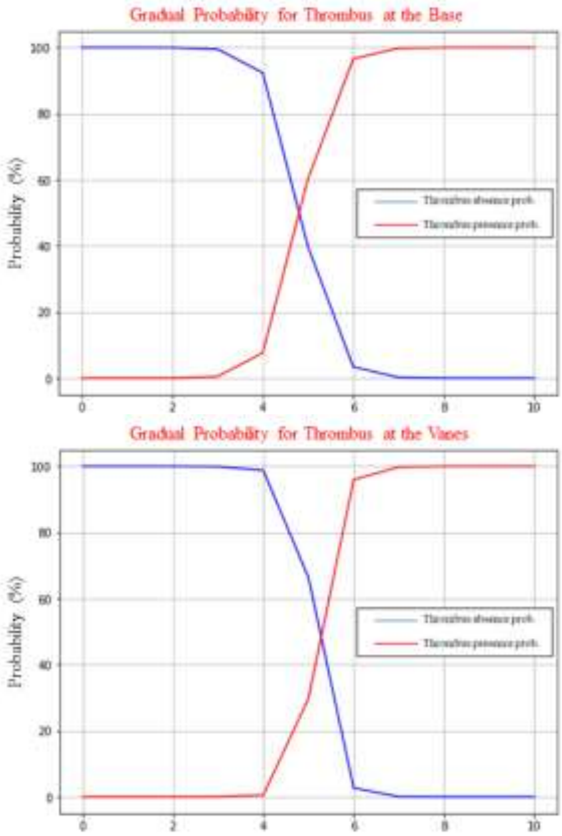
DOI: 10.37394/23208.2024.21.1

5.4 Predictive Algorithm

To demonstrate the capability of the ANN to predict thrombus formation with a small frequency signature, the output probabilities are presented in Figure 10 for three thrombus positions. In all scenarios, illustrated throughout the iterations, where the iterations represent the degree of mixing of signals with the absence and presence of thrombus, the probabilities of thrombus absence and presence vary. As expected, the probabilities always start with 100% for thrombus absence. With the increase in mixing, they converge to around 50% when approximately half of each signal type is being analyzed. After reaching this equilibrium point, the curves begin to diverge, reaching values of 0% for thrombus absence and 100% for thrombus presence when about 30% of the signals correspond to thrombus absence, and the remaining 70% are signals of thrombus presence.



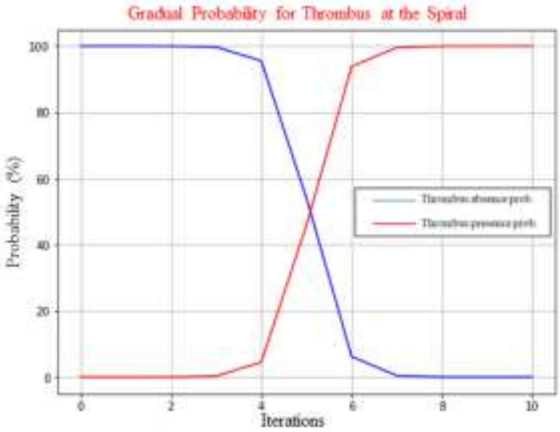


Fig. 10: Predictive analysis over the time

6 Conclusion

This study investigated the application of signal processing and machine learning algorithms for the detection of thrombi in VADs under different operating conditions. The analysis covered signal reconstruction techniques, signal analysis, classification by ANNs, and their application in a predictive algorithm. Frequency analysis highlighted specific characteristics for each scenario, with some frequencies indicating normality and the absence of a thrombus, while others indicated the presence of a thrombus, signaling anomalies and imbalances in the rotor.

A signal made by mixing signals with and without a thrombus was verified using wavelet analysis to represent how thrombus formation might develop over time, indicating that at a certain point, the signs indicating the presence of a thrombus become measurable. Classification analyses were carried out using ANNs, considering data in the time domain and the frequency domain.

Overall, frequency domain signals demonstrated superiority to time domain signals in terms of sensitivity to disturbances caused by noise, although the frequency domain requires greater computational effort to pre-process the measured signals. The frequency domain signals were used to carry out predictive analyses to calculate the probabilities of the presence or absence of thrombi in various VAD operating scenarios, including situations of total absence or presence of thrombi, as well as the variable combination of these signals over time. It was found that the probabilities varied significantly as the proportions of thrombus presence and absence data changed.

Therefore, the results of this study, especially those obtained by the predictive algorithm, contribute to the further development of a smart pump, where more effective monitoring and control systems can be incorporated into VADs, making them more efficient, as well as suggesting the feasibility of implementing prescriptive maintenance strategies. By analyzing the data, the device itself can indicate to the patient or physician when and what should be done. It is important to note that the results of this study were obtained using only one VAD model and cannot yet be generalized.

Acknowledgement:

Special thanks to the Laboratory of Bioengineering and Biomaterials crew and the Federal Institute of Education, Science and Technology of São Paulo for their support throughout the research process.

References:

[1] G. Renugadevi, G. Asha Priya, B. Dhivyaa Sankari, and R. Gowthamani, 'Predicting heart disease using hybrid machine learning model', *J Phys Conf Ser*, vol. 1916, no. 1, 2021, doi: 10.1088/1742-6596/1916/1/012208.

[2] J. N. Heaton, S. Singh, M. Li, and S. Vallabhajosyula, 'Adverse events with HeartMate-3 Left ventricular assist device: Results from the Manufacturer and User Facility Device Experience (MAUDE) database', *Indian Heart Journal*, vol. 73, no. 6, pp. 765–767, 2021, doi: 10.1016/j.ihj.2021.10.008.

[3] J. I. Glitza, F. Müller-von Aschwege, M. Eichelberg, N. Reiss, T. Schmidt, C. Feldmann, R. Wendl, J. D. Schmitto, and A. Hein, 'Advanced telemonitoring of Left Ventricular Assist Device patients for the early detection of thrombosis', *Journal of Network and Computer Applications*, vol. 118, no. May, pp. 74–82, 2018.

[4] G. Malone, G. Abdelsayed, F. Bligh, F. Al Qattan, S. Syed, P. Varatharajullu, A. Msellati, D. Mwipatayi, M. Azhar, A. Malone, S. H. Fatimi, C. Conway, and A. Hameed, 'Advancements in left ventricular assist devices to prevent pump thrombosis and blood coagulopathy', *J Anat*, vol. 242, no. 1, pp. 29–49, 2023, doi: 10.1111/joa.13675.

[5] M. Barboza, F. Junqueira, E. Bock, T. Leão, J. Dias, J. Dias, M. Pessoa, J. R. Souza, and D. dos Santos, 'Ventricular Assist Device in Health 4.0 Context', *IFIP Adv Inf Commun Technol*, vol. 577, pp. 347–354, 2020.

[6] K. Salaunkey, J. Parameshwar, K. Valchanov, and A. Vuylsteke, *Mechanical support for heart failure 2C04 3C00*, vol. 14, no. 3. 2013. doi: 10.1177/175114371301400309.

[7] A. I. Fiorelli, J. de Lima, O. Junior, H. B. Coelho, and D. Cristo, 'Mechanical circulatory support : why and when', vol. 87, no. 1, pp. 1–15, 2008.

[8] U. P. Jorde, K. D. Aaronson, S. S. Najjar, F. D. Pagani, C. Hayward, D. Zimpfer, T. Schlöglhofer, D. T. Pham, D. J. Goldstein, K. Leadley, M. J. Chow, M. C. Brown, and N. Uriel, 'Identification and Management of Pump Thrombus in the HeartWare Left Ventricular Assist Device System: A Novel Approach Using Log File Analysis', *JACC Heart Fail*, vol. 3, no. 11, pp. 849–856, 2015.

[9] F. Ortiz and T. Thenappan, 'Low Flow Alarm in a Patient With Left Ventricular Assist Device: What Went Wrong?', *Journal of the American College of Cardiology*, vol. 73, no. 9, p. 2194, 2019, doi: 10.1016/s0735-1097(19)32800-1.

[10] E. J. Molina, P. Shah, M. S. Kiernan, W. K. Cornwell, H. Copeland, K. Takeda, F. G. Fernandez, V. Badhwar, R. H. Habib, J. P. Jacobs, D. Koehl, J. K. Kirklin, F. D. Pagani, and J. A. Cowger, 'The Society of Thoracic Surgeons Intermacs 2020 Annual Report', *Annals of Thoracic Surgery*, vol. 111, no. 3, pp. 778–792, 2021.

[11] T. Gyoten, M. Morshuis, S. V. Rojas, M. A. Deutsch, R. Schramm, J. F. Gummert, and H. Fox, 'Identification of characteristics, risk factors, and predictors of recurrent LVAD thrombosis: conditions in HeartWare devices', *Journal of Artificial Organs*, vol. 24, no. 2, pp. 173–181, 2021, doi: 10.1007/s10047-020-01228-2.

[12] A. L. Meyer, C. Kuehn, J. Weidemann, D. Malehsa, C. Bara, S. Fischer, A. Haverich, and M. Strüber, 'Thrombus formation in a HeartMate II left ventricular assist device', *Journal of Thoracic and Cardiovascular Surgery*, vol. 135, no. 1, pp. 203–204, 2008, doi: 10.1016/j.jtcvs.2007.08.048.

[13] D. J. Goldstein, R. John, C. Salerno, S. Silvestry, and N. Moazami, 'Algorithm for the diagnosis and management of suspected pump thrombus', *Journal of Heart and Lung*

Transplantation, vol. 32, no. 7, pp. 667–670, 2013, doi: 10.1016/j.healun.2013.05.002.

[14] T. D. Rossing, *Shock and Vibration Handbook , 2nd ed.* , vol. 45, no. 7. 1977. doi: 10.1119/1.10796.

[15] S. Neto, S. Sobrinho, C. Costa, T. Leão, S. Senra, E. Bock, G. Santos, S. Souza, M. Silva, C. Frajuca, and M. Souza, 'Investigation of MEMS as accelerometer sensor in an Implantable Centrifugal Blood Pump prototype', *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 42, no. 9, pp. 1–10, 2020.

[16] T. Guo, T. Zhang, E. Lim, M. Lopez-Benitez, F. Ma, and L. Yu, 'A Review of Wavelet Analysis and Its Applications: Challenges and Opportunities', *IEEE Access*, vol. 10, pp. 58869–58903, 2022, doi: 10.1109/ACCESS.2022.3179517.

[17] G. M. Khan, 'Artificial neural network (ANNs)', *Studies in Computational Intelligence*, vol. 725, pp. 39–55, 2018, doi: 10.1007/978-3-319-67466-7_4.

[18] S. Biswal and G. R. Sabareesh, 'Design and development of a wind turbine test rig for condition monitoring studies', *2015 International Conference on Industrial Instrumentation and Control, ICIC 2015*, no. Icic, pp. 891–896, 2015, doi: 10.1109/IIC.2015.7150869.

[19] D. P. Kingma and J. L. Ba, 'Adam: A method for stochastic optimization', *3rd International Conference on Learning Representations, ICLR 2015 - Conference Track Proceedings*, pp. 1–15, 2015.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Thiago Santos was responsible for the research and algorithm creation and implementation.
- Oswaldo Martins was responsible for double-checking the results and paper review.
- Dennis Toufen and Eduardo Bock were responsible for supporting the algorithm's creation and paper review.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare.