Kristinsson O. The ICEROSS concept: a discussion of a philosophy. Prosthet Orthot Int. 1993;17(1):49-55. Available at: https://doi.org/10.3109/03093649309164354.

30. World Medical Association (WMA). WMA Declaration of Helsinki – Ethical principles for medical research involving human participants. Helsinki: 75th WMA General Assembly; 2024 [cited June 22, 2025]. Available at: https://bit.ly/40k4BRS.

31. Colombia. Ministerio de Salud. Resolución 8430 de 1993 (octubre 4): Por la cual se establecen las normas científicas, técnicas y administrativas para la investigación en salud [Internet]. Bogotá D.C.; octubre 4 de 1993 [cited June 22, 2025]. Available at: https://bit.ly/3Q3R0t8.