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An analytical framework for enhancing cancer care efficiency in North London hospitals

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ABSTRACT

We use mathematical and statistical techniques on operational data to examine the impact of different factors on the time to treatment for cancer patients in North London hospitals. Understanding the factors which prolong the time between referral and treatment starting for cancer patients on pathways which cross healthcare providers is imperative to improved patient care. We analyse three tumour pathways which involve transfer of patients between hospitals: sarcoma, urological, and head and neck cancers. Several factors impact on the time to first treatment including demographic characteristics, day of the week first seen and method of communicating the cancer diagnosis. In particular, we found that head and neck patients from lower socioeconomic areas were more likely to have longer times from referral to treatment. Patients with sarcoma who were first seen on a Sunday are more likely to breach the 28-day faster diagnosis standard. This analysis is an important first step in highlighting where focus is needed to improve cancer care pathways. Understanding and mitigating the factors influencing the length of time between referral and treatment could enhance the efficiency of cancer care pathways and, consequently, patient outcomes.

1. Introduction

There is an accumulating body of evidence linking delays in cancer treatment initiation to adverse clinical outcomes and compromised survival rates [1–6]. These delays can be due to factors such as inefficient processes, resource limitations, and administrative bottlenecks within healthcare systems [7,8]. Understanding impediments in the pathway and devising practical solutions to expedite the pathway from referral to treatment is crucial to improve patient care quality and mitigate the adverse effects of delayed interventions.

In recent years, data collection within health services has dramatically increased with the development and adoption of digital technologies alongside a rapid increase in data analysis and machine learning methods. Data analysis methods can help healthcare providers understand factors which may impact on patient cancer diagnosis and survival rates [9], determine optimal treatment strategies [10], identify and reduce healthcare access disparities [11], and model the most effective response to healthcare resourcing [12]. Using data that is collected for

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operational purposes can help highlight bottlenecks in care systems and detect care centres which are performing below requirements [13]. Visualisation methods such as Sankey flow diagrams can provide healthcare services an efficient means by which to identify bottlenecks and areas of interest and to help focus interventions [14]. By visualising and treating healthcare systems as a whole, rather than individual parts, operational managers are able to have better oversight [12]. One area where this is particularly critical is when patients are transferred between hospitals [15].

The occurrence of delays in the referral-to-treatment timeline for cancer patients, particularly when transfers between different healthcare institutions are involved, can be attributed to several factors [16–18]. The complexity of coordinating care across multiple facilities, each with distinct administrative processes, clinical protocols, and resource availability, can lead to logistical challenges and inefficiencies [17,19]. Moreover, the necessity to synchronize scheduling, obtain and transfer medical records, and align treatment strategies can introduce additional layers of complexity that contribute to prolonged care pathways. Clinicians and managers have limited oversight of bottlenecks in the pathway and the relative use, demand, and capacity of diagnostic resources, especially for patients cared for across multiple hospitals [15,20].

The UK's National Health Service (NHS) Faster Diagnosis Standard (FDS) was introduced to ensure patients who are referred for investigation of suspected cancer receive a timely diagnosis [21–23]. The standard aims to ensure that patients will be given a diagnosis or have cancer ruled out within 28 days of urgent referral by their general practitioner (GP) for suspected cancer. In addition, waiting times standards, as of 2024, state that patients should wait a maximum of 62 days from an urgent GP referral to first definitive treatment of cancer ('treatment start date'; TSD) [24]. At the time of this study, there was also a 'two week wait' (2WW) target which aimed for patients with suspected cancer to see a specialist within 14 days of urgent GP referral, which has subsequently been retired [24–26].

In this paper, we aim to identify factors that are associated with prolonged time between referral and TSD for cancer patients, particularly focusing on pathways which cross providers. We have chosen to analyse three tumour pathways which involve transfer of patients between hospitals within our healthcare system: sarcoma, urological, and head and neck cancers. Timely treatment of sarcoma poses specific challenges stemming from its rarity, diverse subtypes, variation of primary anatomical sites, and complex diagnostic and therapeutic pathways. The rarity of sarcomas necessitates specialized expertise that is commissioned in a limited number of centres, with a recent service specification mandating all patients with a suspected sarcoma or confirmed sarcoma be referred to a specialist multidisciplinary team [27]. Additionally, the complexity of staging, biopsy, and surgical planning in sarcoma cases demands careful coordination among multidisciplinary teams, potentially causing delays in treatment initiation [28–30]. Urological cancers encompass a wide range of tumours, including prostate, bladder, and kidney cancers. Each of these has their own distinct diagnostic and treatment pathways which may complicate the diagnosis and treatment planning, causing delays in patient treatment [31,32]. Head and neck cancers present their own challenges due to the intricate anatomy of the region, the diversity of tumour types, and the complexities of treatment modalities. The complex anatomical structures within the head and neck region can complicate both diagnosis and treatment planning, potentially leading to delays in definitive management [33–36]. There are also studies which suggest that restructuring the head and neck pathway may result in better patient outcomes, without further increasing cost [37,38].

Here we report on the development of data analysis and visualisation methods using cancer datasets from North London NHS trusts to find factors which influence pathway length from referral to treatment. There is not currently a single platform within or between hospitals, even within single NHS trust networks, that can track and visualise the patient journey. This analysis therefore provides a unique insight into possible bottlenecks and may inform future targeted interventions to optimise care pathways, streamline resource allocation, and enhance care coordination.

2. Methods

2.1. Data

Sarcoma, head and neck, and urological cancers were selected for this analysis as the patient cohorts are typically cared for within implicitly complex pathways involving multiple hospitals to receive specialist care.

Pseudonymised patient-level data were used covering patient demographics, diagnoses, appointment times and appointment locations. Data was provided by and extracted from NHS Trusts across North Central and North-East London, including the Royal Free London, Barts Health, and the Royal National Orthopaedic Hospital. The organisation codes of the Trusts used in this study have been anonymised in the analysis, so each site has been relabelled as a six-character code (e.g., '93BAE') when appearing in figures and the results section.

All the data collected were part of the Cancer Outcomes and Services Data set [39], sourced from either cancer management information systems (e.g., Somerset, Infoflex) or hospital electronic patient records.

Patient data was extracted for those with either.

a) urgent suspected cancer referrals, who had a referral date on or after May 1, 2019, and their first appointment on or after July 1, 2019 up to February 28, 2023, or
b) first treatment date, as a proxy for date of diagnosis, on or after July 1, 2019 and up to February 28, 2023 with a sarcoma, head and neck, or urological diagnosis (selected using International Classification of Diseases [ICD]-10 codes; Appendix A).

Note that if an urgent referral is made for a suspected recurrence of cancer, the FDS would apply (Group A). If the patient is subsequently diagnosed as a recurrence, it would be recorded as a "subsequent treatment", and so the patient would not be included in Group B as they would not have a first treatment date within the time periods listed above.

To allow patient pathways to be compared across the whole period of the data extract, the number of days between referral and the following key pathway steps were calculated.

a) First appointment following 2WW referral ("First Seen"; if available)
b) FDS appointment where patient is told they have cancer, or cancer is excluded
c) Decision To Treat (DTT) where patient agrees a treatment plan (for patients with cancer)
d) Treatment Start (for patients with cancer), which can be either the first intervention intended to remove, debulk or shrink the tumour, or palliative intervention/care was provided where no definitive anti-cancer treatment is planned.

2.2. Analytical model

In Section 3.1, we use Sankey diagrams [14] to effectively visualise the flow of patients from referral to treatment. These diagrams enable us to highlight delays, inefficiencies, and disparities in the cancer care pathways being analysed. In each diagram, the width of the lines is proportional to the number of patients at each stage for each cancer being investigated. The colour scheme indicates the average time taken for patients to move between stages of their pathway. By comparing these timings to the targets set by the NHS, we are able to efficiently highlight steps of each pathway which are underperforming, allowing a focused analysis of factors which are impacting on timely patient

diagnosis and treatment.

In Section 3.2, we use contingency table analysis and Pearson's chi-squared test of independence of variables [40] to analyse similarities and differences between patients who meet, or do not meet, the target timings for diagnosis and treatment start dates. Patients are split into categories based on properties outlined in Section 2.3 to identify the factors which have the greatest impact on whether a patient is likely to meet their target pathway timings. Expected values are calculated from contingency tables for each factor based on the total patients in each group [41]. The scale of the effect of each factor on whether a patient breaches targets was calculated as the difference between the expected values and actual observed values as a percentage of the expected values [47]. This analysis method can help identify factors affecting treatment delays and guide targeted interventions.

2.3. Analysis

The datasets were linked via anonymous patient identifiers and duplicate entries removed.

Suspected cancer referral guidance from the National Institute for Health and Care Excellence is designed to encourage early cancer diagnosis and most patients referred via this route are likely to not have cancer and will have a different diagnostic route according to tumour site [42]. In addition, different cancers will have different prevalence rates. For example, sarcoma urgent referrals had a conversion rate of 33 per 100,000 in 2022/23 [43]. Our analysis has taken this into account, and we reviewed each tumour site in two sub-cohorts: (a) all patients who were referred on the 2WW urgent care pathway, and (b) focused analysis of patients with cancer diagnosis to allow for the differences in clinical pathway following confirmation of cancer.

Using the number of days between each step in the patient pathway, we created Sankey diagrams showing patient flow between hospital sites over the course of their diagnosis and treatment as well as the average time taken between each step in the pathway (Section 3.1). Showing this flow for all referred patients and patients who were diagnosed with cancer allows a clear visualisation of where bottlenecks are occurring for each cancer type.

Patients were classified based on whether they ended their diagnosis pathway in more than 28 days ('breached') or 28 days or fewer ('unbreached'). We then examined the properties of the two groups to determine any areas where they differed. The properties examined were.

- Whether the patient had previously breached the 2WW target or also breached the 62-day treatment start target.
- Age group (0–18, 19–29, 30–49, 50–79, 80+).
- Index of multiple deprivation (IMD) deciles, where IMD decile 1 is the most deprived and IMD decile 10 the least deprived.
- Site where the patient was first seen (first point of contact).
- Site where the patient was listed at the end of their diagnosis pathway.
- How many different hospital sites (specified by trust organisation code) the patient attended during diagnosis and treatment (excluding "not listed").
- Diagnosis (cancer/not cancer/excluded/interval scanning).
- Day of the week the patient was referred and first seen.
- Method of communication at the end of the diagnosis pathway.

For each property, we calculated a contingency table and used a Pearson's chi-squared test of independence of variables [40] to determine whether the breached and unbreached patient groups showed similar distributions across the categories. That is, for a given property (e.g., age group) and total number of patients, does the distribution of breached patients match what is expected from the distribution of unbreached patients? The null hypothesis is that the property being examined has no correlation with whether the patient is breached or unbreached at the end of the FDS pathway. We use $p < 0.05$ to indicate that the null hypothesis may be rejected, and the property has a correlation with whether patients breach the 28-day FDS. We then examine the individual categories within properties; for example, if the distribution of age groups overall showed a statistically significant difference, we show how each age group individually compares for breached and unbreached patients. All results shown with $p < 0.05$ have a statistical power >0.9 unless stated otherwise. We emphasise that correlation in this study does not necessarily imply causation and any results showing a relationship between properties or categories and patient breaches needs further investigation into the root cause of that relationship.

3. Results

Completeness of the data extracts varied due to the data collection process. Hospitals provided what they were able to confidently extract from their systems. Data relating to 2WW referrals were mostly complete in response to regional and national focus at the time, whereas data quality is poorer for patients referred via a different route. This may affect different cancer results more than others, for example sarcoma patients are less likely to be diagnosed following 2WW referrals and so are more likely to have incomplete data. Overall, for patients with a diagnosis of cancer, 46.2 % were referred on the urgent referral pathway (suspected cancer and exhibited (non-cancer) breast symptoms). For head and neck cancers, urological cancers and sarcoma respectively, 41.6 %, 50.9 %, and 23.2 % of cancer patients were referred on the urgent referral pathway. We have more than 90 % completeness for urgent 2WW referral data, including date first seen and FDS end date.

3.1. Patient flow between pathway stages and different hospitals to understand bottlenecks

In this section, we present Sankey diagrams showing the movement of patients between hospital sites for each stage of their diagnosis pathway: First Seen, FDS, DTT, Treatment Start. In the diagrams (Figs. 1–3, Appendix B), the height of bars represents patient volume, and the coloured 'ribbons' show the mean number of days between steps in the pathway.

Fig. 1 shows the flow of patients referred on the urgent referral pathway with suspected sarcoma. Most patients are referred to and treated at one particular site (anonymised code 6Z9R7), with smaller patient numbers being referred to and treated at a number of other sites. Approximately 2 % of patients are seen at more than one site across their total pathway (shown by the linking coloured lines in Fig. 1). Figs. 2 and 3 similarly show the patient flow for suspected head and neck and urological cancers. For head and neck and urological cancer referrals, patients are referred into more initial sites than sarcoma. 0.6 % of head and neck patients are seen at more than one site across their total pathway. For urological cancers, 5 % of patients are seen at more than one site.

Figs. 1–3 show that, for patients with suspected cancer referrals, the average number of days from referral to First Seen is consistent between cancer types. The median time between referral and First Seen (excluding patients where the number of days was not calculable) was 10 days for sarcoma, 8 days for head and neck, and 9 days for urological cancers, with 75th percentiles of 13, 12 and 13 days respectively, suggesting that at least 75 % of patients were meeting the target two weeks for a first appointment. The median time between First Seen and FDS show wider variation, with median 14, 5 and 14 days and 75th percentile 26, 14 and 30 days for sarcoma, head and neck, and urological cancers respectively. Overall, we found that 38 % of referred sarcoma patients, 20 % of referred head and neck patients, and 43 % of referred urological patients breached the 28 day FDS.

We repeated this analysis for those patients selected as having a cancer diagnosis, irrespective of referral route. The Sankey diagrams may be found in Appendix B. The median times are consistent with those for all cancer referrals, but the proportion of patients seen at multiple

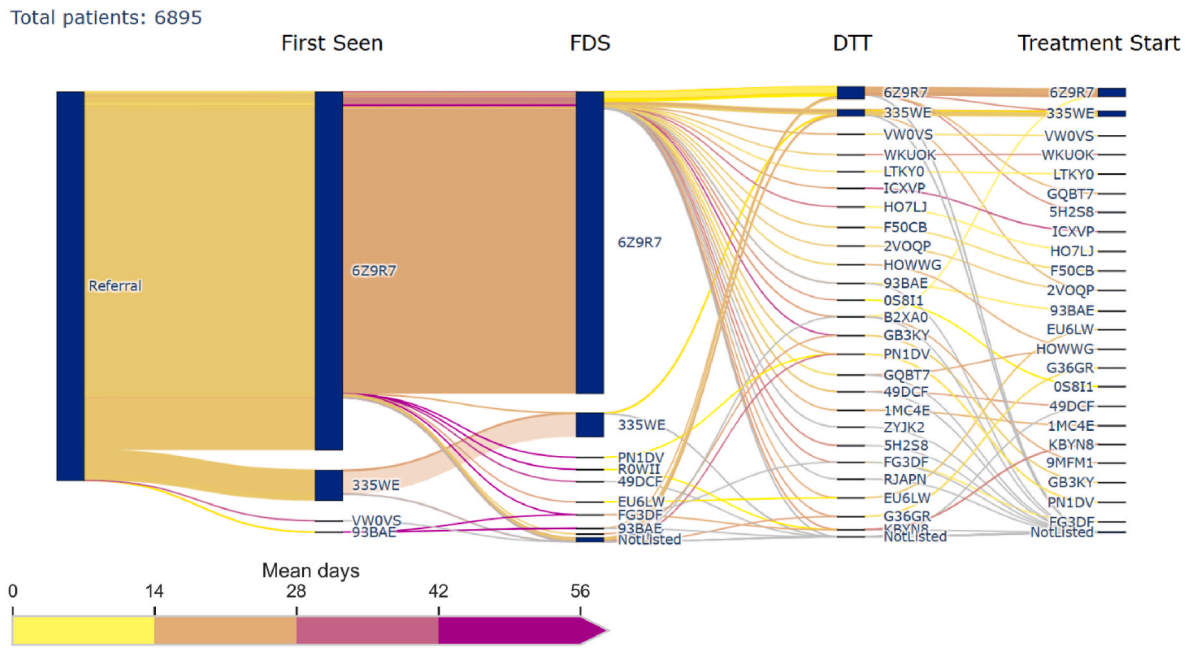

Fig. 1. Sankey diagram of all patients referred onto the sarcoma pathway. The diagram shows the number of patients (shown by the height of the blue boxes) seen at each site, for each stage of the diagnosis pathway: first appointment following 2WW referral ("first seen"); FDS appointment at which cancer may be excluded and the patient leaves the pathway; decision to treat (DTT); and treatment start date. The organisations used in this study have been anonymised to six-character codes in the labels. Coloured ribbons show the number of patients between each pathway step. The colouring shows the average number of days taken between pathway steps.

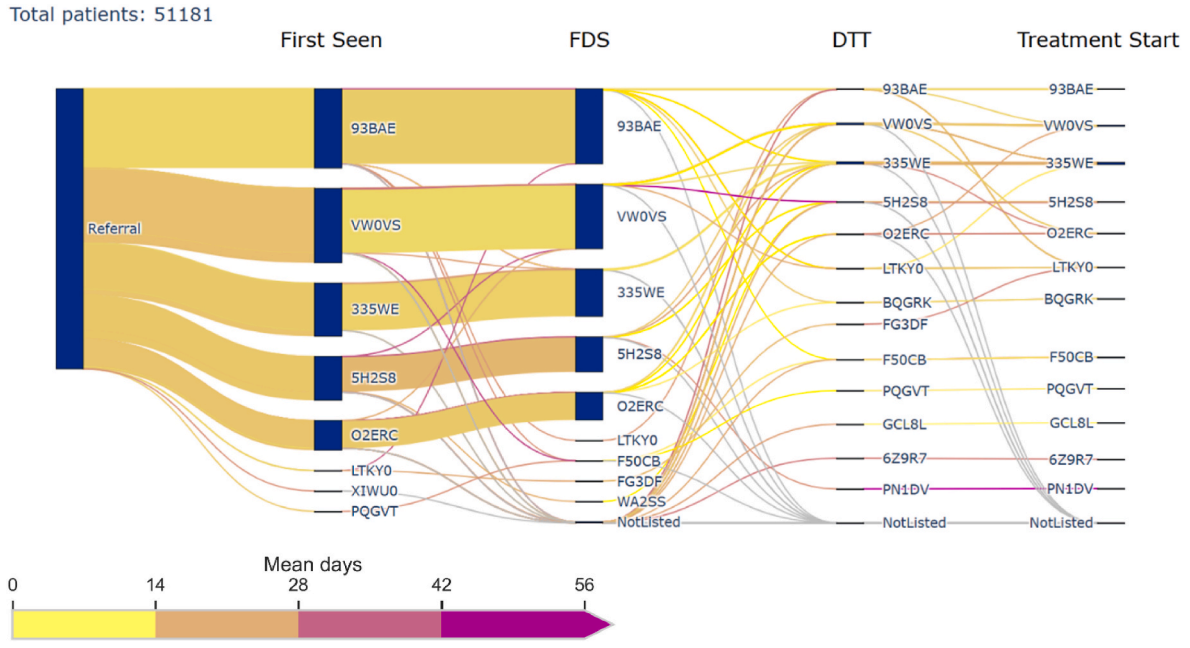

Fig. 2. Sankey diagram of all patients referred onto the head and neck pathway. As in Fig. 1, coloured ribbons show the number of patients between each pathway step and average number of days taken between pathway steps. The organisations used in this study have been anonymised to six character labels.

sites increases to 43 %, 29 %, and 29 % for sarcoma, head and neck, and urological cancers respectively.

For patients with a cancer diagnosis, we find that the median time from referral to FDS is longer than 28 days: 35 days for sarcoma, 34 days for head and neck cancers, and 42 days for urological cancers, with 75th percentiles of 48, 50 and 60 days respectively.

3.2. Further analysis of patient, operational and service design factors contributing to pathway delays

In this subsection, we further examine the factors which correlate with breaching of the 28 day FDS. We note that any correlations do not necessarily imply causation but can nevertheless provide insights into factors which may identify whether a patient is more, or less, likely to breach the 28 day FDS.

For properties for which we reject the null hypothesis (that the property being examined has no correlation with whether the patient is

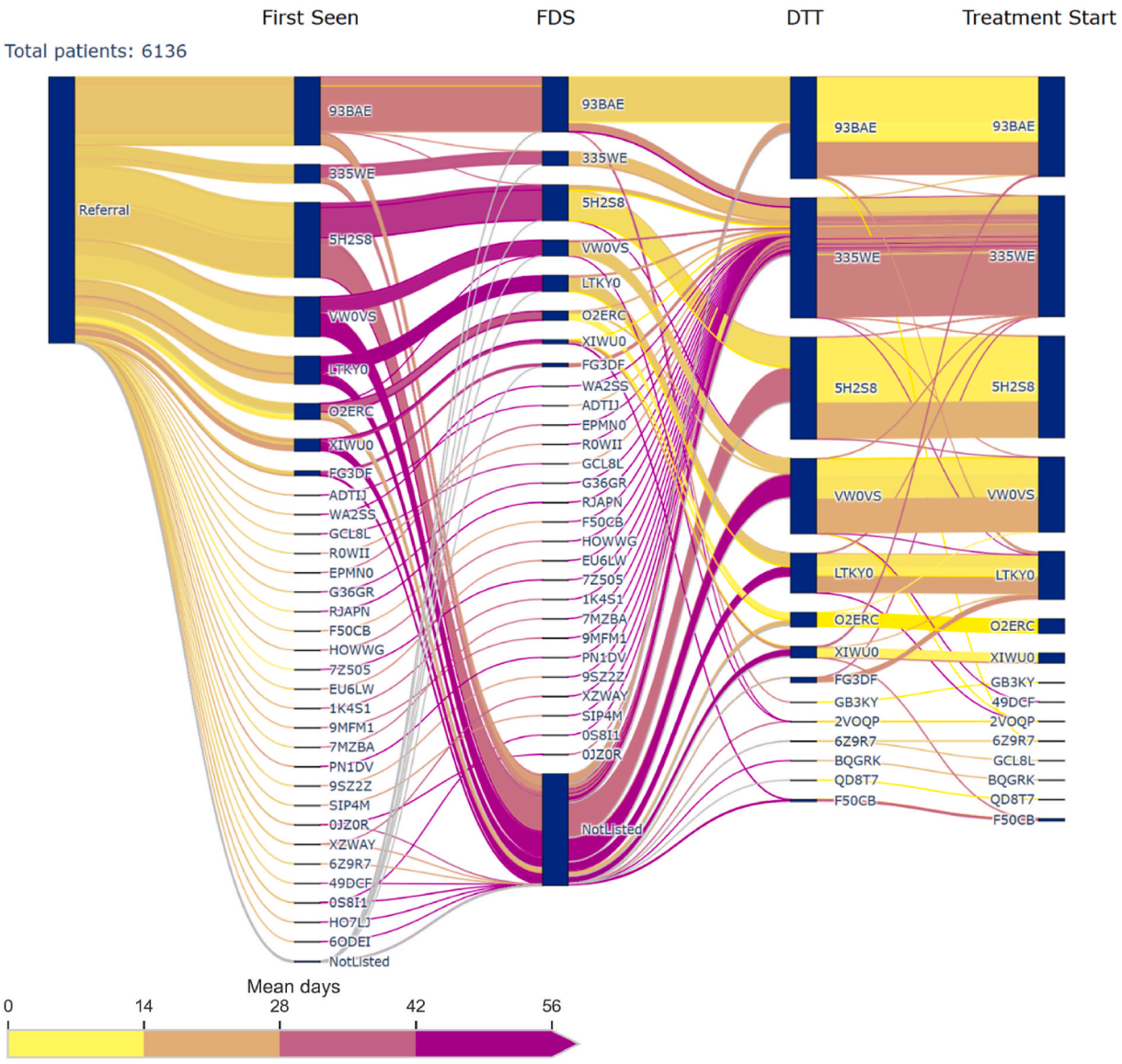

Fig. 3. Sankey diagram of all patients referred onto the urological pathway. As in Fig. 1, coloured ribbons show the number of patients between each pathway step and average number of days taken between pathway steps. The organisations used in this study have been anonymised to six character labels.

breached or unbreached at the end of the FDS pathway), we examine the scale of the effect of each variable on whether a patient breaches the 28-day FDS. This effect was calculated as the difference between the expected values and actual observed values as a percentage of the expected values [44]. I.e., in a sample of patients, if there was no correlation between a property and breaching the 28 day FDS, how many of those patients would we expect to be in each category and breached/unbreached and how much larger or smaller are the actual numbers compared to these expected values?

Figs. 4–6 show the effect of a variable on whether different patients are likely to be in breach of the 28-day FDS. The following subsections discuss this for each cancer pathway in turn. All results shown with $p < 0.05$ have a statistical power >0.9 unless stated otherwise. We do not show the effect of properties if they return $p > 0.05$ and are therefore not correlated with breaching the 28-day FDS. As we are simply looking at correlations in this analysis, any results showing a relationship between properties and patient breaches will need further investigation into the root cause of that relationship.

3.2.1. Sarcoma

Fig. 4 shows the effect of different variables for all patients on a sarcoma referral pathway (N = 6895). For example, the 'method of communication' variable showed a difference between breached patients and unbreached patients; the fractions of patients receiving each communication method was different at a statistically significant level ($p < 0.001$). For each category, the x-axis in Fig. 4 shows in percentage how much more likely (or for negative numbers, how much less likely) patients are to be in breach (red points) or not (gold points). For example, sarcoma patients were 50 % (1.5 times) more likely to have breached the 28-day FDS if the method of communication was a letter, and 100 % (2 times) more likely to not breach the 28-day FDS if the method of communication was a telephone call.

Patients referred with suspected sarcoma are more likely to breach the 28-day FDS if.

- The final method of communication is a letter ($p < 0.001$)
- The diagnosis is cancer ($p < 0.001$)
- The day of the week they were first seen was a Sunday ($p = 0.035$).

The lower figure in Fig. 4 shows a similar diagram, but only showing the sub-cohort of patients with a new sarcoma diagnosis (N = 517). Due to lower numbers of patients, we are unable to calculate a Pearson's chi-

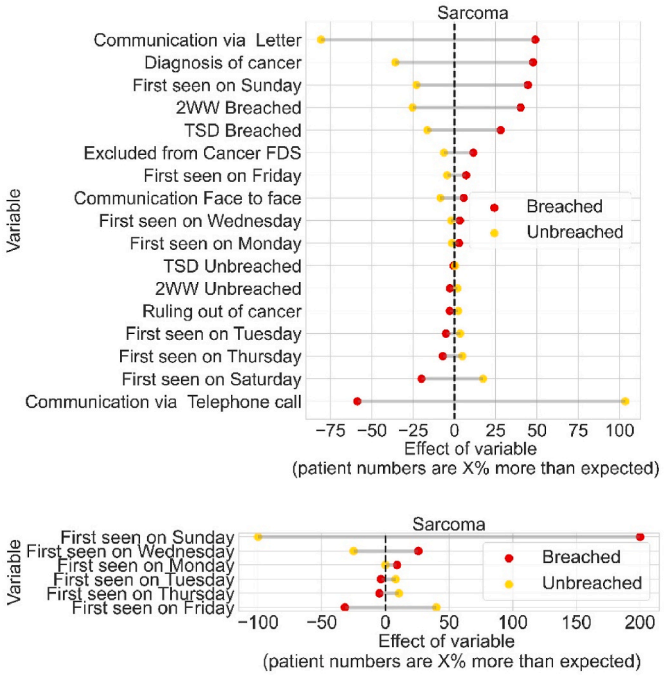

Fig. 4. The effect of different variables on whether a patient is more or less likely to breach the 28-day FDS. All results shown have $p < 0.05$. For each variable, the red points show how much more likely (or for negative numbers, less likely) patients are to breach the 28-day FDS. Gold points show how much more (or less) likely patients are to not breach the 28-day FDS. Top: All suspected sarcoma patients (statistical power for the TSD breach data = 0.58). Bottom: sarcoma diagnosed patients (statistical power = 0.32).

squared statistic for the communication method. We find a significant difference between breached and unbreached patients for the day of the week on which a patient is first seen, although the statistical power is only 0.32. Having a first appointment on a Sunday is 200 % more likely to be associated with taking longer to receive a diagnosis.

Although this correlation is not necessarily indicative of a direct effect, it is potentially informative that patients are most likely to breach the FDS if they have their first appointment on Sundays (although this applies to less than 1 % of patients). Conversely, they are least likely to breach if their first appointment falls on a Friday. Sarcoma multidisciplinary team (MDT) meetings in the major Trust examined here (anonymised code 6Z9R7) are typically held on Fridays, suggesting there may be an influence of the timings between the first appointment and the MDT on whether a patient breaches the FDS target or not.

3.2.2. Head and neck

Fig. 5 shows the effect of a variable on whether a patient is likely to be in breach of the 28-day FDS for patients on a head and neck cancers referral pathway (N = 51,181).

Patients referred with suspected head and neck cancers are more likely to breach the 28-day FDS if.

- They had care from two sites or more ($p < 0.001$)
- They took longer than two weeks to have their first appointment ($p < 0.001$)
- The final method of communication is an email ($p < 0.001$).

Additionally, patients who breached the 28-day FDS are likely to go on to breach the 62-day referral to treatment standard. Patients are most likely to breach the FDS if they have their first appointment on a Tuesday, Friday, or Sunday; they are least likely to breach if their first appointment falls on a Monday or a Thursday. MDTs for head and neck cancers are typically held on a Wednesday.

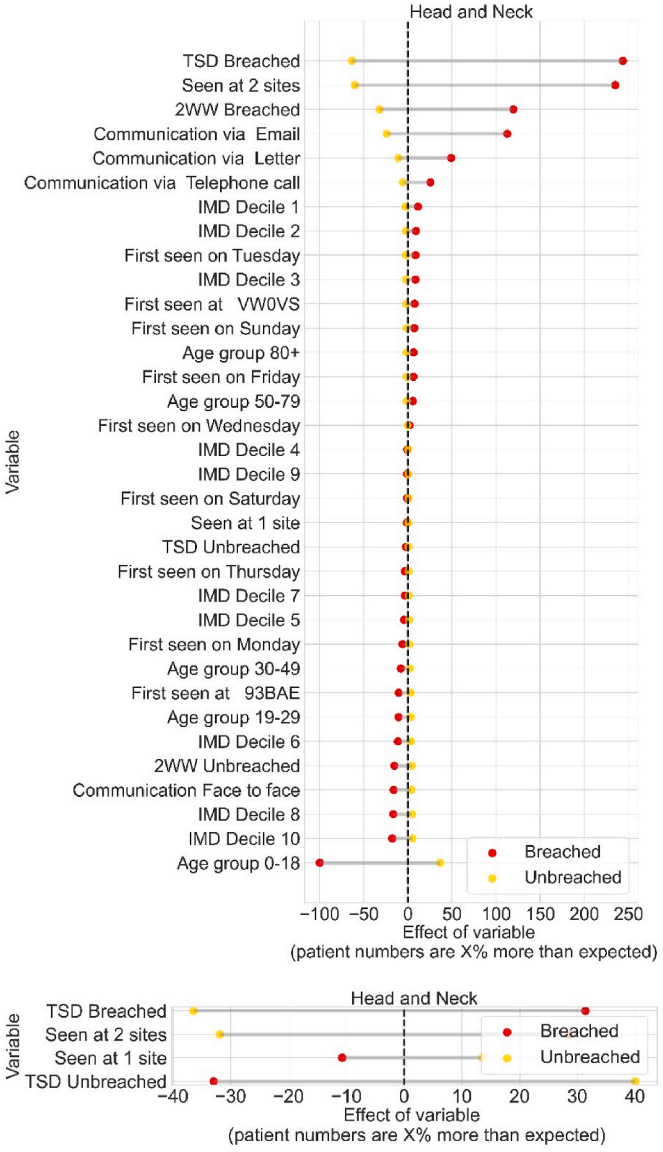

Fig. 5. The effect of different variables on whether a patient is more or less likely to breach the 28-day FDS. All results shown have $p < 0.05$. Top: all suspected head and neck patients (statistical power for the age group data = 0.78, for the IMD data = 0.58, and for the day of the week (first seen) data = 0.33). Bottom: head and neck diagnosed patients. As in Fig. 4, for each variable, the red points show how much more likely (or for negative numbers, less likely) patients are to breach the 28-day FDS. Gold points show how much more (or less) likely patients are to not breach the 28-day FDS.

Fig. 5 also shows a similar analysis for patients with a new head and neck cancer diagnosis (N = 1567). If they have been cared for by at least two hospital sites, patients are 29 % more likely to breach the 28-day FDS. This suggests that patients moving between sites may delay their care.

3.2.3. Urological

Fig. 6 shows the effect of a variable on whether a patient is likely to be in breach of the 28-day FDS for patients on a urological cancer referral pathway (N = 46,148). Patients referred with suspected urological cancers are more likely to breach the 28-day FDS if.

- They had care from two or more sites ($p < 0.001$).

As with head and neck cancers, patients who took more than 28 days

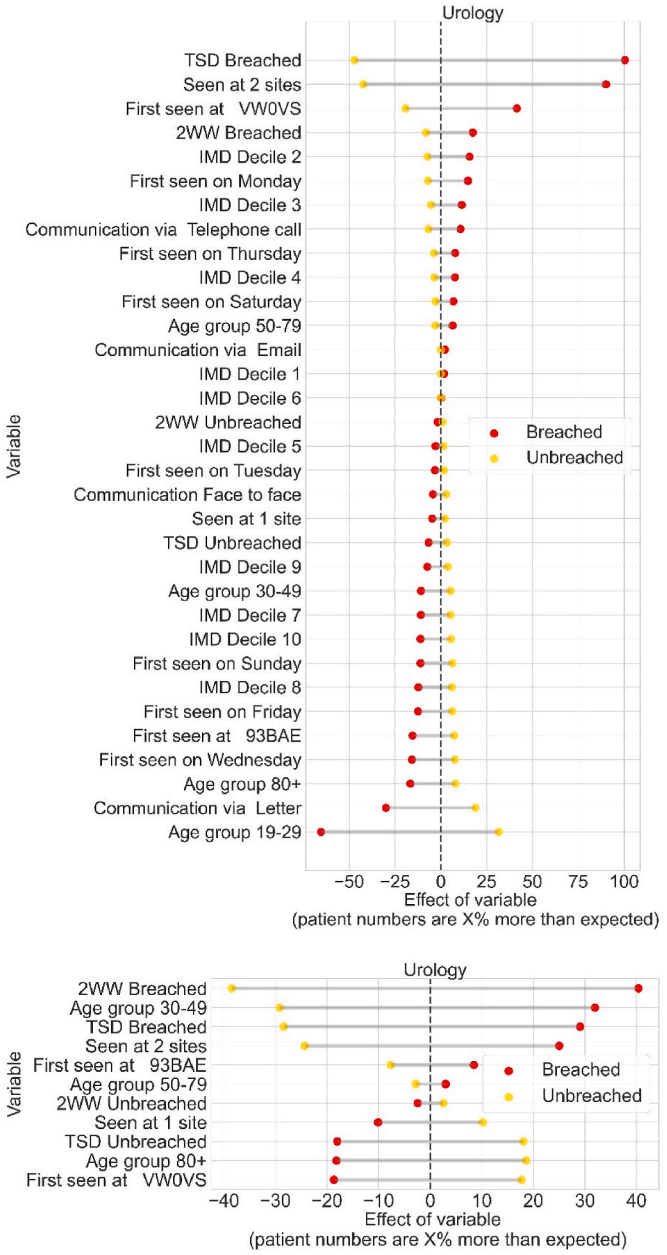

Fig. 6. The effect of different variables on whether a patient is more or less likely to breach the 28-day FDS. All results shown have $p < 0.05$. Top: all suspected urology patients (statistical power for the IMD data = 0.64). Bottom: urology diagnosed patients (statistical power for the age group data = 0.78). As in Fig. 4, for each variable, the red points show how much more likely (or for negative numbers, less likely) patients are to breach the 28-day FDS. Gold points show how much more (or less) likely patients are to not breach the 28-day FDS.

to receive their cancer diagnosis are likely to go on to breach the 62-day referral to treatment standard. Patients are most likely to breach the FDS if they have their first appointment on a Monday; they are least likely to breach if their first appointment falls on a Wednesday, Friday, or Sunday. Urology MDT meetings are held on Tuesdays and Fridays.

The lower part of Fig. 6 shows those patients with a new urological cancer diagnosis (N = 8011). If they have been cared for by at least two hospital sites, patients are 25 % more likely to breach the 28-day FDS. If the patient has breached the two weeks wait target, they are 40 % more likely to breach the 28-day FDS and, once breached at 28 days, are 29 % more likely to also breach at 62 days. This shows the importance of achieving the target times within cancer pathways; once a patient has breached an early target, it impacts all further target timing, which will impact on patient care and outcomes.

3.2.4. Summary

Table 1 summarises the three factors with the largest correlation with a patient breaching the 28-day FDS for each of the cancer pathways, and the top three factors that correlate with a patient not breaching the 28-day FDS. Table 2 summarises the same as Table 1, but for the sub-cohort of patients who have a cancer diagnosis.

As we only report here on correlations, further analysis is required in order to determine why these factors correlate with patients breaching the FDS, and what, if any, interventions may be suitable to minimise further breaches.

4. Discussion and conclusions

By combining clinical data from across three cancer care pathways, we have attempted to unravel factors relevant to the duration of the referral-to-treatment timeline for cancer patients. We hope to provide clinical operations managers and their healthcare systems with analytical insights which could be used to enhance the efficiency of cancer care pathways and, consequently, enhance patient outcomes.

In this analysis, we focus on the 28-day FDS to classify patients as breached or unbreached. However, we note that for all three cancers examined here, breaching the two-week wait target and the 62-day TSD target are both correlated with breaching the 28-day FDS. This implies that, once a patient has started to fall behind target stages in their diagnosis and treatment pathway, on average they do not “catch up” at future stages.

Our analysis highlighted several factors which impacted on the time to diagnosis including demographic factors, day of the week first seen and method of communicating the cancer diagnosis. In particular, we found that sarcoma patients who are first seen on a Friday are 40 % more likely to achieve the 28-day FDS target, whereas those patients first seen on a Sunday are 200 % more likely to breach the 28-day FDS. The day of the week a patient is first seen for cancer evaluation can potentially impact the duration between referral and treatment initiation due to several interconnected factors [2]. We note that sarcoma is a rare disorder and so the numbers seen on a Sunday are low. However, Sunday appointments tend to be either emergency admissions or additional clinics put on by the hospital. Thus, a patient may be able to see a consultant but may not have the ability to, for example, also obtain necessary blood tests or additional scans etc. By contrast, these

Table 1
Summary of the top three factors that correlate with a patient breaching and not breaching the 28-day FDS.

Properties most correlated with patient breaching 28-day FDS	Cancer pathway for referral		
	Sarcoma	Head and neck	Urological
#1	Communication via letter	Breached 62 day treatment start target[a]	Breached 62 day treatment start target[a]
#2	Diagnosis of cancer	Seen at 2 sites	Seen at 2 sites
#3	First Seen on a Sunday	Breached 2WW target	First seen at site VW0VS
Properties most correlated with patient not breaching 28-day FDS			
#1	Communication via telephone call	Age group 0-18	Age group 19-29
#2	First Seen on a Saturday	IMD decile 10	Communication via letter
#3	First Seen on a Thursday	IMD decile 8	Age group 80+

[a] If a patient breaches the 62 day treatment start target, they are more likely to have also breached the earlier 28-day FDS than those patients who do not breach the 62 day target.

Table 2
Summary of the top three factors that correlate with a patient breaching and not breaching the 28-day FDS for patients who have a cancer diagnosis.

Properties most correlated with patient breaching 28-day FDS	Cancer pathway for referral		
	Sarcoma	Head and neck	Urological
#1	First Seen on a Sunday	Breached 62 day treatment start target	Breached 2WW target
#2	First Seen on a Wednesday	Seen at 2 sites	Age group 30-49
#3	First Seen on a Monday	N/A	Breached 62 day treatment start target
Properties most correlated with patient not breaching 28-day FDS			
#1	First Seen on a Friday	Achieved 62 day treatment start target	First seen at site VW0VS
#2	First Seen on a Thursday	Seen at 1 site	Age group 80+
#3	First Seen on a Tuesday	N/A	Achieved 62 day treatment start target

additional investigations are often available mid-week on the same day. Further investigation is needed to determine the root cause of delays to patient timings when they are first seen on a Sunday but, if the NHS wishes to include weekend patients on the 2WW pathway, it is important to have the full support structure available. Understanding the impact of day-of-the-week variations on the cancer care pathway can help healthcare systems strategize resource allocation, appointment scheduling, and staffing to mitigate delays and optimise timely treatment delivery for all patients.

Our analysis shows mixed results between cancers for correlation between patients breaching the 28-day FDS and the method of communication of their diagnosis. For example, sarcoma patients were more likely to breach the 28-day FDS target when they received a letter compared to a telephone call. By contrast, urological patients were less likely to breach if they received a letter. It is important to consider with increasing digital communications in recent years that there may be a divide between patients and to ensure that any existing digital divides are not exacerbated [45].

Our results for patients referred on the head and neck and urological pathways shown in Figs. 5 and 6 suggest that patients from lower socioeconomic areas (IMD decile 1–4) were more likely to have longer times from referral to treatment (although see Ref. [46]). Factors such as limited access to travel to healthcare facilities, financial constraints including employment restrictions, and lower health literacy levels can impede early detection and timely intervention [47,48]. Addressing health inequalities requires targeted efforts to improve healthcare accessibility, raise awareness, and promote culturally sensitive approaches to cancer prevention, diagnosis, and treatment, ensuring that all individuals have equal opportunities for optimal care and improved outcomes [49,50].

Whilst we have tried to extract insights into the influencing factors on timeliness of patient diagnosis and treatment, we acknowledge this study had some limitations. For example, for some patients diagnosed with cancer, all we have is the date of diagnosis, so their timings cannot always be included in the analysis. We do not have sufficient information to be able to conclude why some properties are correlated with breached targets – for example, the method of communication. The datasets used here were the best available that could be confidently extracted and anonymised by the hospital trusts, and we were limited to data that is routinely collected at scale. Further studies would require additional funding to be able to collect the non-routine data that is needed to make firm conclusions on the root cause of the correlations we note here.

Future work should be aware of the need to involve staff across disciplines to perform similar studies. This project was a multidisciplinary effort requiring input from both clinical and non-clinical staff. Two project subgroups contributed to this paper: firstly, a clinical subgroup with specialty leads from the three tumour groups to ensure metrics were aligned to the intended health improvement on cancer pathways. Secondly, a data management subgroup who agreed the datasets and the optimal data transfer standard for cancer pathway data and provided recommendations to the steering group. Cancer managers were also involved at project board, and on request in subgroups.

Implementing modelled insights into the NHS poses difficulties due to the complex nature of healthcare systems, resource limitations, and organizational dynamics. While mathematical models can provide valuable insights into improving patient care pathways and resource allocation, translating these insights into tangible changes within the NHS requires much work. Limited funding, workforce constraints, and competing priorities can hinder the allocation of resources necessary for implementing new strategies based on modelled recommendations [51–53]. Overcoming these challenges requires collaborative efforts among policymakers, healthcare leaders, clinicians, and researchers to devise feasible implementation strategies that address financial, organisational, and structural considerations while aligning with the overarching goals of the NHS.

Ethics

This study involved the analysis of operational data derived from patient care activities. As no clinical data was used, ethics approval was not required. All data used were accessed in compliance with applicable privacy laws and institutional policies.

Data sharing

Data collected for this work will not be made available beyond what is reported in this paper.

Declaration of competing interest

DH declares that she is the clinical co-director of the NCL cancer alliance. All other authors declare no conflicts of interest exist.

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Appendix A. ICD-10 codes

Below are the ICD-10 codes used to select the cancer sites in this study.
Sarcoma: C40, C400, C401, C402, C403, C408, C409, C41, C410, C411, C412, C413, C414, C418, C419, C46, C460, C461, C462, C463, C467,

C468, C469, C48, C480, C481, C482, C488, C49, C490, C491, C492, C493, C494, C495, C496, C498, C499, C786, C795.

Head and neck cancers: C00 – C14, C30, C300, C301, C309, C31, C310, C311, C312, C313, C318, C319, C32, C320, C321, C322, C323, C328, C329, C73, C73X, C77, C770.

Urological cancers: C61, C64, C65, C66, C67, C68, C790, C791.

Appendix B. Flow diagrams for patients with a cancer diagnosis

This appendix shows Sankey flow diagrams showing the movement of patients who have been diagnosed with cancer for each stage of their diagnosis pathway: First Seen, FDS, DTT, Treatment Start. The height of bars represents patient volume, and the coloured 'ribbons' show the mean number of days between steps in the pathway. As this dataset was extracted based on their treatment start date, the completeness of the pathways before DTT is low (for example, completeness is only 15 % for site at FDS end for sarcoma patients).

Figure B1 shows the flow of sarcoma patients, Figure B2 shows head and neck patients, and Figures B3 – B5 show urological patients split into prostate, renal, and bladder cancer.

We find consistent median timings from referral to First Seen between cancer types: 9 days for sarcoma, 8 days for head and neck cancers, and 8 days for urological cancers, with 75th percentiles 12, 12 and 13 days respectively.

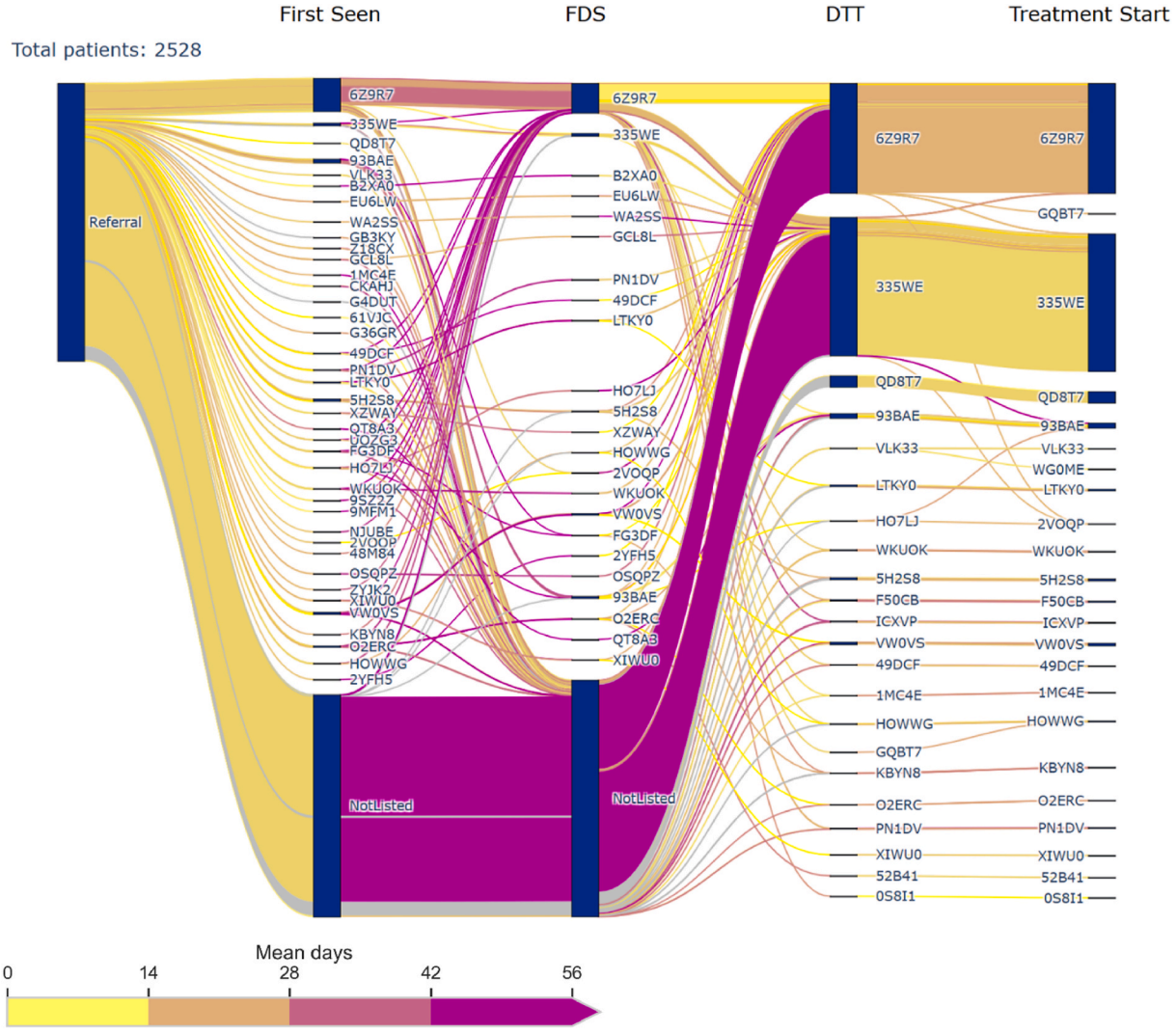

Fig. B1. Sankey diagram of Sarcoma patients with a cancer diagnosis. The ribbons show patient flow across the pathway and between different sites. Colours indicate the average number of days taken between pathway steps for a patient diagnosed with cancer. The organisations used in this study have been anonymised to six-character codes in the labels.

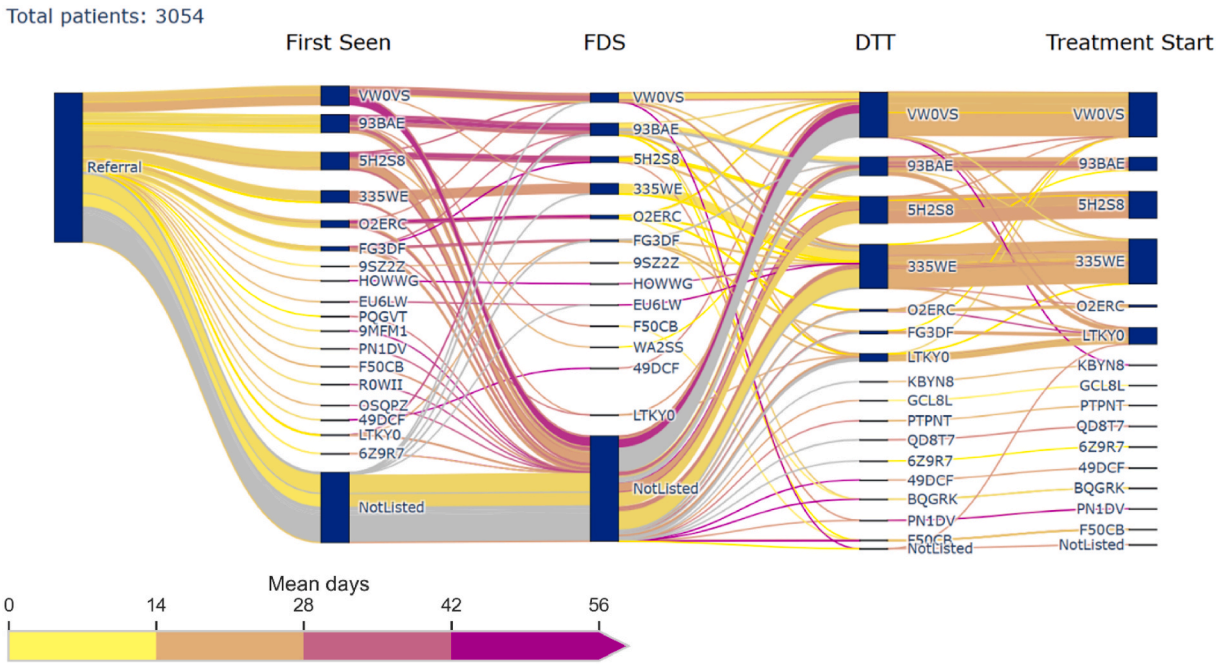

Fig. B2. Sankey diagram of head and neck patients with a cancer diagnosis. As in Figure B1, the ribbons show patient flow across the pathway and between different sites. Grey lines are used when the average number of days is unavailable. The organisations used in this study have been anonymised to six-character codes in the labels.

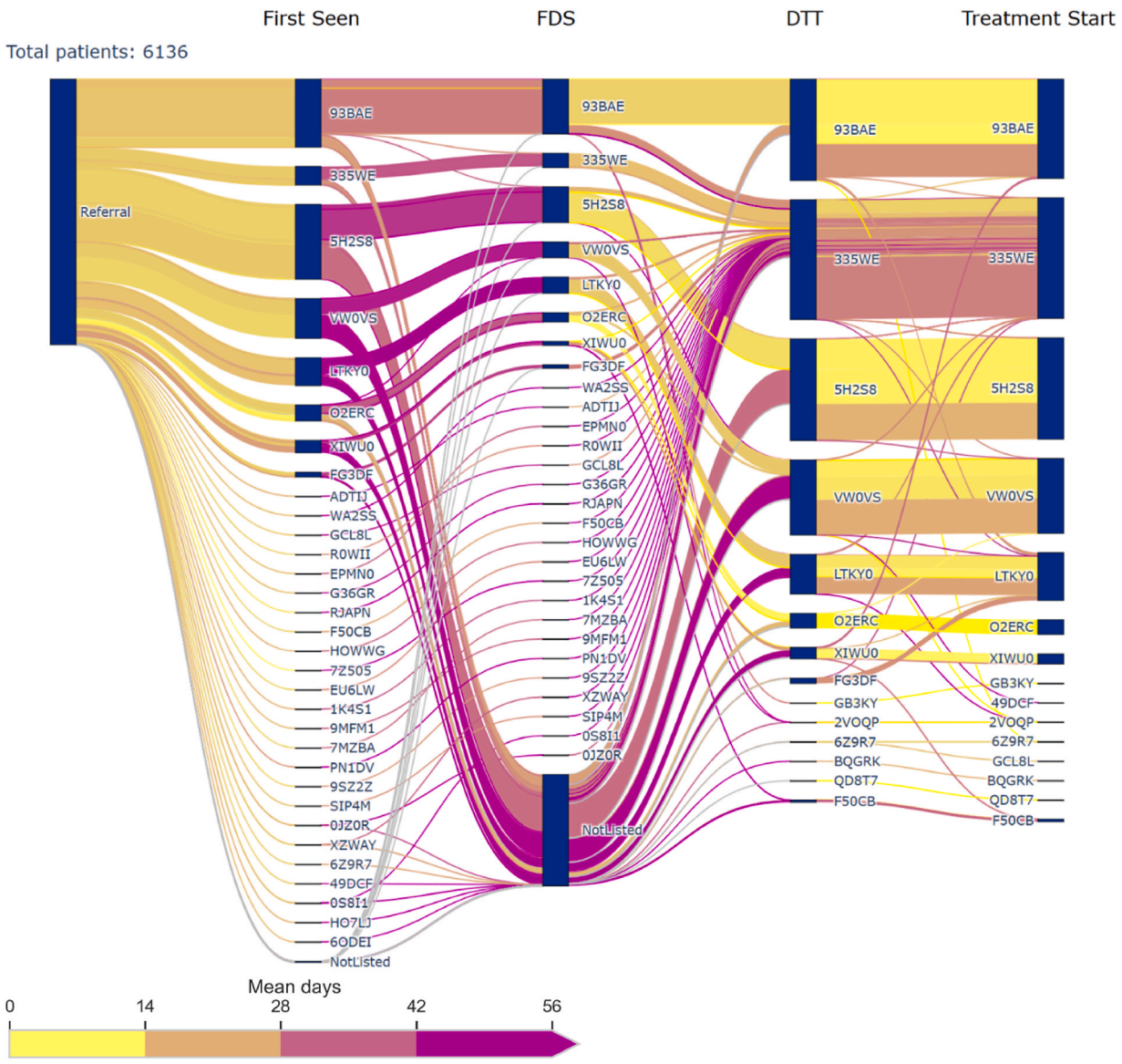

Fig. B3. Sankey diagram of prostate (urology) patients with a cancer diagnosis. As in Figure B1, the ribbons show patient flow across the pathway and between different sites. Colours indicate the average number of days taken between pathway steps for a patient diagnosed with cancer. The organisations used in this study have been anonymised to six-character codes in the labels.

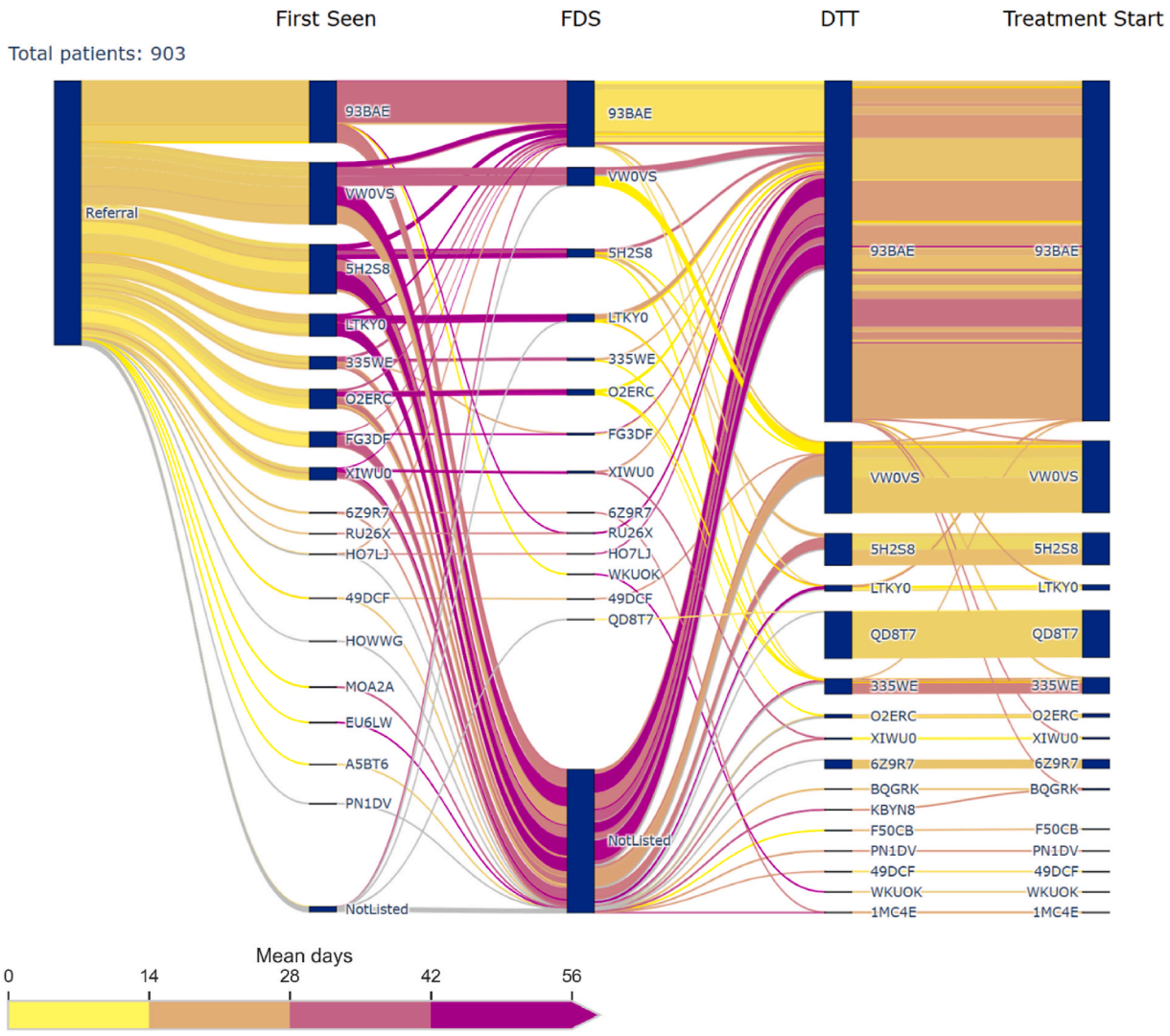

Fig. B4. Sankey diagram of renal (urology) patients with a cancer diagnosis. As in Figure B1, the ribbons show patient flow across the pathway and between different sites. Colours indicate the average number of days taken between pathway steps for a patient diagnosed with cancer. The organisations used in this study have been anonymised to six-character codes in the labels.

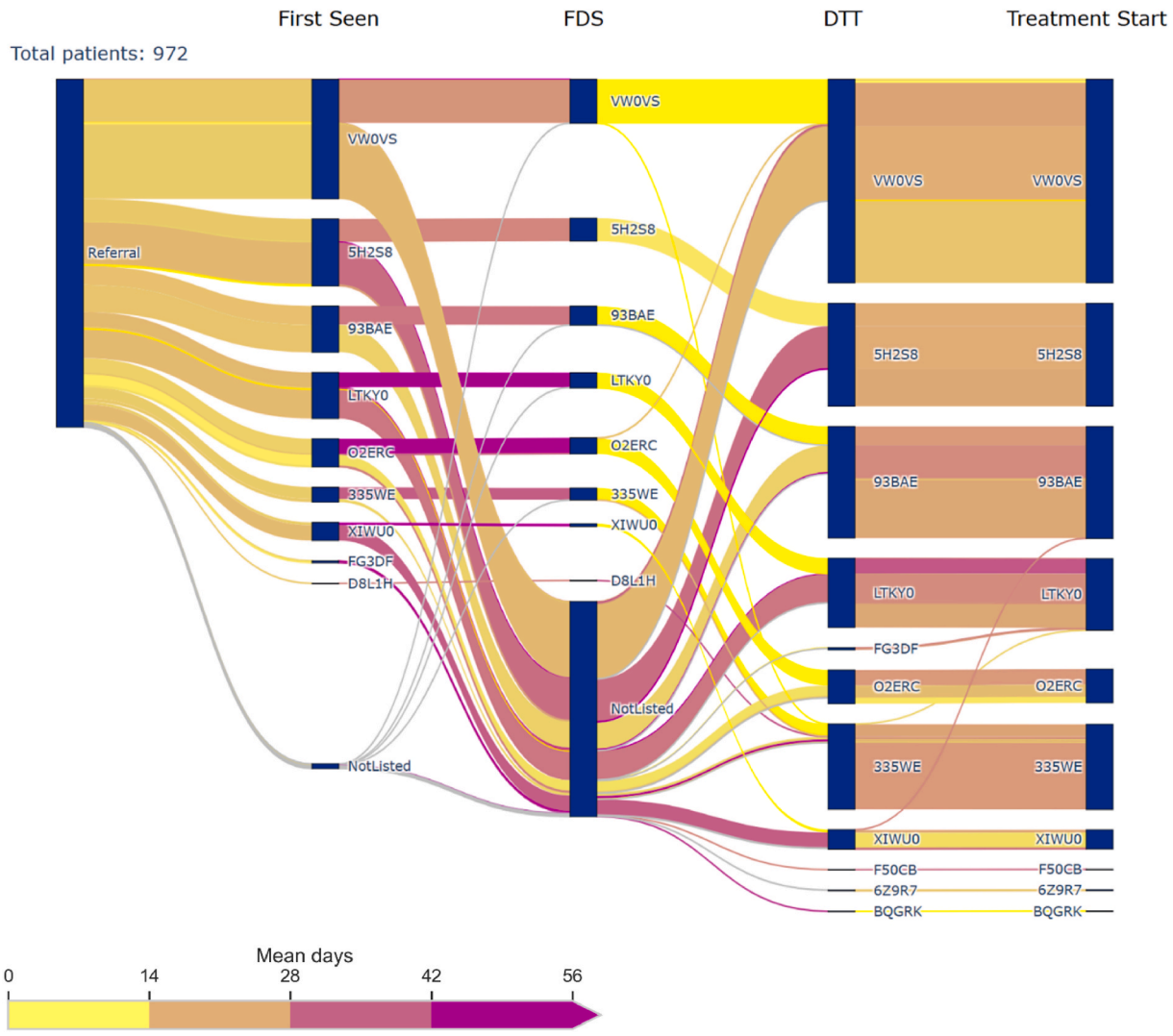

Fig. B5. Sankey diagram of bladder (urology) patients with a cancer diagnosis. As in Figure B1, the ribbons show patient flow across the pathway and between different sites. Colours indicate the average number of days taken between pathway steps for a patient diagnosed with cancer. The organisations used in this study have been anonymised to six-character codes in the labels.

Data availability

The authors do not have permission to share data.

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