Study of patient transfers during the COVID-19 pandemic using complex networks

T. Cicchini [*1], L. Otero[2], A. Salgado[1], A. Yacobitti[2], V. Doldan[2], S. Kochen[2,3], L. Boechi[1], and I. Caridi[1]

[1]Instituto del Cálculo (IC), UBA-CONICET. Buenos Aires, Argentina.
[2]Hospital de Alta Complejidad Nestor Kirchner, El Cruce, Pcia Buenos Aires, Argentina
[3]Unidad Ejecutora de Estudios en Neurociencia y Sistemas Complejos (ENyS, CONICET-HEC-UNAJ)

Abstract

The COVID-19 pandemic placed health systems worldwide in crisis, and the pre-existing health infrastructure had to adapt to its new and changeable conditions. Here we analyze a hospitals network representing the *Red Sudeste* in Buenos Aires, Argentina. This network has health centers from the Red Sudeste as nodes, and each link represents the number of patient transfers between pairs of health centers. A fragmented structure arises when exploring the aggregated network in time. The evolution of the network, separated into three different stages, shows an increase in the efficiency of patient transfers through time.

Keywords: Network Medicine, Temporal Networks, Health Systems, COVID-19

Introduction

The COVID-19 pandemic placed health systems worldwide in crisis. The lack of health personnel and supplies, and the saturation of hospital beds, were some of the effects generated at the beginning of the pandemic. The functioning of hospitals in a network is a common practice that allows the optimization of physical and human resources at critical moments, facilitating the referral of patients of medium and high complexity between the network's hospitals [1]. However, the pandemic generated abrupt changes in the coordination of these networks. Here we consider the *Red Sudeste*, a hospitals network including the Public Hospitals of four municipalities in the Southeast of the Metropolitan Area of Buenos Aires, Argentina. The public hospitals of *Red Sudeste* have different capacities and complexities. In particular, *UPAs*(Promt Care Units), by its initials in Spanish, are primary attention centers and *Módulos Hospitalarios*(Hospital Module) are high complexity health centers. We analyze an aspect of the coordination between the health centers: the patient transference within the network's fourteen hospitals, in the period comprised between 01/03/20 and 15/07/21.

A computer system built at the beginning of the pandemic to collect, organize and display information on the use and availability of patient beds in the hospital network [2, 3] stored all data on transfers within *Red Sudeste*. Representing patient transfers as directed and temporary links between health centers, we study the network's structure change over time. At the same time, we quantify the complexity of the transfers in terms of bed type, clinical risk, and differences between the involved health centers, seeking to understand the functioning of the network at the different key moments of the pandemic.

*tcicchini@df.uba.ar

Hospitals Network: Construction and Aggregated Analysis

From the data collected by the system mentioned above, it is possible to build an origin-destination matrix that accounts for the patient transfers between different health centers. Considering all the data of the studied period, we assemble a weighted and directed complex network, where the nodes represent the hospitals and the weight of the links accounts for the number of transfers between two hospitals. This representation (see, for example, [4]) allows us to study characteristics of the hospital network related to its level of centralization, fragmentation, and efficiency.

After removing links representing less than 4 transfers, the remaining links only connect hospitals from the same district (Figure 1[A]). *El Cruce* is the only exception, connecting to hospitals from different districts. In turn, *Evita Pueblo* and *UPA 10-BE* are isolated from the rest of the network.

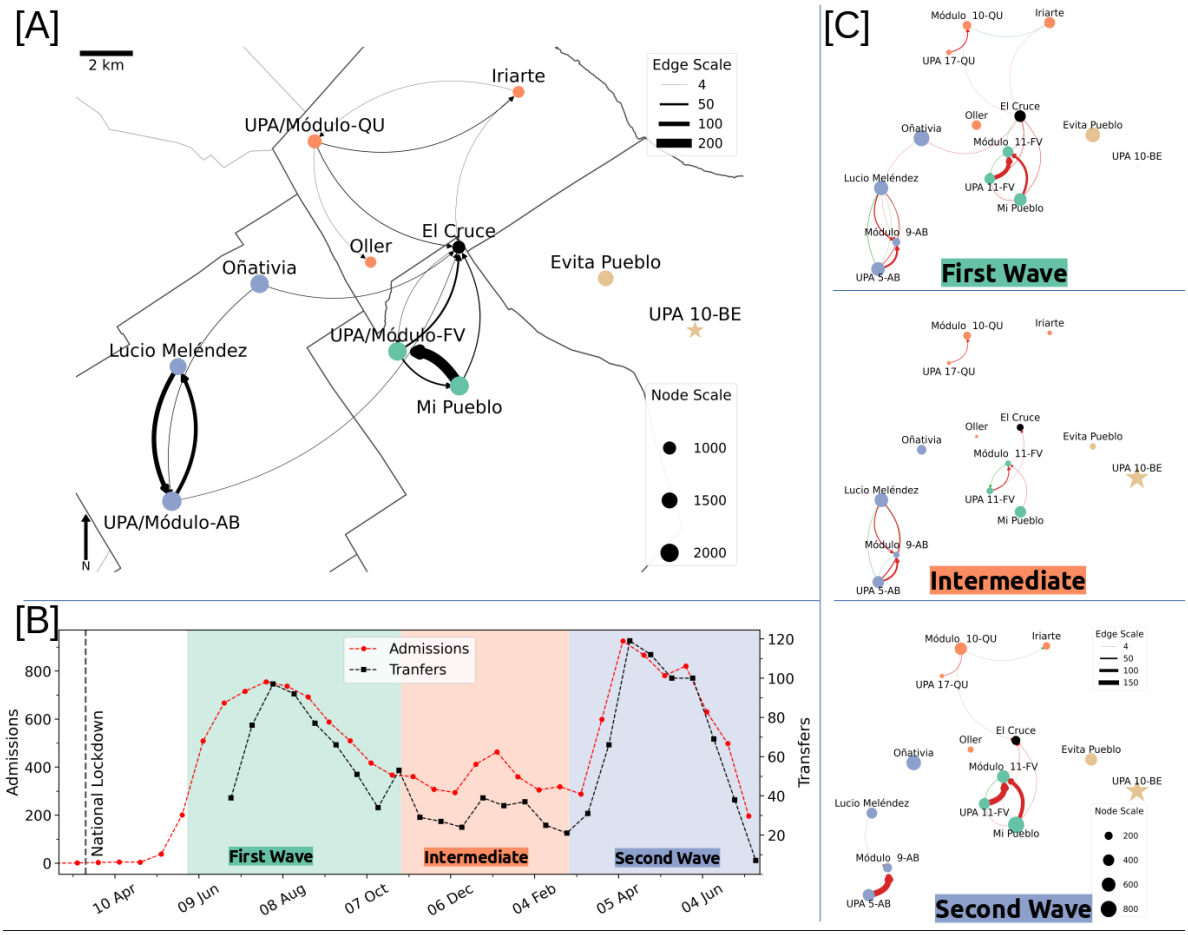

Figure 1: *[A] Aggregated hospitals network. Node size represents the total amount of admissions over the total period. Node layouts correspond to the geographic place of the hospitals. Node colors refer to the distinct districts where the hospitals belong. Edge width linearly stands for the number of transfers between hospitals. [B] Temporal evolution of the total number of transfers and admissions in the different pandemic stages. [C] Temporal snapshots of the temporal hospitals' network.*

Hospital Network: Evolution Throughout the Pandemic

The daily number of patient admissions and patient transfers does not remain constant throughout the pandemic. Moreover, the dynamic of the pandemic changed over time. We divide the period into three different moments, following the criterion defined by the health system administration: first wave (01/06/20 to 31/10/20), intermediate (1/11/20 to 28/02/21) and second wave (1/03/21 to 30/06/2021) (Figure 1[B]). Taking into account the date of each patient transfer, it is possible to build a separate network for each pandemic stage.

	First Wave	Intermediate	Second Wave
Admissions	5017	2674	5559
Total transfers	531	263	612
Ambulance transfers	279 (52.5%)	138 (52.5%)	188(30.7%)
Total traveled distance / median distance by transfer [km]	1518 / 5.41	840 / 5.59	811 / 3.18
UPA-Modulo transfers	252 (47.5%)	123 (46.8%)	424 (69.3%)

Table 1: *Patient admissions and transfers data of the different studied stages. Percentage of Ambulance and UPA-Modulo transfers indicate percentage of total transfers.*

Figure 1[C] shows the networks for each stage. Unlike the aggregated network, the nodes corresponding to *Modulos Hospitalarios* and UPAs were split. While they belong to the same physical space, they operate as different health centers in practice. This distinction allows us to observe the large number of transfers between them. These transfers were made without the need to use ambulances. When observing Figure 1[B] and Table 1, it is evident that the number of admissions and transfers are similar in the first and second waves. However, the UPA-Modulo transfers increase from first to the second wave (see Table 1). Moreover, while the percentage of ambulance transfers represents around 50% of the total transfers on the first wave, they represent only 30% on the second wave (Table 1). In addition, we see an abrupt drop in the total travelled distance and median traveled distance from first to second wave. This reflects the increase in efficiency of the network throughout the pandemic.

Discussion and Further Analysis

The methodology allows us to build a network between hospitals to analyze aspects of the functioning of the Red Sudeste through their transfers. Moreover, by using the temporal characterization of the transfers, we can study the evolution of the network through time. These preliminary results contribute to our better understanding of the behavior of the *Red Sudeste* throughout the COVID-19 pandemic. In particular, the aggregated network analysis shows that the system is highly fragmented with *El Cruce* being the node that connects health centers from different districts. This makes sense because *El Cruce* Hospital has the greatest level of complexity in *Red Sudeste*, receiving patients with severe risk from many health centers. Also, the analysis by stages confirms that transfers became more efficient, since ambulance transfers and traveled distance dropped significantly.

Currently, our work focuses on the different levels of complexity that characterize hospitals (according to their care capacities and resources) and transfers (considering the type of beds and the patient's state of health). Making use of this information will provide a deeper understanding of the system.

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