Rhythmicity of patient flow in an acute medical unit: relationship to hospital occupancy, seven-day working, and the effect of COVID-19

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Running title: Patient flow in acute medical unit

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Abstract

Background: The Acute Medical Unit (AMU) provides care for unscheduled hospital admissions. Seven-day Consultant presence and morning AMU discharges have been advocated to improve hospital bed management.

Aims: To determine whether a later time of daily peak AMU occupancy correlates with measures of hospital stress; whether seven-day Consultant presence, for COVID-19, abolished weekly periodicity of discharges.

Design: Retrospective cohort analysis

Methods: Anonymised AMU admission and discharge times were retrieved from the Profile Information Management System (PIMS), at a large, urban hospital from 14th April 2014 - 31st December 2018 and 20th March - 2nd May 2020 (COVID-19 peak). Minute-by-minute admission and discharge times were combined to construct a running total of AMU bed occupancy. Fourier transforms were used to determine periodicity. We tested association between i) average AMU occupancy and ii) time of peak AMU occupancy, with measures of hospital stress (total medical bed occupancy and 'medical outliers' on non-medical wards).

Results: Daily, weekly and seasonal patterns of AMU bed occupancy were evident. Timing of AMU peak occupancy was unrelated to each measure of hospital stress: total medical inpatients (Spearman's rho, r_s=0.04, P=0.24); number of medical outliers (r_s=-0.06, P=0.05). During COVID-19, daily bed occupancy was similar, with continuation of greater Friday and Monday discharges than the weekend.

Conclusions: Timing of peak AMU occupancy did not alter with hospital stress. Efforts to increase morning AMU discharges are likely to have little effect on hospital performance. Seven-day Consultant presence did not abolish weekly periodicity of discharges – other factors influence weekend discharges.

Introduction

Optimising patient flow, the movement of patients through a healthcare system, may allow hospitals to run closer to their theoretical capacity and use their resources efficiently across time. Discharge delays and increased demand are thought to contribute to poor flow.[1] Hospitals may struggle to operate effectively and meet quality standards when admission rates are high in relation to available resources such as beds, staff and operational capacity.[2] The Acute Medical Unit (AMU) was designed to improve outcomes for unscheduled medical admissions and improve the operative performance across the hospital. Its primary role is to provide rapid assessment, investigation and treatment for acute medical patients, through a concentration of resources.[3] Transfer of patients from the AMU to another ward is conditional on beds being available. The point at which a hospital has too few beds to achieve operational efficiency can be recognised as the point at which medical outliers occur. Patterns of AMU discharge may affect operational performance of the whole hospital. This has encouraged attempts to increase the low numbers of weekend discharges[4] and to move discharges to earlier in the day. These 'discharge before noon' programmes are intended to improve hospital throughput, by matching supply more closely to demand, but have debatable efficacy.[5-8] While the seasonal and weekly cycle in hospital admission is known,[9] the temporal relationship between daily patterns of bed occupancy in an AMU, and hospital underperformance ('stress') - such as the presence of medical outliers – has never been examined.

The COVID-19 pandemic led to a major re-organisation of in-hospital care,[10] with limitation - as much as possible - of non-COVID attendance and admissions. Staffing rotas were reconfigured and in our Trust, seven-day Consultant presence was instituted on all medical wards. This gave a unique opportunity to see the effect of radical reorganisation of care on admission and discharge patterns – patient flow.

We evaluated AMU admission and discharge data (prior to COVID) to determine whether the periodicity of AMU discharges, and timing of peak AMU occupancy, shifts in response to system stress (numbers of medical outliers or total number of medical inpatients). We also evaluated whether the institution-wide change to seven-day consultant presence on all medical wards, during the COVID-19 pandemic, altered the rhythmicity of bed occupancy.

Methods

<u>Data collection</u>

Data collection was 14th April 2014 to 31st December 2018, plus COVID-19 period (RDL and AZ, two adjoining wards, comprising the AMU, became COVID wards on 20th March and 25th March 2020 respectively until ward closure on 17th April and 2nd May 2020 respectively). Admission and discharge times were recorded, routinely and contemporaneously, on the Profile Information Management System (PIMS). Anonymous admission and discharge times were then extracted by the Business Intelligence Unit (BIU) at the hospital. In addition, for the period 1st January 2016 to 31st December 2018, the BIU provided daily medical inpatient numbers at midnight for the whole hospital and for the number of medical outliers. Ethical approval was considered not required by the hospital Trust's Research & Innovation department.

The Acute Medical Unit

The AMU receives patients from the emergency department (ED) or primary care. Following initial assessment and treatment, patients are then either discharged home or transferred to another appropriate ward, usually within 72 hours of arrival. Consultant-led AMU ward rounds, commencing at 8am, determine patient management, including suitability for discharge, in real-time. The round is complemented by multi-disciplinary meetings at midday, and at 3pm for ongoing management, and evening and next-day discharge planning of more complex patients. For evaluation, we applied the term 'discharges' for all patients exiting the AMU. The AMU does not receive paediatric, psychiatric, surgical or obstetric/gynaecology patients. Our hospital has seven-day working for diagnostic services, speciality input, and pharmacy input. In addition, at the start of the COVID-19 pandemic, daily Consultant rounding was introduced on all wards. With the onset of COVID-19, a greater number of wards were created as receiving wards, to augment the existing AMU. Therefore, not all COVID-19 admissions came through the pre-existing AMU.

Data analysis

Over the four-year period, there were 37,324 AMU admissions and subsequent discharges of 23,079 individual patients. Individual admission and discharge times were combined to construct a running total of the number of patients in the AMU at any one time. A Fourier transform of the resulting time-series showed pronounced peaks at one day and at seven days, suggesting the presence of daily and weekly patterns.[11] These patterns were further explored by constructing daily and weekly average patterns. For calculating AMU occupancy, an event-based approach was taken. For example, for the daily patterns, all combined discharge and admission events were ordered in time modulo one day and a running average occupancy constructed. To quantify admission and discharge rates, the admissions (discharges) were again ordered in time modulo the time interval under consideration. For each minute, the admission rate was then calculated. The time-course of the

admission and discharge rates showed that admission and discharge times were frequently rounded to the nearest 15 minutes leading to peaks in admission and discharge rates at 15-minute intervals. Consequently, for presentational purposes the data, were smoothed by constructing a weight moving average using a 1.5 h window.

To test the association between AMU occupancy and measures of hospital stress, two daily AMU measures were constructed. One, the average AMU occupancy, related to capacity, the other, the time of peak AMU occupancy, related to timing. While clear daily and weekly patterns emerged from >1400 days of data, there was considerable day-to-day variability.

The two measures of hospital stress consisted of one data point per day for each measure - one giving the total medical inpatient occupancy and one the number of medical outliers at midnight at the beginning of the day in question.

The data were non-normally distributed since the AMU and the hospital both have finite capacity and often operated close to the limits of that capacity. For that reason, we used Spearman's rho (r_s) to test for associations between measures.

Results

Daily, weekly and seasonal patterns in AMU occupancy

AMU admission and discharge rate, and resultant bed occupancy followed a daily rhythm (**Fig. 1a**). Admissions were highest late evening, around 21:30 and lowest in the morning around 8:00. Even after smoothing, small dips in admissions were evident at 8:00 and 20:00, possibly because of shift handover. The discharge rate overnight, particularly between 2:00 and 8:00, was low. During the day, the discharge rate gradually increased, peaking in late afternoon, around 17:30. From 20:00 to 10:00, the admission rate was higher than the discharge rate, so AMU occupancy increased - reaching a maximum at around 10:00. Thereafter, from 10:00 through to 20:00 the discharge rate exceeded the admission rate, so AMU occupancy dropped.

These general patterns were repeated on each day across the week (**Fig 1b**), with admission and discharge rates lowest on Saturday and Sunday. Occupancy peaked on a Tuesday and then dropped, with the largest drop on Friday, when the discharge rate peaked in advance of the weekend.

Although there was considerable variation from one year to the next, seasonal patterns did also occur, with occupancy levels on average lower in the summer months (**Fig 1c**). Across all four years

of data, there were dips in June and August but a peak in occupancy in July. This did not appear to align with changes in junior doctor rotation or school holidays.

Time-course of measures of hospital pressure

Both measures of hospital pressure: total medical inpatients and number of medical outliers, showed seasonal patterns (**Fig. 2a**), with highest values over winter months. There was significant correlation between the two measures (r_s = 0.17; P<0.001; **Fig. 2b**). There was a significant weekly pattern (**Fig. 2c**), with total medical inpatients reaching a minimum on Friday night and a maximum on Monday night.

Association of AMU occupancy with hospital stress

Daily peak AMU occupancy correlated with both measures of hospital stress (total inpatient population, r_s = 0.25; P<0.001, medical outliers, r_s = 0.27; P<0.001; **Fig. 3a**).

Timing of peak AMU occupancy showed a weekly oscillation, with the peak occurring earliest on Tuesdays (**Fig. 3b**), and latest on Sundays. There was no seasonal difference in the timing of peak occupancy (**Fig. 3c**). The two measures of hospital stress used consisted of a single time point for each day at midnight. We could therefore consider the timing of the peak occupancy both for the day leading up to midnight (prior day) and for the day after midnight. In each case, the timing of peak occupancy was unrelated to the total number of medical inpatients. (Day prior: r_s = 0.04, P=0.24; Day after: r_s = -0.05, P=0.13 **Fig. 3d**). There was a significant negative correlation in the timing of peak AMU occupancy with medical outliers, with peak occupancy levels in the AMU occurring earlier in the day when there were a large number of medical outliers. However, the effect size was very weak (Day prior: r_s = -0.06; P=0.05. Day after: r_s = -0.08; P=0.007; **Fig. 3d**).

AMU occupancy during COVID-19

The time-course of the AMU occupancy during COVID-19 is shown in **Fig. 4a**). Pre-COVID, the median stay length was a little under 2 days (44.7 h, mean stay length, 57.7 h). During COVID, the median stay length was closer to 3 days (76.5 h, mean stay length, 113.6 h).

Overall AMU occupancy levels were lower, with a mean occupancy of 43.6 patients compared to 51.0 for the same weeks in the other four years for which we had data (2015-2018). There was a similar daily pattern in occupancy both before and during COVID, with a broad maximum during the day and a dip in the evening (**Fig. 4b**). With only three full weeks of data, weekly patterns in admissions were hard to discern. However, the discharge rate was higher on Fridays and on Mondays (**Fig. 4c**).

Discussion

We have shown that there is no change in the daily periodicity of flow - into or out of the AMU - either before or after hospital-wide over-capacity ('hospital stress'). Furthermore, despite the major COVID-19 pandemic and consequential introduction of a seven-day Consultant presence on all medical wards, there was little evidence of change in the weekly periodicity of discharges from an AMU. Discharges both before and during the COVID-19 pandemic were highest during the week and lowest at the weekend.

There were predictable seasonal, weekly and daily temporal rhythms for bed occupancy on the AMU. Seasonal periodicity of hospital admissions has been described,[9,12] especially for influenza.[13,14] Seasonal periodicity has also been described for cerebrovascular,[15] cardiovascular,[16,17] and gastrointestinal [18] pathologies and may relate to weather patterns, the availability of services, and patient behaviours.[19] Weekly and daily periodicity might also relate to pathogenesis of the disease – for example demand distribution of cardiovascular disease peaks in the late morning and there are greater case numbers on Mondays[15-17]. Timing of attendance may therefore shift the clinical odds for a particular disease - undifferentiated chest pain presenting in the late morning may be more likely a consequence of epicardial artery disease.[17] Pathways of care provision will also influence daily patterns of attendance. Examination of an elderly care emergency admission pathway found that individuals whose initial acute clinical contact was with the GP, were not seen and referred on to the hospital until after midday; arrival to hospital was early afternoon, and (two-thirds) of patients then 'arrived' on the medical assessment unit (MAU, equivalent to AMU) after 18:00.[20]

Patient discharge has received critical attention from the assumption that variation and delays in this process create 'bottlenecks' that ultimately delay most care-pathways, especially new admissions from the ED.[21] Fewer weekend discharges from AMUs have been considered a consequence of a lack of medical staff to review patients.[1,22] Our data show large numbers of Friday discharges and a drop in discharges over the weekend. This might be interpreted as a consequence of an inability to successfully discharge patients at the weekend. Although the decision to discharge an individual patient from hospital should predominately be a clinical one, there may be non-clinical factors that influence decision-making. These may include patient and/or family preferences, physician preference, hospital organisational features (including staffing levels) or post-acute capacity.[23-25]

Discharges before midday are advocated to improve hospital throughput,[5,7,8] however early discharges may be a consequence of discharge delay, where a marginal discharge decision on the

preceding evening is deferred to the following morning.[6] We found that the pattern of discharges during the day was remarkably consistent over the years, as was recently reported from acute care centres in the USA.[26] We also found no shift in the curve of hospital discharges either before, or after, escalation in the hospital 'stress measures'. This suggests that attempts to promote morning discharges would be unlikely to have a large impact on improving hospital bed management. Instead, we found a consistent pattern of the timing of discharges across the week, with the timing of the peak in discharge rate latest on Friday when the discharge rate was highest.

COVID-19

To our knowledge, there have been no publications examining changes of patient flow following hospitalisation, during COVID-19. Reductions in admissions for non-COVID pathologies such as stroke[27] and acute coronary syndrome[28] have been described. However, trend analysis of the numbers of emergency ambulance callouts in UK showed no diminution for these exemplar conditions.[29] This implies that there was a greater threshold for admission from the ED and requires further study. Our data confirms less bed occupancy and reduction in overall medical admissions with COVID-19,[30] but ours is the first evaluation of the periodicity of AMU attendance or discharge during COVID-19. The 'NHS COVID-19 Hospital Discharge Service Requirements' document stipulated that Acute Hospitals must discharge all patients as soon as they were clinically safe to do so.[31] Therefore, why did Mondays and Fridays persist as having greater discharges, during peak COVID-19 pandemic? A 2012 report by The Academy of Medical Royal Colleges, outlining standards for seven-day consultant-present care in the delivery of inpatient care, stipulated that support services both in hospitals and in the community setting should be balanced and aligned to meet patients' need, seven days a week.[32] It may be that in the urgency of reconfiguring care for COVID-19, the community support component was not met. During the pandemic a greater awareness evolved of the inadvisability of discharging patients to residential or nursing homes. This may have influenced timing of discharge.

New policies have been introduced to facilitate patient care and flow, including short-stay elderly care units,[33] post ED multi-disciplinary team meetings,[34] and ambulatory care services.[35] Whether these developments affect patient care needs evaluation. As part of the preparation for the COVID-19 pandemic, these components were suspended at our Hospital Trust.

This observational study benefited from being conducted at a single site with consistencies in Consultant work patterns, ward round frequency, admission criteria, treatment pathways and

sources of referral to AMU. We used two methods ('medical outliers' on specialist wards and total hospital bed occupancy) as surrogates for hospital stress, with similar outcomes as there is no recognised metric for capturing hospital stress.[36]

In summary, we found little relationship between periodicity of AMU bed occupancy and measures of hospital stress. During COVID-19, there was persistence of weekly periodicity, with greater Friday and Monday discharges, despite seven-day Consultant presence. This reflects wider challenges of discharging patients safely at the weekend.

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Figure legends

Figure 1. Daily, weekly and seasonal patterns in AMU occupancy and rates of admission and discharge.

(a) and (b) show daily and weekly patterns in the admission rate (blue line), discharge rate (red line) and resultant occupancy (black line) of the AMU. Occupancy increases when the admission rate is greater than the discharge rate and falls when the discharge rate outpaces the admission rate. (c) Shows the annual patterns for the entire period of the study (coloured lines) with the average superimposed on black.

Figure 2. Time course of measures of hospital pressure.

(a) Total medical inpatient numbers (green line) and medical outliers (red line) (b) Violin plots showing the distributions of total medical inpatient numbers by day of week, where Monday refers to midnight occupancy on Monday night etc. (c) Association of the medical inpatient numbers and medical outliers.

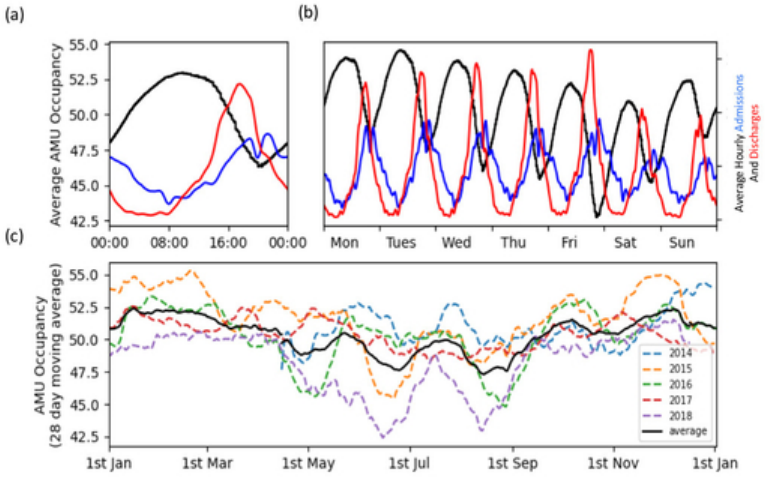
Figure 3. Timing of maximum AMU occupancy and the association of AMU occupancy with measures of hospital stress.

(a) Association between medical outliers at midnight and AMU occupancy for the day leading up to midnight. (b) Average daily AMU occupancy by day of week. On days of the week where peak AMU occupancy is highest, the daily peak occupancy tends to occur earlier in the day. (c) Average daily AMU occupancy by season,

showing that average daily occupancy levels are lowest in the winter but that there is little seasonal change in peak time. (d) Association between medical outliers at midnight and peak time of AMU occupancy on the subsequent day.

Figure 4. Daily and weekly AMU occupancy patterns during COVID.

(a) Time course of AMU occupancy for the 3 weeks during which the two wards (TDL and AZ), which make up the AMU, became COVID wards. (b) Average AMU occupancy during COVID as compared with the same 3-week period in the years 2015, 2016, 2017 and 2018. (c) Average weekly admissions and discharge rates during the COVID period.



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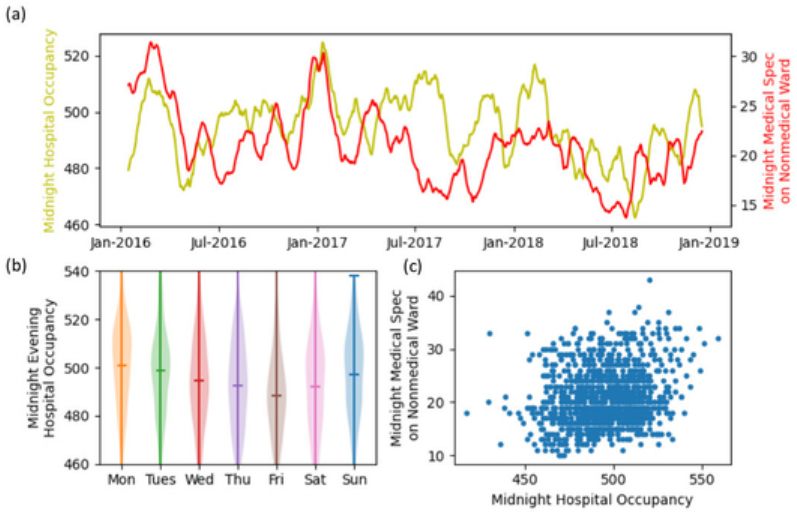

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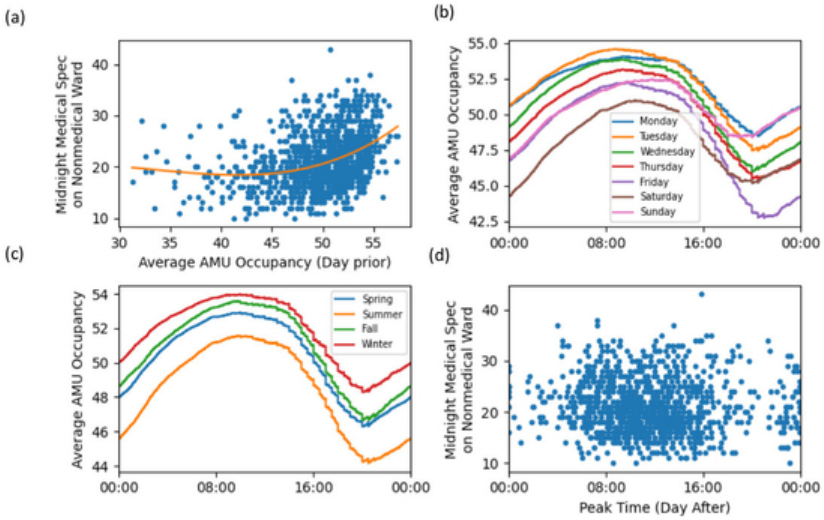

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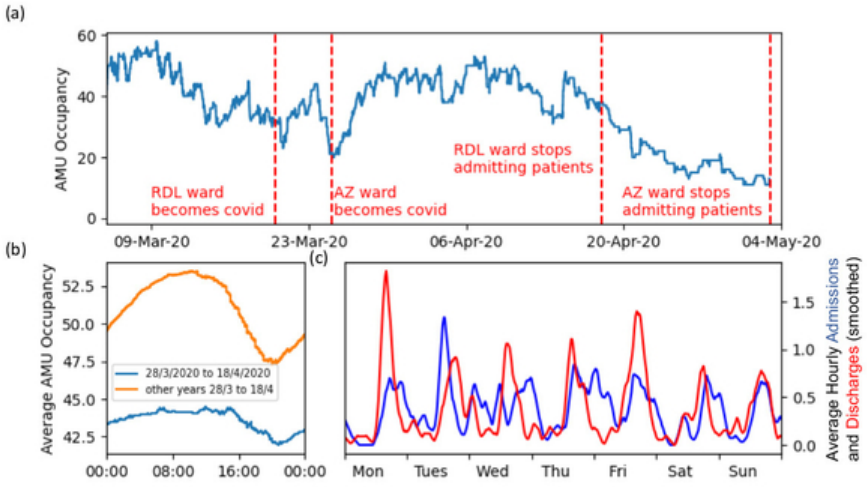

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List of acronyms

AMU	Acute Medical Unit
COVID-19	Coronavirus disease
ED	Emergency Department
MAU	Medical Assessment Unit
PIMS	Profile Information Management System