Computational Time Series Analysis of Patient Referrals to a Primary Percutaneous Coronary Intervention Service

Abstract

This paper retrospectively analyses a Primary percutaneous coronary intervention (PPCI) dataset comprising of patient referrals that were accepted for PPCI and those who were turned down between January 2015 to December 2018 at Altnagelvin hospital (UK). Time series analysis of these referrals was undertaken for analysing the referral rates per year, month, day and per hour.

The overall referrals have 70% (n=1466, p<0.001) males. Out of total referrals, 65% (p<0.001) referrals were 'out of hours'. Seasonality decomposition shows a peak in referrals on average every 3 months (SD=0.83). No significant correlation (R=0.03 p=0.86, R= -0.11 p=0.62) was found between the referral numbers and turndown rate. Being female increased the probability of being out of hour in all the groups. The 30 days mortality was higher in turndown group.

The time series of all the referrals depict variation over the months or days which is not the same each year. The average age of the patients in the turndown group is higher. The number of referrals does not impact on the turndown rate and clinical decision making. Most patients are being referred out of hours especially females. This analysis leads to the emphasis on the importance of working 24/7 CathLab service.

Keywords: CathLab, PPCI, Patient referrals, STEMI, Time series analysis

1. Introduction

Whenever a patient calls the emergency services complaining of any kind of chest pain, paramedics or another healthcare professional records and interprets the patient's 12-lead electrocardiogram (ECG) using the ST-segment elevation myocardial infarction (STEMI) criteria. On referral for primary percutaneous coronary intervention (PPCI), the activator (specialist nurse) will further adjudicate whether to refer the case on to a cardiologist who then interprets the patient's case including the 12-lead ECG, demographics and other symptoms such as chest pain to make a decision on whether to accept or turn down the patient for referral to the CathLab.

When a patient is diagnosed with an acute STEMI, they are referred to CathLab via a PPCI service for coronary reperfusion. Understanding clinical workflows, pathways and patient referrals to a PPCI service could be useful for identifying sub-optimal clinical decision making and result in new improved protocols and procedures. Unfortunately, there is a lack of data analytics and data mining research to elicit insight into patient pathways and PPCI referrals, which is the aim of this paper. Acute MI or a STEMI is caused by atherosclerotic plaque, and treatment via reperfusion therapy (PPCI/angioplasty/stenting) for these patients is time critical (1) (2)(3). The time (in minutes) from the patient entering the hospital to the time when a balloon-tipped catheter is used to reopen the blocked artery is referred to as 'door-to-balloon time'. Recommended door-to-balloon time was previously

≤90 minutes which has now decreased to ≤60 minutes (4) (5)(6). Scholz et al. (7) investigated the consequence of contact-to-balloon time on mortality in STEMI patients with and without hemodynamic instability. One research study was conducted to analyse mortality in relation to sex and race alone resulting in no statistically significant findings (8). Lawesson et al. (9) presented the gender dependency on the symptoms in STEMI patients. They found that chest pain was less prevalent in women as compared to men, furthermore, other symptoms like shoulder, throat and back pain are as twice as common in men. Another study (10) investigated whether the effectiveness of in-hospital and long-term outcomes for STEMI patients treated by PPCI within normal working hours compared with those treated out-of-hours (OOHs) and found similar effective treatment provision for all the patients regardless of the time of presentation. Another study evaluated the effect of implementing a dashboard for the STEMI patients to calculate the door to balloon time. They highlighted the importance of monitoring, evaluation and providing feedback on ischemic time delays in STEMI patients. It was concluded that use of this dashboard named H2H (home to hospital) improved the overall performance and process and approximately 90% of the patients achieved the recommended door-to-balloon time of 60 minutes (11). Sillesen et al. suggest, transmission of prehospital ECG and the correct identification of STEMI by paramedics can decrease door-to-balloon times (12). Many studies have also been completed to showcase the performance in ECG interpretation. Veronese et al. (13) conducted a survey for 135 physicians who interpreted 4603 ECGs showing an overall accuracy of 69.1%. They also concluded that ECG interpretation for diagnosing a STEMI lacks the necessary sensitivity and specificity to be considered a reliable 'stand-alone' diagnostic test. Bhalla (14) conducted a survey of a similar nature where 420 paramedic staff interpreted 10 different types of ECGs. The study showed that only thirty-nine percent (185/472, 95% CI 35%-44%) correctly identified all three STEMIs. The study (15) compares ECG diagnostic skill among cardiologists and of other internal medicine specialties (non-cardiology fellows). The conclusion suggested that skills in ECG interpretation were not adequate. However, comprehensive method to ECG education is necessary. In another similar study heatmaps were used to track the eye gaze for the interpretation of the ECG (16). The authors recommend ECG annotators to adopt an initial first impression/pattern recognition approach followed by a conventional systematic protocol to ECG interpretation. This recommendation is based on observing misdiagnoses given due to first impression only. Another study concluded that physicians can have an accuracy as low as 40% in ECG interpretation (17).

The aforementioned literature shows that there have been many studies on different aspects and analysis of the PPCI pathway, however, there is a lack of time series analysis to unveil unique patterns with respect to the acceptance and turndown of patients referred to the CathLab. Nevertheless, Cox,

J. et.al. (18) conducted a retrospective time series analysis of primary care trusts to assess the impact of three referral-management centers (RMCs) and two internal peer-review approaches to referral management on hospital outpatient attendance rates. The study used linear regression and autocorrelation to determine the time series effects of attendance ratio/rate with introduction of referral management. The study concluded there was not any association between referral management and reduction in the outpatient attendance rate in any group. Another study conducted time series analysis (19) from 2004 to 2008, and explored the possible association between the occurrence of varicella infection and various climatic factors in Hong Kong. The study concluded that lower relative humidity in cool seasons is associated with higher number of pediatric varicella hospital admissions. As can be seen in this literature, such referral time series analysis can provide useful and actionable insights which can be beneficial for optimizing healthcare services.

This paper comprises of the following research questions:

1. What time series patterns exist per hour, per day, per week, per month and per season for all PPCI referrals and for referrals that were turned-down or accepted?
2. Are the time series patterns of PPCI referrals per hour, per day, per week, per month and per season consistent for each independent year?
3. Do turn-down rates for PPCI change over a time series, i.e. per hour, per day and per month?
4. Does 30-day mortality change over time series, i.e. per hour, per day and per month?
5. What are the gender and age differences in the referral data for those turned down and for those who were accepted for PPCI?

2. Methods

This study involved analysis of an anonymized dataset collected at Altnagelvin Hospital (Northern Ireland, UK) which has a 24/7 PPCI service. The total study population consisted of 2096 patients including 882 patients that were accepted for a PPCI intervention (76% men, n=673) and 1464 patients that were referred by turned down for a PPCI intervention (68% men, n=996). Data was collected in the cardiac care unit (CCU) during January 2015 to December 2018 for STEMI patients. However, the accepted referrals dataset includes data from January 2015 to December 2018. For patients who were referred but then turned down for PPCI referral data was collected from January 2015 to December 2017. For analysis, both groups were aggregated for the common years, i.e. 2015-2017. This referral data was routinely recorded by a staff nurse using a paper-based form and then digitized using a spreadsheet. After the approval of an ethics application to undertake this analysis, the staff nurse removed all personal identifiable information such as names, DOB and patient identifiers.

2.1. Data analysis

All statistical analyses were performed using R-Studio and the R programming language. Time series visualisations were generated using ggplot2 (a R package for visual analytics). Data was interrogated for missing values and data completeness. Regarding the most important outcome measurements (i.e. time series data) there were no missing values. Frequencies and proportions were computed to summarise distributions in the patient referral dataset. Comparisons between the proportions in distinct groups were investigated for significance using Chi-square tests for categorical dichotomous variables. Student t-test or Mann-Whitney test were used for continuous variables depending upon whether the variables were normally distributed. Continuous variables were summarised using means±SD or medians (interquartile range, IQR). Logistic multivariable regression analysis was performed on independent variables such as gender and age where the response variable was activation for one model and mortality for another model. Correlation was computed using Pearson product moment correlation coefficient. Other aspects we found interesting to investigate include the gender distribution of the referrals, in hour and out of hour ratio and finally 30 days mortality.

2.2. Ethical aspects

Permission for the study was obtained from the regional Ethical Review Board IRAS 251710, NHS (ORECNI) and complied with the Declaration of International Research Integrity Association [12].

3 Results

3.1 Time Series Analysis of all referrals

The turndown group also had similar results as of total referrals with the year 2016 had maximum turndown referrals with 38% (548, $p<0.001$) compared to 29% in 2015 and 33% in 2017. Similarly, for the acceptance referral rate for the years available (2015,2016,2017,2018) was 23%, 23% 26% and 28% respectively. December had the maximum acceptance rate of 11% ($p=0.008$). Figure 1 shows the detail of referral rates per month. It is evident that the first two months of a year have more turndown referrals as compared to accepted referrals benchmarked against the end of the year.

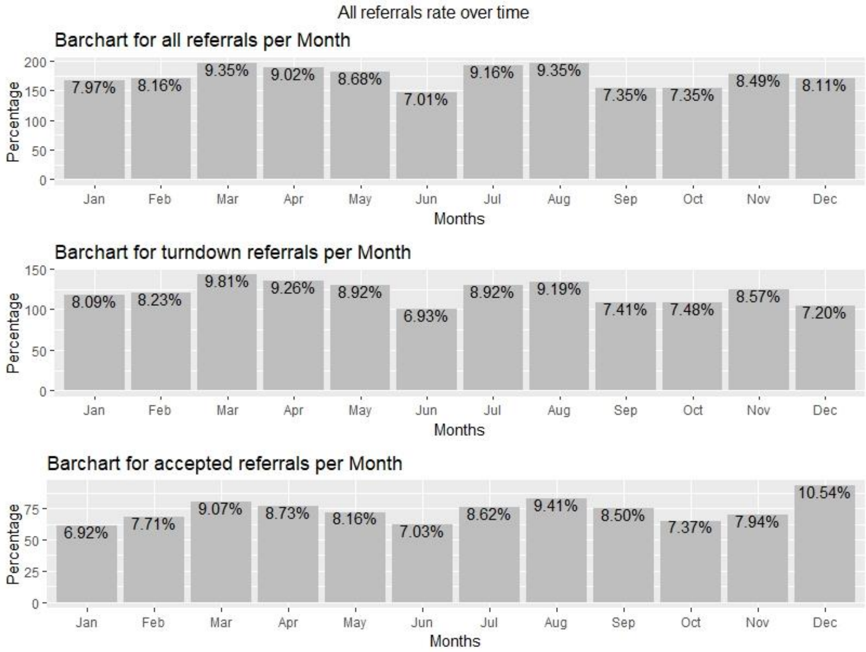

Figure 1 Showing referrals rate over time a) all referrals, b) turndown referrals and c) accepted referrals

Figure 2 shows the seasonality, trend and autocorrelation of the total referral data. The seasonality of the data shows 9 different peaks for all the three years. Average interval between each peak is calculated as 3 months (SD=0.83). The autocorrelation shows a correlation every 4 months that depicts the relation of the referrals every 4 months.

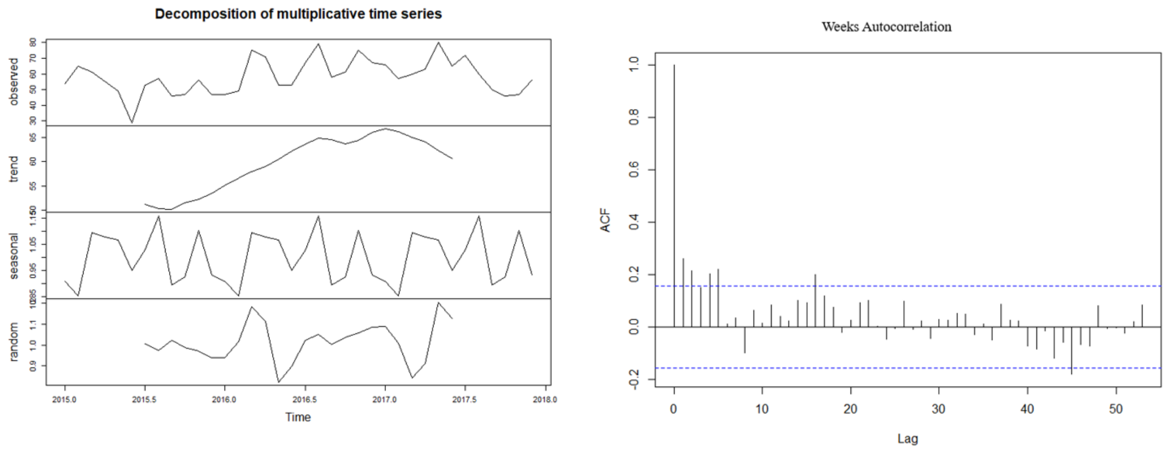

Figure 2 Showing time series decomposition and autocorrelation of all referrals

Figure 3 depicts the overall time series analysis of total referrals over years. The bar chart shows the referral rate per season for each year. The overall increase each year per season is observable, however among the four seasons, summer had a visible gradual increase over each year. Nevertheless, there is a lack of consistency in the distribution of referrals per year based on season.

All years have multiple peaks over the months. However, there has been a significant decrease in referrals for the month of June (p = 0.007). Also, no correlation was found between the monthly referral rate of each year (p>0.05). Therefore, seasons or the times of the year does not cause or correlate with people having heart attacks.

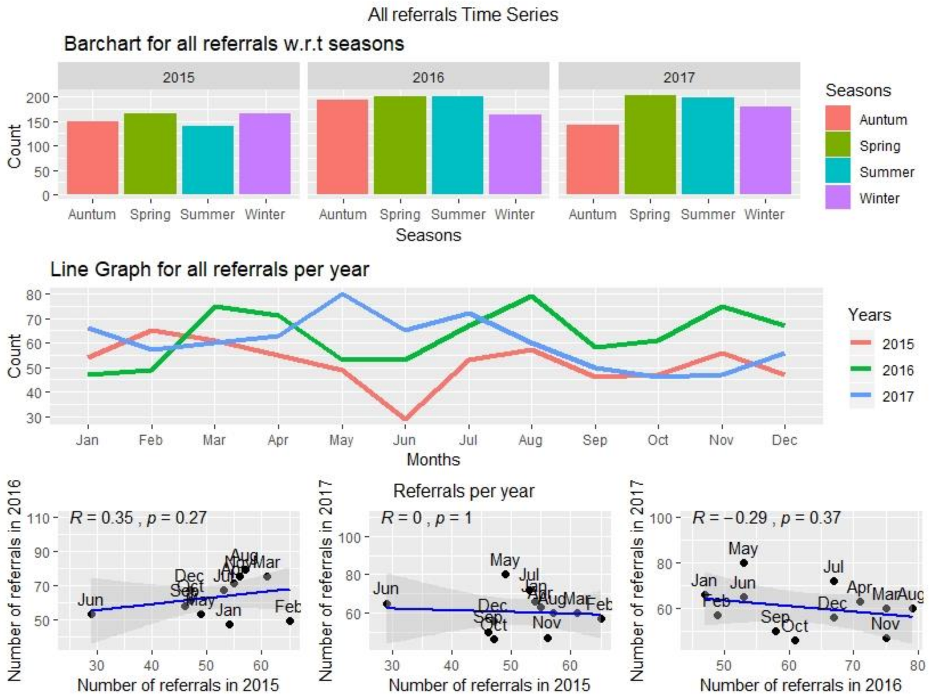

Figure 3 Time Series of referral rates, a) per season, b) per month and c) correlation between the number of referrals per month in one year with another year

The weekly distribution of total referrals depicts multiple peaks. Figure 4.a show the referrals distribution as well as the scatter plot which shows a strong correlation between the referrals of the year 2015 and 2016. The hourly distribution of total referral rates is similar for each year. Figure 4.b shows the referral rate distribution on an hourly basis as well as the scatter plot which shows a strong correlation (r ~ 0.7) between the hourly referral rates of year 2015, 2016 & 2017.

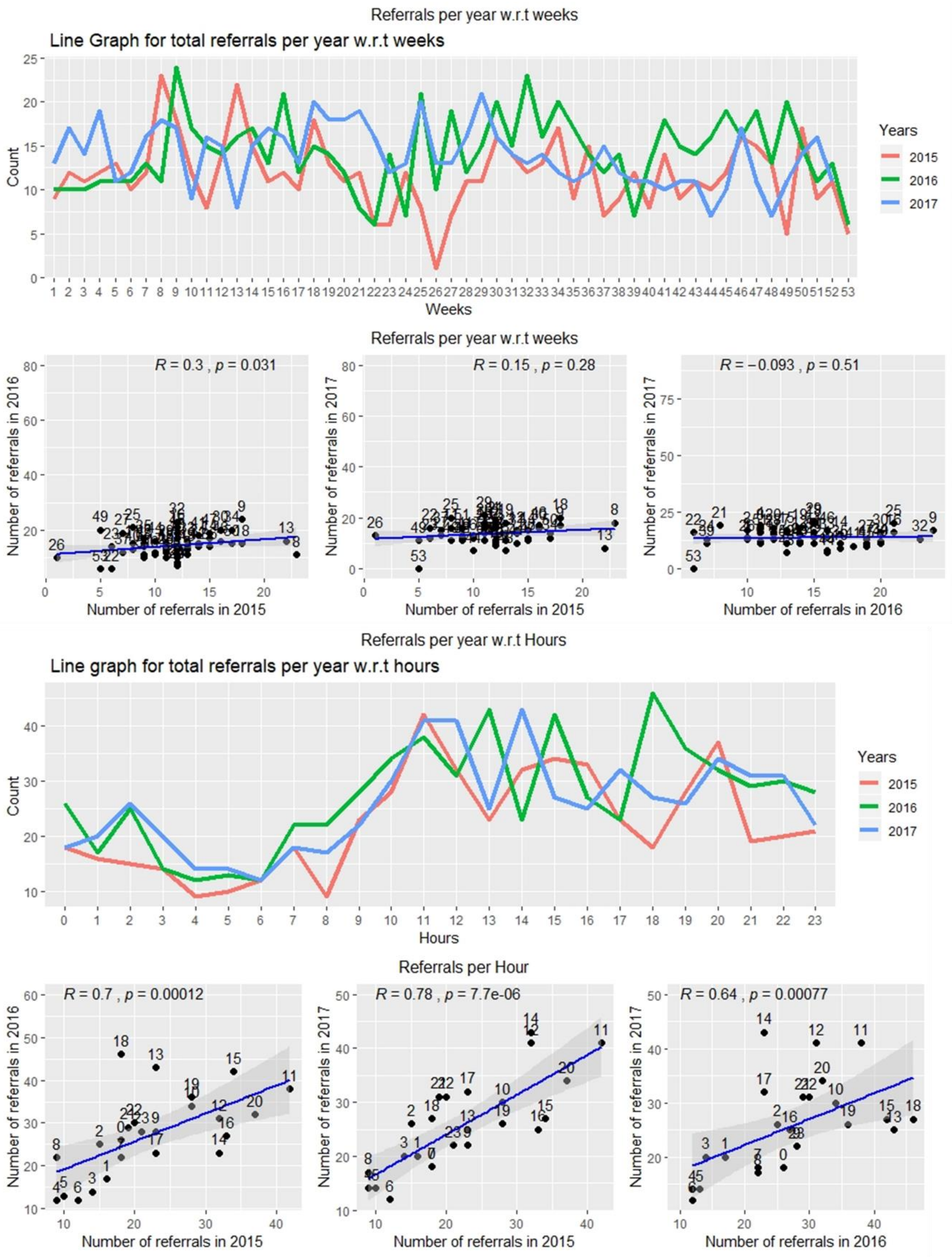

Figure 4 Scatter plots showing a correlation value between the number of referrals a) per week, b) per hour in one year with another year

3.2 Turned down and accepted referral Time Series Analysis and comparison

3.2.1 Turned down and accepted referrals Time Series Analysis

Figure 5 shows the referral rates over each month, weekday and hour for each year respectively for those patients who were turned down. Fig 5.a provides a time series analysis for the turndown and accepted referral patterns per month for each year. No single month in all the years exhibit a significant turndown or accepted count. Collectively March, April and May had the maximum number of turndown referrals for all years (28%).

Figure 5.b and Figure 5.c shows the referrals pattern over weekdays and hours. In turndown group Tuesday had the highest variation with SD = 6.03 and Thursday was most consistent with SD =2.74. In terms of hour 11am has highest variance with SD= 3.66 and 4am SD=1.31 had highest consistency over the months. In accepted group Thursday was highest variant day with SD= 4.50 and Friday was the highest consistent with SD= 2.54 over the months. In terms of hours 11am and 2pm had maximum variation with SD= 2.01 and 6am is the most consistent with SD= 0.866 over the months.

Figure 6 shows the correlation between the total number of all referrals with referral turndown rate for each month over all three years. The analysis shows no statistical significance which implies that an increase in referrals may not impact on decision making or a disproportionate increase in turn downs (see fig 6).

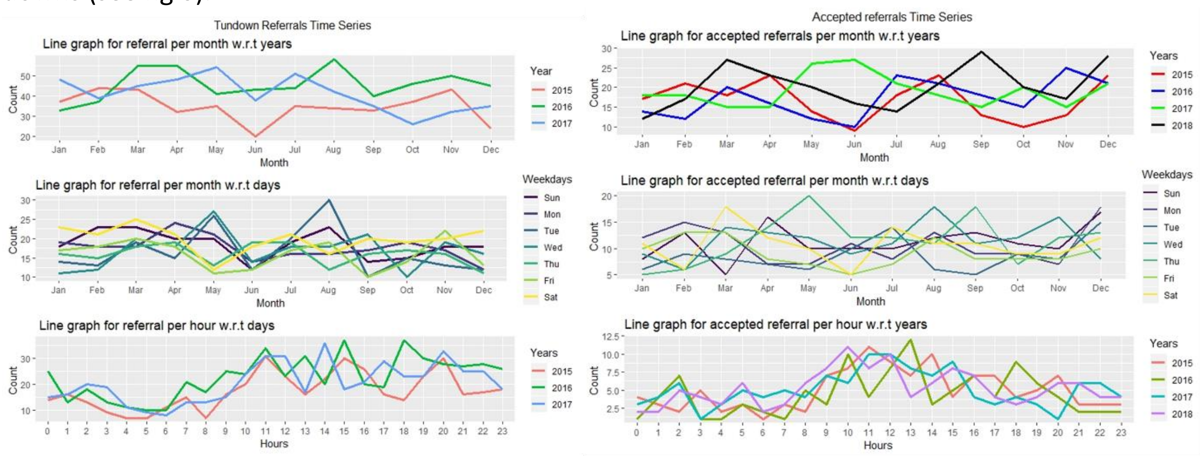

Figure 5 Turndown and accepted referrals Time Series Analysis for a) per month, b) per week and c) per hour

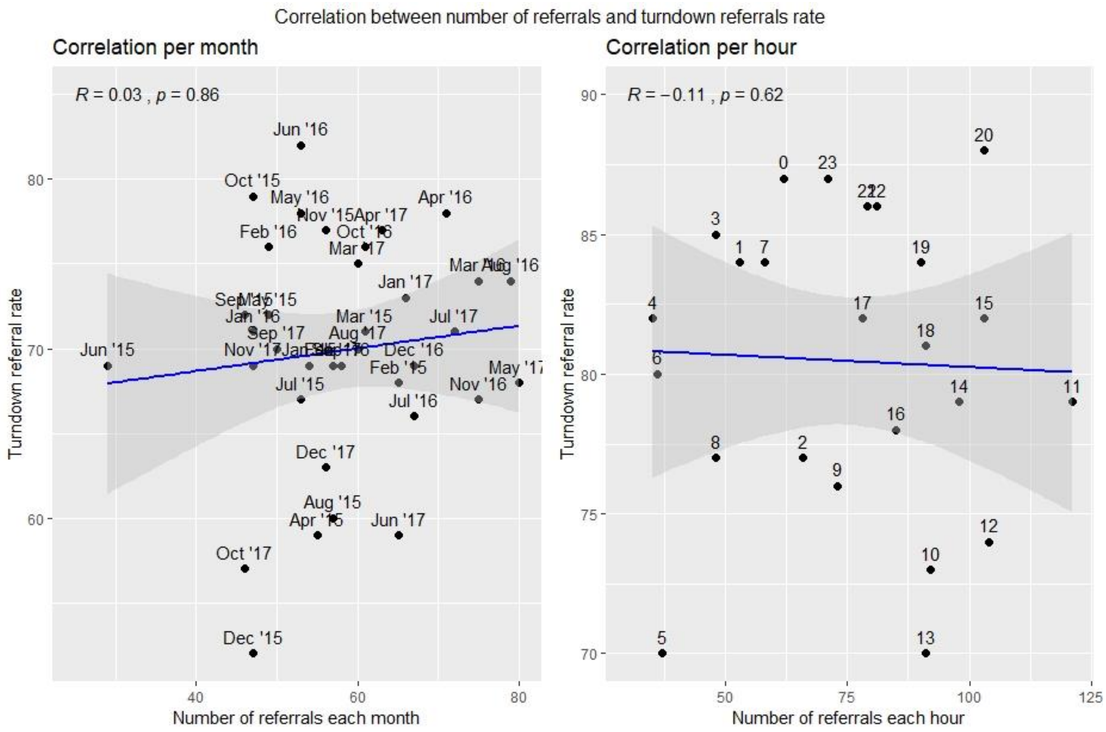

Figure 6 Turndown referrals rate correlation with number of referrals

3.3 Analysis of all referrals

Figure 7 shows the bar chart for each group respectively. The gender distribution of all referrals are predominantly male. A total of 70% of the referrals were male patients. More than 50% of the referrals are out of hour (up to 75%) with more referrals reported over the weekends ($P<0.001$). This indicates the necessity for 24/7 PPCI services.

Figure 8 depicts that 4am and 8pm were the peak referral times for those patients with 30 days mortality. However, the month of September had maximum of 30 days mortality for turndown referrals whereas January, July and November had a greater number of patients with 30 days mortality in accepted referrals.

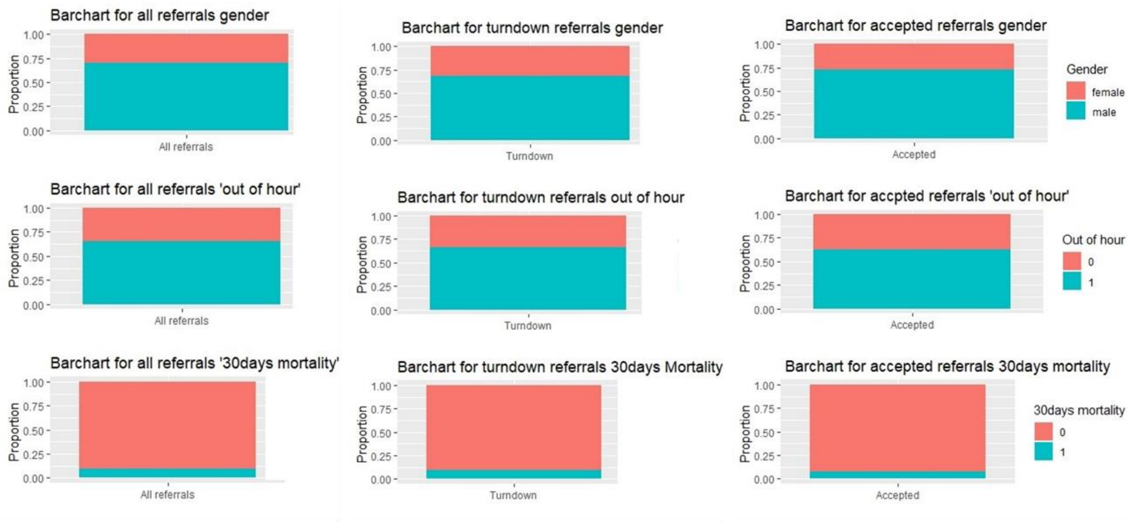

Figure 7 Referrals) general analysis of all referrals, turndown and accepted referrals

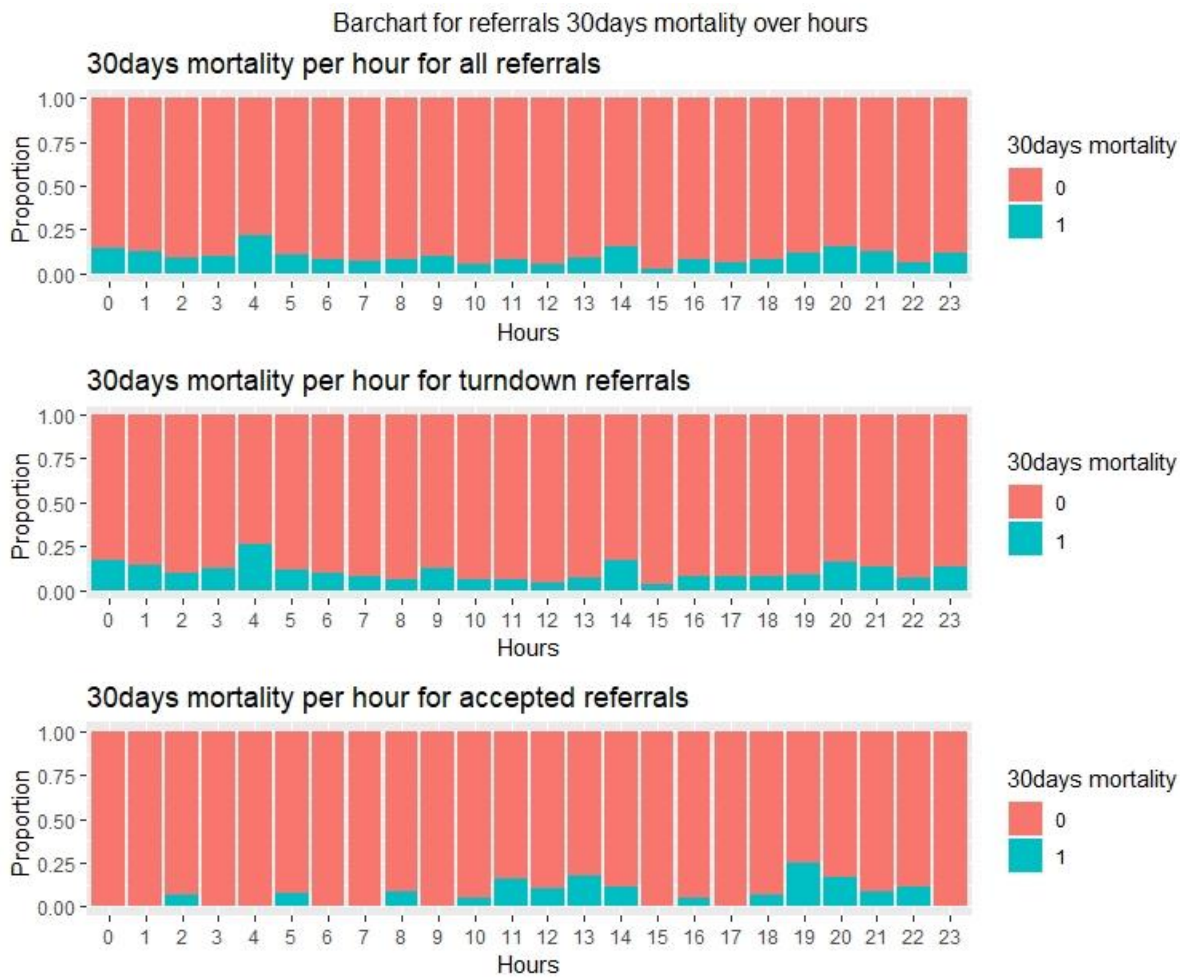

Figure 8 Referrals) 30days mortality analysis per hour of 'all referrals', turndown and accepted referrals

3.4 General analysis and comparison between turndown and accepted group

The figure 9 shows that the women were older than men in both the groups, i.e. the turndown group (mean ages 73.0 vs 64.9 years, $p < 0.001$) and the accepted group (70.48 vs 61.44 years, $p < 0.001$). Both male and females have greater mean age in the turndown group. Regarding the 'out of hour' referrals, 66% of the total referrals were turned down 'out of hours' among which 32% were made on the weekends whereas in accepted patients, 59% of referrals were accepted 'out of hour' amongst which 52% were made on weekends shown in figure 7. The out of hour referrals for both groups merged is significant ($p < 0.001$) compared to in hour referrals. For all the referrals that were turned down, the peak hours were 11am [7%], 3pm [6%], and 8pm [6%]. The rate of acceptance peaked during the morning hours 10am (38/540[7%]), 11am (38/540 [7%]) and 12pm (48/540 [7%]). Patients that were accepted during these peak hours included ~30% females and ~70% males. There is a significant difference between the 30 days mortality rate amongst accepted patients and turned down patients, i.e. 5.4% vs. 8.0% in the turndown referrals ($p=0.01$). 60% of patients with 30 days mortality in the accepted group are 'out of hour' and 73% of patients with 30 days mortality in the turndown group are 'out of hour' (see figure 8).

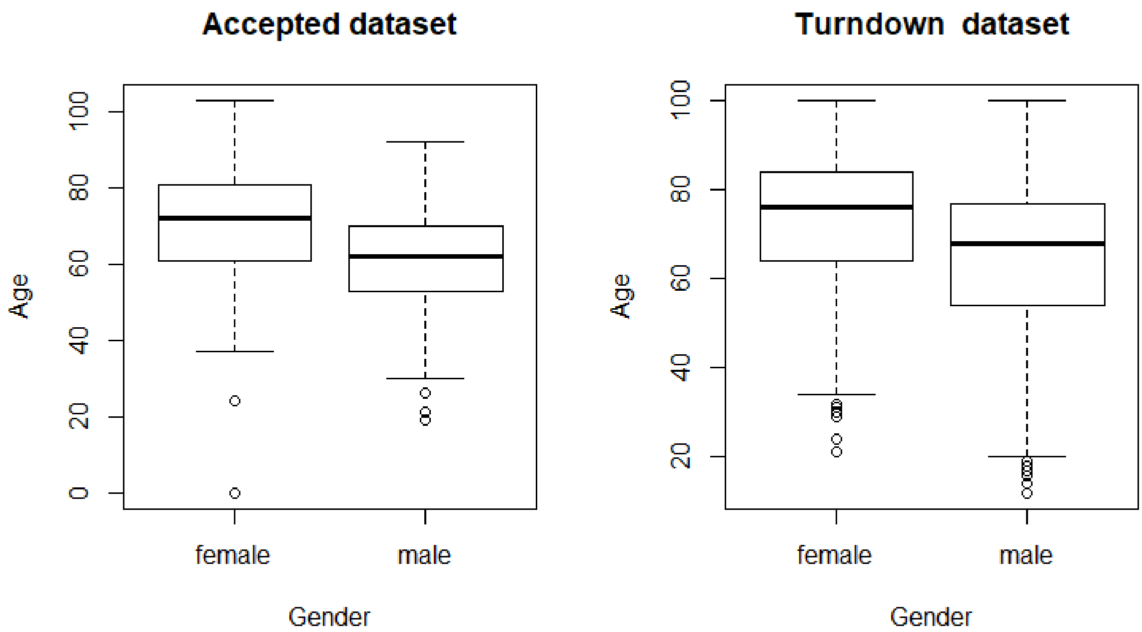

Figure 9 Mean age w.r.t gender

3.5 Logistic regression

Table 1 shows the odds ratios for all referrals, table 2 shows the results for the turndown group and table 3 shows results for the accepted group. In 'all referrals' and in the 'turndown referrals' both, age ($p<0.001$) and being an out of hour referral ($p>0.05$, not significant) increased the odds of mortality after 30 days (Table 1 and 2). Being a female increased the odds of being referred 'out of hour' ($p=0.039$).

In the accepted group, there could be true activations as well as a false activation. A false activation is when a patient referral is accepted and taken to the CathLab, but the angiogram reveals that there is no blockage. The 30 days mortality (p<0.001) reduced the odds of a true activation in accepted referrals (Table 3). Age (p<0.001) and being 'out of hours' increased the odds of mortality after 30 days. The STEMI true activation, and being a female increased the odds of being referred 'out of hours'.

Table 1. Odds ratios of variables derived from multiple logistic regression in all referrals group

All Referrals	Response variable is '30days mortality'	Odds Ratio (CI)	Std. Error	P-value
	Out of hour	1.19(0.82, 1.73)	0.188	0.375
	Age	1.06 (1.04, 1.07)	0.007	<0.001
	Sex (Female)	0.98(0.67, 1.40)	0.186	0.903
All Referrals	Response variable is 'out of hour'			
	Age	1.00 (0.99, 1.00)	0.003	0.928
	Sex (Female)	1.16 (0.94, 1.42)	0.118	0.155

Table 2. Odds ratios of variables derived from multiple logistic regression in turndown group

Turndown Referrals	Response variable is '30days mortality'	Odds Ratio (CI)	Std. Error	P-value
	Out of hour	1.35(0.87, 2.12)	0.225	0.183
	Age	1.06 (1.04, 1.08)	0.008	<0.001
	Sex (Female)	0.98(0.64, 1.48)	0.214	0.932
Turndown Referrals	Response variable is 'out of hour'			
	Age	0.99 (0.99, 1.00)	0.003	0. 424
	Sex (Female)	1.13(0.89, 1.45)	0.123	0.289

Table 3. Odds ratios of variables derived from multiple logistic regression in accepted group

Accepted Referrals	Response variable is 'true activation'	Odds Ratio (CI)	Std. Error	P-value
	Out of hours (true/false)	1.01 (0.64, 1.56)	0.223	0.960
	Age	1.02 (0.99, 1.04)	0.008	0.022
	Sex (Female)	0.65 (0.41, 1.05)	0.243	0.078
Accepted Referrals	Response variable is 'mortality in 30 days'			
	Out of hours (true/false)	0.79 (0.41, 1.55)	0.330	0.497
	Age	1.03 (1.01, 1.06)	0.014	0.002
	Sex (Female)	0.85 (0.39, 1.75)	0.378	0.671
	Activation	0.13 (0.05, 0.34)	0.484	<0.001
Accepted Referrals	Response variable is 'out of hour'			
	Age	1.01 (0.99, 1.02)	0.006	0.884
	Sex (Female)	1.11(0.80, 1.55)	0.171	0.255
	Activation	1.01 (0.65, 1.56)	0.224	0. 547

Discussion

The results depict a lack of consistency in the distribution of referrals over the seasons for each year. Furthermore, referral rates per hour show similar patterns between the referral rates for each year. For weeks, no correlation was found except for year 2015 and 2016. However, there was a statistically significant correlation ($r=0.7$, $r=0.7$, $r=0.6$, $p<0.001$) between the hours of each year (2015, 2016, 2017).

This research found some gender differences, i.e. 70% of referrals were male. Lawesson et al. (9) illustrates the gender dependency on STEMI symptoms where females tend to have less chest pain. Another significant finding in the analysis includes the fact that 65% ($p<0.001$) of the total referrals were out of hours. This result determines the importance of a working 24/7 CathLab. A study investigated the effectiveness of STEMI patients treated by PPCI within normal working hours compared with those treated out-of-hours, resulting no significant difference (10). However, that study used a single centre's experience which limits the results. Females were older in both the turndown and accepted groups. Also, we found that 'younger' patients were accepted for PPCI when compared to the turndown group. It is evident from the analysis that mortality within 30 days is higher in the turndown patients when compared to the accepted referrals. Also, mortality rate in accepted referrals is lower at night time (midnight to 6am) when compared to turndown referrals.

This is an early development hence we are currently working with Raigmore Hospital in NHS Scotland to gather their PPCI referral data for aggregation and comparison. Therefore, in the future we aim to perform a multi-centre study. Also, we aim to add the ethnicity or socioeconomic status differences in the referral data to our analysis as well. Given a time series of data, we did use an AR model for predicting future values in this series. The AR part involves regressing the variable on its own lagged (i.e., past) values. However, we did not use the moving average model in this study, but it will be interesting to use the ARMA model in a future paper.

Limitations

These findings are based on one dataset of a single hospital of Northern Ireland which can limit the results and may not be a depiction of all PPCI services. However, in future analysis, enhancement has been planned in terms of including the dataset from other UK hospitals.

Conclusion

This research identified the time series for PPCI referrals as well as for each type of referral (accepted and turndown). The variation/fluctuation of referral rates over the months or days of the week are unpredictable since the rates are not similar for each year. However, the changes in the referral rates over hour of the day is consistent and predictable for each year. A pattern of referral rate peaks of 3 months seasonality can be found. Each respective referral group have more male referrals as compared to the females. The average age of the patients in turndown group (68 ± 27) is higher when compared to the accepted patients (63 ± 40), which perhaps indicates that there is less chance of having STEMI at an older age. Furthermore, the two groups have different peak referral months, days and hours, for example most of the referrals were made and turned-down at the start of the year however, most referrals were accepted at the end of the year. Similarly, the maximum number of referrals were turned-down at 11am however, most referrals were accepted at 10am. Most patients (58%-65%) were referred out of hours ($p<0.001$). Females are more likely to be referred out of hours in all three groups. This analysis leads to the emphasis on the importance of a 24/7 CathLab and PPCI service. Also, patient referrals that are accepted at night time (after midnight) are less likely to die within 30 days. However, if patients are referred and turndown in the night hour then they are more likely to die within 30 days.

Disclosure Statement: The author(s) have no conflicts of interest to disclose.

References

1. Widimský P. Long distance transport for primary angioplasty vs immediate thrombolysis in acute myocardial infarction Final results of the randomized national multicentre trial—PRAGUE-2. Eur Heart J [Internet]. 2003 Jan [cited 2019 Mar 6];24(1):94–104. Available from: https://academic.oup.com/eurheartj/article-lookup/doi/10.1016/S0195-668X(02)00468-2

2. Keeley EC, Boura JA, Grines CL. Primary angioplasty versus intravenous thrombolytic therapy for acute myocardial infarction: a quantitative review of 23 randomised trials. Lancet [Internet]. 2003 Jan [cited 2019 Mar 6];361(9351):13–20. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0140673603121137

3. Silber S, Albertsson P, Avilés FF, Camici PG, Colombo A, Hamm C, et al. Guidelines for Percutaneous Coronary Interventions. Eur Heart J [Internet]. 2005 Apr 1 [cited 2019 Mar 7];26(8):804–47. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15769784

4. National Clinical Guideline Centre Myocardial infarction with ST-segment elevation The acute management of myocardial infarction with ST-segment elevation [Internet]. [cited 2019 Mar 6]. Available from: https://www.nice.org.uk/guidance/cg167/evidence/myocardial-infarction-with-stsegment-elevation-full-guideline-191476189

5. 7 Day Services Clinical Guidance-STEMI [Internet]. [cited 2019 Mar 6]. Available from: http://www.bcis.org.uk/documents/7A3_BCIS_STEMI_Guidelines_July_2016.pdf

6. Antman EM, Anbe DT, Armstrong PW, Bates ER, Green LA, Hand M, et al. ACC/AHA Guidelines for the Management of Patients With ST-Elevation Myocardial Infarction—Executive Summary. Circulation [Internet]. 2004 Aug 3 [cited 2019 Jun 5];110(5):588–636. Available from: https://www.ahajournals.org/doi/10.1161/01.CIR.0000134791.68010.FA

7. Scholz KH, Maier SKG, Maier LS, Lengenfelder B, Jacobshagen C, Jung J, et al. Impact of treatment delay on mortality in ST-segment elevation myocardial infarction (STEMI) patients presenting with and without haemodynamic instability: results from the German prospective, multicentre FITT-STEMI trial. Eur Heart J [Internet]. 2018 Apr 1 [cited 2019 Mar 6];39(13):1065–74. Available from: https://academic.oup.com/eurheartj/article/39/13/1065/4855284

8. Krishnamurthy A, Keeble C, Burton-Wood N, Somers K, Anderson M, Harland C, et al. Clinical outcomes following primary percutaneous coronary intervention for ST-elevation myocardial infarction according to sex and race. Eur Hear J Acute Cardiovasc Care [Internet]. 2017;204887261773580. Available from: http://journals.sagepub.com/doi/10.1177/2048872617735803

9. Sederholm Lawesson S, Isaksson R-M, Thylén I, Ericsson M, Ängerud K, Swahn E. Gender differences in symptom presentation of ST-elevation myocardial infarction – An observational multicenter survey study. Int J Cardiol [Internet]. 2018 Aug 1 [cited 2019 Mar 15];264:7–11. Available from:

https://www.sciencedirect.com/science/article/pii/S0167527317366500?via%3Dihub

10. Rathod KS, Jones DA, Gallagher SM, Bromage DI, Whitbread M, Archbold AR, et al. Out-of-hours primary percutaneous coronary intervention for ST-elevation myocardial infarction is not associated with excess mortality: a study of 3347 patients treated in an integrated cardiac network. BMJ Open [Internet]. 2013 Jun 28 [cited 2019 Apr 16];3(6):e003063. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23811175

11. Drexhage O, Schalij M, Velders M, Hautvast R, Ytsma T, Hermans M, et al. Call-to-balloon time dashboard in patients with ST-segment elevation myocardial infarction results in significant improvement in the logistic chain. EuroIntervention. 2017;13(5):e564–71.

12. Sillesen M, Sejersten M, Strange S, Nielsen SL, Lippert F, Clemmensen P. Referral of patients with ST-segment elevation acute myocardial infarction directly to the catheterization suite based on prehospital teletransmission of 12-lead electrocardiogram. J Electrocardiol [Internet]. 2008 Jan 1 [cited 2019 Mar 1];41(1):49–53. Available from: https://www.sciencedirect.com/science/article/pii/S0022073607007777

13. Veronese G, Germini F, Ingrassia S, Cutuli O, Donati V, Bonacchini L, et al. Emergency physician accuracy in interpreting electrocardiograms with potential ST-segment elevation myocardial infarction: Is it enough? Acute Card Care [Internet]. 2016 Jan 2 [cited 2019 Mar 15];18(1):7–10. Available from: https://www.tandfonline.com/doi/full/10.1080/17482941.2016.1234058

14. Mencl F, Wilber S, Frey J, Zalewski J, Francis Maiers J, Bhalla MC. Prehospital Emergency Care Paramedic Ability to Recognize ST-segment Elevation Myocardial Infarction on Prehospital Electrocardiograms) Paramedic Ability to Recognize ST-segment Elevation Myocardial Infarction PARAMEDIC ABILITY TO RECOGNIZE ST-SEGMENT ELEVATION MYOCARDIAL INFARCTION ON PREHOSPITAL ELECTROCARDIOGRAMS. Prehospital Emerg Care [Internet]. 2013 [cited 2019 Mar 15];17(2):203–10. Available from: https://www.tandfonline.com/action/journalInformation?journalCode=ipec20

15. Novotny T, Bond RR, Andrsova I, Koc L, Sisakova M, Finlay DD, et al. Data analysis of diagnostic accuracies in 12-lead electrocardiogram interpretation by junior medical fellows. J Electrocardiol [Internet]. 2015 Nov [cited 2019 Jun 18];48(6):988–94. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0022073615002654

16. Bond RR, Zhu T, Finlay DD, Drew B, Kligfield PD, Guldenring D, et al. Assessing computerized eye tracking technology for gaining insight into expert interpretation of the 12-lead electrocardiogram: an objective quantitative approach. J Electrocardiol [Internet]. 2014 Nov [cited 2019 Jun 18];47(6):895–906. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0022073614002258

17. Peace A, Ramsewak A, Cairns A, Finlay D, Guldenring D, Clifford G, et al. Using computerised interactive response technology to assess electrocardiographers and for aggregating diagnoses. J Electrocardiol [Internet]. 2015 Nov [cited 2019 Jun 18];48(6):995–9. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0022073615002253

18. Cox JMS, Steel N, Clark AB, Kumaravel B, Bachmann MO. Do referral-management schemes reduce hospital outpatient attendances? Time-series evaluation of primary care referral management. Br J Gen Pract. 2013 Jun;63(611).

19. Chan JY, Tian L, Kwan YW, Chan WM, Leung CW. Hospitalizations for varicella in children and adolescents in a referral hospital in Hong Kong, 2004 to 2008: A time series study [Internet]. 2011 [cited 2019 Apr 11]. Available from: http://www.biomedcentral.com/1471-2458/11/366