Software-Assisted Optimisation of Linear Accelerator Energy Consumption

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Abstract

In the pursuit of environmental sustainability within healthcare, this study introduces a pioneering approach to optimise the energy consumption of linear accelerators using a software-based approach. Through a comprehensive analysis at the South West Wales Cancer Centre, the energy utilisation of various linac models was scrutinised, as well as stereotactic ablative body radiotherapy (SABR) and hypofractionated radiotherapy (HFRT) treatment methods. The findings reveal that SABR and HFRT treatments exhibit significantly lower energy consumption compared to conventional methods, indicating the potential for substantial energy savings. Furthermore, the newer Agility and Versa HD Elekta linacs had significantly decreased energy consumption compared to the older Precise linac demonstrating that replacement of linac technology can also lead to substantial energy savings. Further research and collaboration targeted at sustainability in radiotherapy can facilitate the optimisation of treatment delivery while maintaining a commitment to sustainability within radiotherapy.

1 Introduction

The UK's National Health Service (NHS) is at the forefront of integrating sustainability into healthcare delivery, aligning with global objectives. This aim is particularly pertinent in the context of linear accelerators (linacs), which, although being a fundamental method of treatment of cancer through radiotherapy, is a significant contributor to the NHS's carbon footprint.

The need to reduce the NHS's environmental impact is set by legislative requirements to deliver a healthcare service with a 'net-zero' carbon footprint by 2040 [1]. The impetus of this legally binding agreement arises from the NHS's carbon footprint being 4-5% of the UK's carbon footprint and 40% of the UK's public sector emissions and therefore a 'net-zero' NHS would significantly decrease national emissions [2].

Linacs are a pivotal technology in cancer treatment, not only being an advanced medical treatment but also as a focal point for energy consumption optimization. The operation of these machines is energy-intensive, with varying power demands depending on their operational states. As 2040 approaches, by which the NHS aims to operationalise its 'net-zero' commitment, the need to interrogate the energy usage of linacs has become increasingly pressing.

Recognising the dual necessity of maintaining clinical efficiency while enhancing energy efficiency, this study introduces an innovative software-based approach to monitor and optimize the power usage of linacs. Doing so addresses the critical gap in the management of healthcare technologies. This initiative is not only a technological challenge but instead represents a larger paradigm shift towards a greener, more sustainable healthcare model that other healthcare providers globally can implement.

2 Materials and Methods

The core of this research is the Linac Energy and Power Analysis Software (LEPAS), an innovative desktop application designed to utilise data analytics in pursuit of optimising the energy efficiency of linacs. LEPAS was engineered with a Python-based graphical user interface using a cross-platform Qt toolkit that provides a user-friendly point of interaction. Through the system, energy consumption data was captured across various operational linac states such as standby and treating states – each having unique energy profiles and patterns.

Data acquisition was facilitated by the Fluke 1738 3-Power Logger, an instrument selected for its precision and reliability. The Fluke Logger was configured to capture energy usage at one-second intervals, providing a high-resolution data stream, critical for assessing the dynamics of linac energy consumption as time passed. This granular data capture allowed for highly detailed analysis, enabling the identification of peak energy consumption periods as well as opportunities for energy-saving interventions [3].

Treatment data was extracted from the oncology information system Mosaiq using Crystal Reports exports. The data retrieved from Mosaiq consisted of multiple variables, including but not limited to, treatment techniques, beam energies and numbers of fractions. Additionally, linac data was procured from linac log files which were decrypted by Elekta. The linac-specific data yielded insights into variables such as operational states, gantry angles, and monitor units among others.

The LEPAS system facilitated the synchronisation of data streams from energy consumption, treatment details and linac operations. A rigorous time calibration process to ensure the integrity and accuracy of the synchronisation process. Subsequent to synchronisation, LEPAS provided functionalities for data filtration predicated on various treatment and linac parameters which enabled the generation of a filtered dataset. LEPAS' analytical capabilities were leveraged to interrogate the filtered dataset. This process using LEPAS allowed the simple analysis of different treatment options, machines and other variables.

The data utilised within the scope of this paper was sourced from the South West Wales Cancer Centre (SWWCC). At the time of data collection, the centre was equipped with three Elekta linac models: Agility, Versa HD and a Precise model fitted with an Agility head. An analytical comparison of energy consumption across these models was conducted to determine their relative energy efficiencies.

In addition to conventional external beam radiotherapy, the centre also regularly performed stereotactic ablative body Radiotherapy (SABR) lung treatments and hypofractionated radiotherapy (HFRT) prostate treatments. An analytical comparison of energy consumption was performed between SABR and conventional lung treatments, as well as between HFRT and conventional prostate treatments. The energy consumption of both SABR lung treatments and HFRT prostate treatments were compared to their conventional counterparts.

For the purposes of the comparisons, only Volumetric Modulated Arc Therapy (VMAT) treatments with an energy of 6 MV were considered. Active energy consumption was sampled at one-second intervals to ensure high-resolution data capture.

3 Results

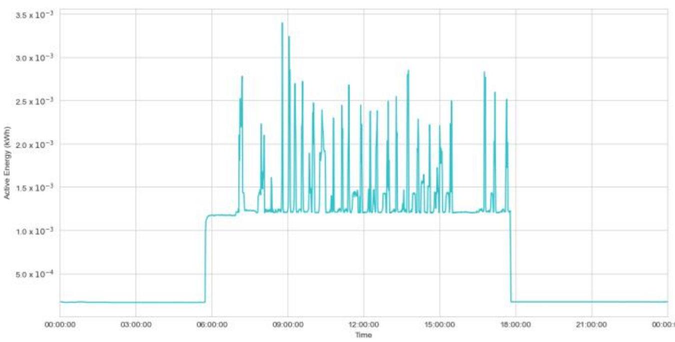

Fig. 1: Line graph displaying the active energy during a treatment day at the SWWCC. Times of interest include linac engineers' run-up at 07:00, radiographers' QC at 07:50, DIBH treatment at 10:15 and SGRT staff training at 15:30.

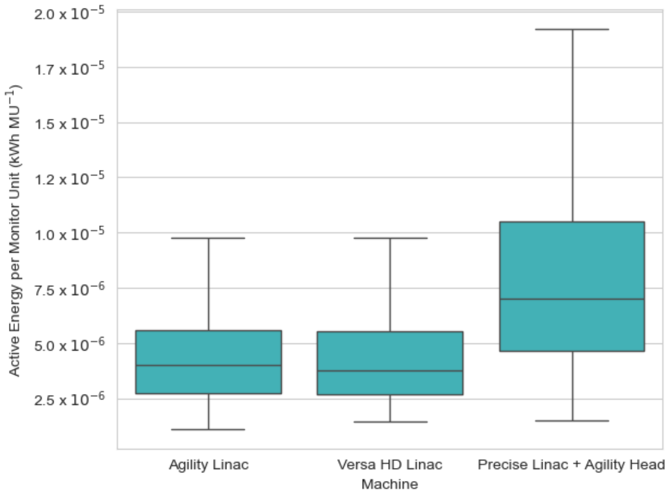

Fig. 2: Box-and-whisker plot displaying the distribution of active energy per monitor unit for three different types of Elekta linacs used at SWWCC.

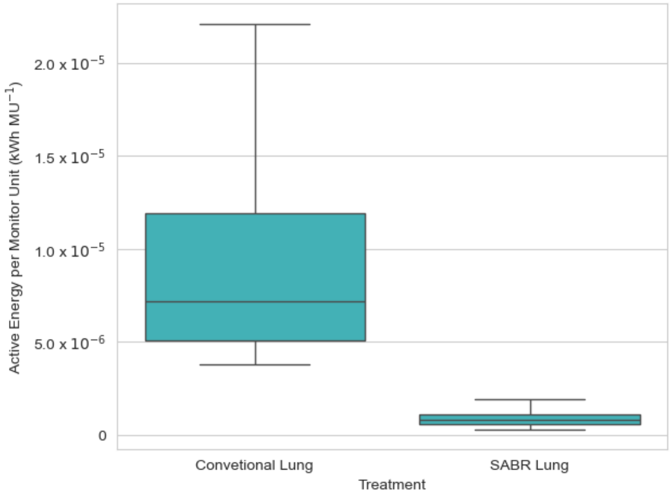

Fig. 3: Box-and-whisker plot displaying the distribution of active energy per monitor unit for conventional lung and SABR lung treatments.

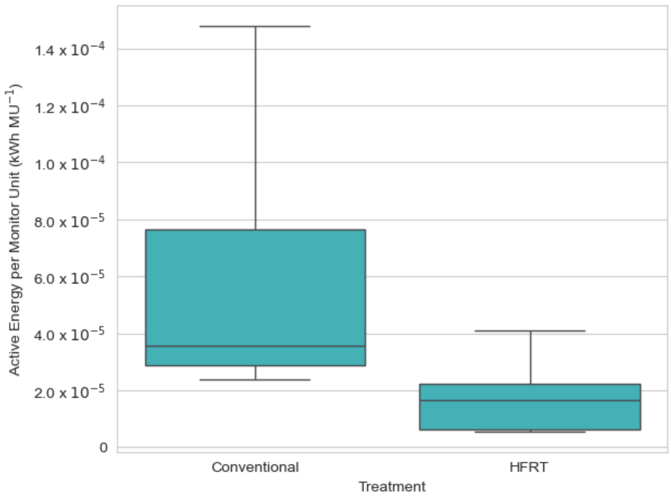

Fig. 4: Box-and-whisker plot displaying the distribution of active energy per monitor unit for conventional prostate and HFRT prostate treatments.

4 Discussion

The analysis of energy consumption during a typical treatment day (Fig. 1) illustrated energy demands during deep inspiration breath-hold (DIBH) treatment techniques was larger than conventional treatments, suggesting that patient-specific treatment adaptations could yield energy savings assuming that clinical effectiveness is not affected. This is likely since between breaths, the surface-guided radiotherapy (SGRT) system forces the beam to pause until the next breath-hold which consumes more energy than if the beam was simply initiated and terminated [4].

Examining the energy consumption patterns among linac models reveals that the newer iterations, such as the Agility and Versa HD, exhibit much more favourable energy consumption profiles than the Precise. The improvements in energy consumption in newer models are likely due to technological improvements, and newer components.

SABR treatments for lungs demonstrated a substantial reduction in active energy consumption per monitor unit in comparison to conventional lung treatments. This observation could be attributed to the omission of a flattening filter in SABR treatments. The inclusion of a flattening filter in conventional treatments necessitates increased beam energy to achieve the desired therapeutic dose, as the flattening filter's presence attenuates the beam [5].

Similarly, HFRT treatments for prostates also demonstrated a reduction in active energy consumption per monitor unit per treatment course in comparison to conventional prostate treatments. The increased efficiency could be due to the reduced frequency of initiation and termination sequences when fewer fractions are used [6]. HFRT treatments not only align with sustainable healthcare practices by reducing the energy expenditure for treatments but also reduce emissions from patient travel. This, in turn, significantly enhances patient convenience and can make radiotherapy treatments more available to patients by increasing machine availability [7].

Despite the clear advantages that HFRT treatments demonstrate, careful implementation is necessary to ensure treatment efficacy is not compromised by the reduction in the number of fractions [8]. Brunt et al. (2020) found that HFRT for breast patients had an equal efficacy as conventional treatments [9]. The guiding principle should be to administer a minimal number of fractions while maintaining treatment effectiveness and patient safety.

These outcomes highlight the potential for software tools like LEPAS to facilitate more nuanced areas concerning medical technologies. Such tools can provide healthcare administrators and policymakers with actionable insights, enabling the development and innovation of departments to reduce the total energy consumption within departments.

The aggregation of datasets from a multitude of treatment centres presents a unique opportunity to broaden the comparative framework to include an array of treatment methodologies. It would also facilitate the evaluation of emergent advanced technologies such as magnetic resonance linacs (MR-linacs) and proton linacs. Upon full development of LEPAS, access to the private repository can be extended to other departments. This collaboration would lead to a robust database that is reflective of the diverse array of treatments that centres offer so the radiotherapy community can optimise treatment delivery while maintaining a commitment to environmental sustainability within radiotherapy.

5 Conclusion

In conclusion, LEPAS represents an instrumental advancement for the energy optimisation of linacs. This study has provided empirical evidence of its potential to significantly inform energy management strategies in radiotherapy thereby supporting the NHS in its net-zero aim. As LEPAS and other energy consumption-focused software evolve, they will become essential components of the sustainable healthcare infrastructure, facilitating not only immediate operational efficiencies but also long-term strategic planning for environmental sustainability in healthcare both within the UK and internationally.

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7 Conflicts of Interest

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8 References

[1] NHS England. (2022). Delivering a net zero NHS. Retrieved from: https://www.england.nhs.uk/greenernhs/a-net-zero-nhs

[2] British Medical Association. (2023). More support needed to help the NHS reach net zero. Retrieved from: https://www.bma.org.uk/news-and-opinion/more-support-needed-to-help-the-nhs-reach-net-zero

[3] Chuter, R., Stanford-Edwards, C., Cummings, J., Taylor, C., Lowe, G., Holden, E., Razak, R., Glassborow, E., Herbert, S., Reggian, G., Mee, T., Lichter, K., & Aznar, M. (2023). Towards estimating the carbon footprint of external beam radiotherapy. Physica Medica, 112(102652). DOI: 10.1016/j.ejmp.2023.102652

[4] Chen, L., Bai, S., Li, G., Li, Z., Xiao, Q., Bai, L., Li, C., Xian, L, Hu, Z., Dai, G., & Wang, G. (2020). Accuracy of real-time respiratory motion tracking and time delay of gating radiotherapy based on optical surface

imaging technique. Radiation Oncology, 15(170). DOI: 10.1186/s13014-020-01611-6

[5] Kragl, G., Baier, F., Lutz, S., Albrich, D., Dalaryd, M., Kroupa, B., Wiezorek, T., Knöös, T., & Georg, D. (2011). Flattening filter free beams in SBRT and IMRT: dosimetric assessment of peripheral doses. Zeitschrift für Medizinische Physik, 21(2), pp. 91–101. https://doi.org/10.1016/j.zemedi.2010.07.003

[6] Salas-Salas, B. G., Domínguez-Nuez, D. J., Cabrera, R., Ferrera-Alayón, L., Lloret, M., & Lara, P. C. (2020). Hypofractionation vs. conventional radiotherapy fractionation in the conservative treatment of T1 glottic cancer: a prospective cohort study. Clinical & Translational Oncology, 22(1), pp. 151–157. DOI: 10.1007/s12094-019-02118-7

[7] Swanson, W., Samba, R., Lavelle, M., Elzawawy, A., Sajo, E., Ngwa, W., & Incrocci, L. (2021). Practical Guidelines on Implementing Hypofractionated Radiotherapy for Prostate Cancer in Africa. Frontiers in Oncology, 11(725103). DOI: 10.3389/fonc.2021.725103

[8] Wong, K., Delaney, G., & Barton, M. (2016). Evidence-based optimal number of radiotherapy fractions for cancer: A useful tool to estimate radiotherapy demand. Radiotherapy and Oncology, 119(1), pp. 145–149. DOI: 10.1016/j.radonc.2015.12.001

[9] Brunt, A., Haviland, J., Wheatley, D., Sydenham, M., Alhasso, A., Bloomfield, D., Chan, C., Churn, M., Cleator, S., Coles, C., Goodman, A., Harnett, A., Hopwood, P., Kirby, A., Kirwan, C., Morris, C., Nabi, Z., Sawyer, E., Somaiah, N., Stones, L., Syndikus, I., Bliss, J., Yarnnold, J. & FAST-Forward Trial Management Group (2020). Hypofractionated breast radiotherapy for 1 week versus 3 weeks (FAST-Forward): 5-year efficacy and late normal tissue effects results from a multicentre, non-inferiority, randomised, phase 3 trial. The Lancet, 395(10237), pp. 1613–1626. DOI: 10.1016/S0140-6736(20)30932-6