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IMPACT ON CHILEAN HOSPITALS FOLLOWING THE 2015 ILLAPEL EARTHQUAKE

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Abstract

In a post-disaster environment, hospitals play a critical role in healthcare services continuities to the population while effectively coping with eventual losses of functionality. These losses come from physical damage to the facility, loss of utility lifelines, failure in supply chains, and reduction of personnel. However, data describing the detailed performance of hospitals during past earthquakes are scarce. Consequently, following the 2015 M_w 8.3 Illapel earthquake in central Chile, an exhaustive field campaign was carried out in the Coquimbo region to collect substantial perishable data to describe physical damage to hospitals and functionality losses. This study presents first the baseline information obtained in nine surveyed government hospitals, including size, location and type of infrastructure. Then, the seismic impact was analyzed and classified to show the main physical structural and non-structural damage, lifeline interruptions, losses in hospital units, and variations in flow of patients and staff. Transfers, discharges and evacuations of patients that occurred after the event were also reported. We found that the earthquake did not affect strongly the healthcare service despite the fact that most of the structural and non-structural damage was localized in the largest regional hospital. The archival nature of the data collected may deepen our understanding of the post-earthquake healthcare system performance, which is very useful in improving disaster preparation and overall resilience.

Keywords: hospital resilience, loss of functionality, healthcare network, seismic performance, earthquake data collection.

1. Introduction

A M_w 8.3 earthquake struck near the coast of Chile on Wednesday, September 16th, 2015 at 19:54 local time. The megathrust faulting on the interface between the Nazca and South America plates occurred 48 km west of Illapel, in the Coquimbo region. Eight minutes after the event, a tsunami alert was issued for the coastal cities of the country, generating the evacuation of more than 660,000 people. The last official report informed a total of 15 deaths, and more than 688,000 people affected [1]. Press releases from the Chilean Ministry of Health (MINSAL) issued days after the earthquake demonstrate that the healthcare network of the country was operating normally, except in the Coquimbo region. MINSAL reported that 22 hospitals in coastal cities had to be completely evacuated, either vertically or inland to safety zones because of being situated below 30 m.a.s.l., official safety line for tsunami inundation hazard in Chile.

In a post-disaster environment, the role of hospitals is critical in maintaining continuity of healthcare delivery to the population while effectively coping with potential losses of functionality. These losses are mainly due to physical damage in the facility (i.e. structural, non-structural, and contents damage), loss of utility lifelines (e.g. water or electric supply), failure in supply chains, and reduction of personnel. However, data describing the performance of hospitals after earthquakes is scarce or nonexistent. Collecting data in hospitals after earthquakes does not only enable improving necessary information databases characterizing the response of the healthcare system, but also helps to calibrate predictive loss of functionality models for healthcare facilities. Identifying strengths and weaknesses in the response of critical infrastructure to extreme events, such as earthquakes, also helps improve somehow the preparation and resilience of healthcare systems.

Several studies summarizing the impacts of earthquakes on hospitals arose in the last decades. A study highlighted how hospitalization service and admissions were disturbed after the 2009 L'Aquila earthquake in Italy, showing how the number of hospitalized patients decreased, while those discharged transferred to other hospitals and those who rejected hospitalization increased [2]. After the 2011 Christchurch earthquake in New Zealand, data collection focused on the public health impacts in Christchurch at two scales: a single hospital [3], and the regional healthcare system [4]. The latter work was used to characterize the resilience of hospitals accounting for the dynamical redistribution of critical clinical and support services [5]. In South America, in 2001 El Salvador earthquakes demonstrated the weakness of the lifelines network impacting hospital functionality [6], and the 2007 Ica earthquake in Peru damaged 60% of the facilities surveyed in the most affected provinces [7]. The 1994 Northridge earthquake in southern California was well documented by various studies that focused on estimating the number of fatalities and injured people [8], described the evacuation process in hospitals following the event [9], and examined the lessons and experiences learned by disaster response agencies [10]. The Northridge earthquake data was later used to build and validate numerical models reproducing the behavior of a hospital emergency department [11]. Similarly, data collection was performed in the Bio-Bio region after the M_w 8.8 2010, Maule earthquake in Chile [12]. A functional loss assessment was standardized using this data in order to use it for US applications [13]. More recently, a performance model for a single hospital was proposed using data collected after the M_w 8.2 2014 Pisagua earthquake in Chile [14].

Consequently, following the 2015 M_w 8.3 Illapel earthquake, an extensive field campaign was performed in the Coquimbo region aimed to collect substantial data describing hospital damage and loss of functionality after the event. This study presents an overview of the physical damage and losses of functionality occurring in the nine public hospitals of the Coquimbo region. Moreover, the healthcare delivery is analyzed, highlighting patient transfers, discharges and evacuations as a consequence of the event. The data collected in this investigation is for archival use, and will be processed to improve knowledge on post-earthquake healthcare-system performance. The rest of the article is structured as follows: Section 2 describes the regional setting of the hospital network of the Coquimbo region. The field campaign and the methodology used to gather the data are described in Section 3. Section 4 presents the results of the surveys, and classifies the observed damage of the hospitals of the Coquimbo healthcare network. The final section draws some perspectives for future research using the collected data.

2. Geographical setting and baseline information of the hospitals

Public hospitals in Chile are classified by MINSAL into three complexity levels –low, medium, or high– depending on their bed count, the importance of the facility within the healthcare network, the availability of therapeutic and backup services for diagnosis at the hospital, the level of resoluteness of the provided medical services, the availability and level of specialization of its clinical staff, and the type of procedures and exams the hospital performs [15]. A thorough description of the Chilean national health system is presented in [13].

Low-complexity hospitals serve mainly as primary delivery services in rural zones. They typically may have up to 30 total beds, provide basic healthcare delivery (e.g., they lack medical specialists, and psychiatric and specialty hospitalizations), perform emergency childbirth (and transfer most of the non-urgent cases), and their infrastructure has only few support services such as a basic laboratory, a small pharmacy and a basic radiography service. Medium-complexity hospitals generally serve as reference centers for low-complexity hospitals, and provide more complex healthcare attention including intermediate intensive care with up to 300 beds, provide specialized medical services (i.e., internal medicine, pediatrics, obstetrics and gynecology, and psychiatry) and sometimes a few additional specialties, and have additional medical support services (e.g., more complex radiography service). High-complexity hospitals are the main reference centers for complex healthcare delivery. The hospitals may have up to 650 beds, provide intermediate and critical intensive care with high specialization of the human resources with specialists and subspecialists in the medical staff, and carry out sophisticated procedures in complex medical services (e.g. radiotherapy and nuclear medicine).

The hospital network of the Coquimbo region is composed of three high-complexity hospitals in the cities of Coquimbo, La Serena, and Ovalle; each city has more than 100,000 inhabitants. The only medium-complexity hospital in the region is in Illapel, and there are five low-complexity hospitals located in Andacollo, Combarbala, Los Vilos, Salamanca, and Vicuña, which are small towns surrounded by rural areas with no more than 30,000 inhabitants each. Fig. 1 shows the geographical region where this survey took place, the epicenter of the earthquake [16], the host cities of the nine public hospitals affected by the event, their year of construction and the maximum number of stories in each facility.

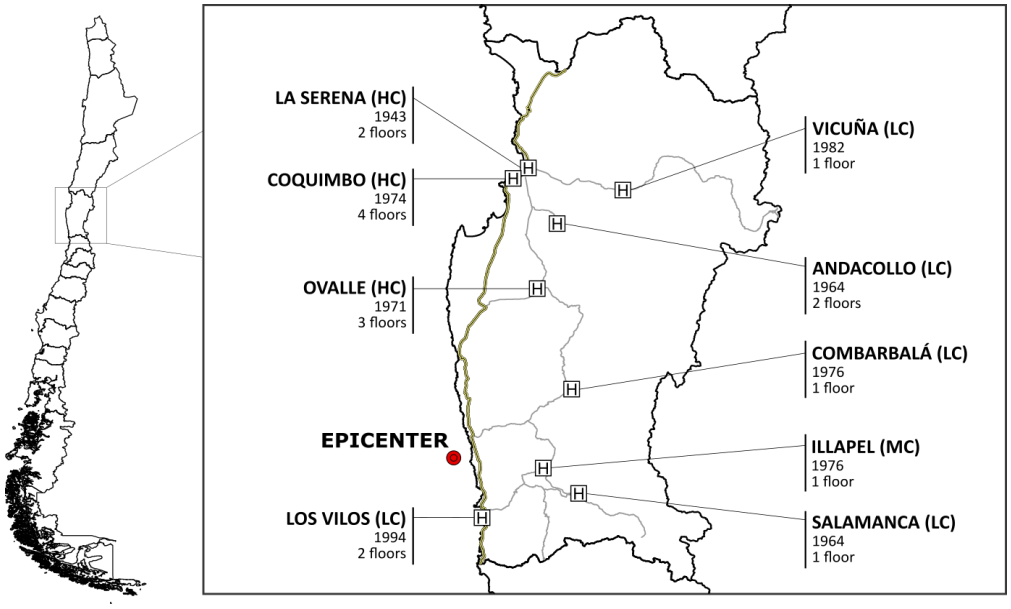

Fig. 1 – The five low-complexity (LC), one medium-complexity (MC), and three high-complexity (HC) hospitals built between 1943 and 1994 that form the public hospital network of the Coquimbo region; shown in the Figure is the earthquake epicenter [16] and main roads.

The hospitals were built mainly with reinforced concrete (RC), clay-brick masonry and timber. The common structural configurations are RC moment frames and shear walls of confined masonry. However, some hospitals declared having retrofits after the 1997 Punitaqui earthquake, meaning that the construction type is rarely homogeneous and/or known by the directors of the facilities. Also, new buildings have been built around the original one to extend the healthcare facility (e.g. in the Coquimbo hospital, the first tower was constructed in 1974 and the last one in 2010), especially in most complex hospital campuses. Table 1 presents a summary of the baseline information of the nine hospitals in the Coquimbo region based on their 2014 annual report, including: the number of physicians, nurses, and total employees working at the facilities; the number of beds; the number of annual hospitalization and Emergency Department (ED) visits; and the population of each city [17, 18]. Because of the lack of more complete data, the population of the city where the hospital is located is used as a proxy for the catchment community of each hospital.

Table 1 – Baseline information for the nine hospitals in the Coquimbo region before the 2015 Illapel earthquake [17, 18]

	Physicians	**Nurses**	**Employees**	**Beds**	**Annual hospit.**	**Annual ED visits**	**City Population**
Coquimbo	147	161	1,260	315	14,663	93,277	233,309
La Serena	153	138	988	284	14,943	68,176	234,300
Ovalle	82	61	639	191	9,522	73,754	115,624
Illapel	28	8	226	54	2,629	32,330	31,245
Andacollo	9	3	77	15	339	8,071	7,791
Combarbala	9	3	85	20	494	3,262	11,672
Los Vilos	11	5	128	33	1,074	21,081	19,120
Salamanca	11	6	113	26	1,114	20,915	25,697
Vicuña	10	3	99	30	1,237	28,851	27,171

"hospit.": hospitalizations.

3. Methods

Data were collected by a field investigation led by the National Research Center for Integrated Natural Disaster Management (CIGIDEN). The field investigation consisted of assessing the impacts of the Illapel earthquake in the critical infrastructures and the RC residential buildings of the region [19]. The reconnaissance team included ten researchers and engineers working on vulnerability and risk analysis; the team visited the Coquimbo region between September 23rd and 25th, one week after the Illapel earthquake. During the visit, seven out of the nine hospitals of the Coquimbo region were surveyed (Andacollo, Combarbala, Illapel, La Serena, Los Vilos, Ovalle, and Coquimbo). The remaining two facilities (Salamanca and Vicuña) were surveyed later by phone. Additionally, the Director of the Coquimbo Regional Healthcare Service was interviewed. The field work only focused on public hospitals; the team did not investigate smaller primary healthcare centers or private hospitals.

The survey tool used to collect data in the hospitals is a structured questionnaire developed at Johns Hopkins University by a multidisciplinary team, with expertise in engineering, disaster management, medicine, and public health. The survey was applied in similar versions to assess the 2010 Maule earthquake in Chile [13], the 2012 Christchurch earthquake in New Zealand [5] and the 2015 Nepal earthquake [20]. The team was trained by an original author of the survey tool in best practices for implementation in the field. The survey has different sections identifying the general impacts of the earthquake on the facility, the physical damages produced by the event (i.e. structural, nonstructural, and utilities and equipment damages), the impacts on service delivery, on supply chains, and on the flow of staff and patients. The team interviewed hospital directors or general services managers, often helped by the emergency chief nurse or a person from the statistics department of the hospital.

Physical damages were assessed directly by the field team when possible. Physical damages were assessed either by surveying the responsible staff on site or directly by the field team, which was composed of structural engineers. A follow up on the surveys was performed by telephone in late 2015 and early 2016 to obtain additional statistics, collect official hospital damage reports and other relevant information to better characterize the response and resilience of each facility.

4. Earthquake impacts on the hospitals

The impacts of the earthquake on the hospitals are divided into four categories: (i) physical impact, including structural, non-structural, and content damages in the hospitals; (ii) impact on lifelines and utilities, such as failures of electric and water supplies and communications networks; (iii) impact on the healthcare services, i.e. affected areas of each hospital and the downtimes of the different units and services; and (iv) variation in patients and medical staff.

4.1 Physical damage assessment

Despite the large magnitude of the earthquake, only slight structural damage was observed in all hospitals except for the one located in Vicuña, which had no damage probably due to its distance to the epicenter (Fig.1). This slight damage is characterized by diagonal cracks in some RC and masonry walls, and by concrete spalling in a limited number of elements, representing no threat for the stability of the structure or the life safety of its occupants. Special attention was paid to the most important hospital located in Coquimbo, where generalized slight damage was observed, and other structural damage, such as heavy cracking in a staircase, and damage in steel columns and beams in the oldest building constructed in 1976. After the 2015 earthquake, the hospital was instrumented with two tri-axial accelerometers placed at different stories to capture the three lateral and torsional components of acceleration. After the correction of the signal, the measured periods of the four first modes were compared with similar measurements performed in 1997 [21] after the Punitaqui earthquake. It was found that the first four natural periods of the building were higher than the ones measured prior to the earthquake by a factor between 5% and 22% [19]. This increase can be due to the reported structural damage, such as cracking of concrete, or by an increase of live loads over the years, e.g. medical records.

Impacts on the functionality of the hospitals were mainly caused by non-structural and content damage. Table 2 presents a summary of the different types of non-structural damage as reported by the hospitals. Damage data are broken down into seven categories: glazing, false ceilings, partition walls, plumbing, elevators and stairs, wall covering and coating (e.g., broken tiles in Fig. 2a, cracks on stucco and ceramics needing replacement, patching, and/or painting), and contents (e.g., falling of hard copies of medical records in Fig. 2b, and medical equipment). According to Table 2, two high-complexity facilities, the hospitals of Ovalle and Coquimbo, were the only ones that experienced damage in all seven categories identified. Falling of building contents was the most commonly observed physical damage after the earthquake, followed by damage to glazing and partition walls. The hospital of Vicuña did not declare any physical damage.

Glazing was damaged in six out of nine facilities, with up to 45 broken windows in the hospital of Salamanca. Glazing was also identified as the most important physical non-structural damage in the hospital of Andacollo. Window protection films were subsequently installed to avoid this problem in future earthquakes. Damage to plumbing was observed in three hospitals: Illapel, Ovalle, and Coquimbo. The water system was damaged in the hospital of Illapel causing minor leaking in a single bathroom In Coquimbo, a sink was damaged and pipes broke on the 4th floor of the old tower causing inundation of the 4th, 3rd, and 2nd floors. The three high-complexity hospitals of the region had problems with their elevators, while the other two hospitals with more than one story had no problems with elevators. The only elevator of the hospital of was inoperative for 12 hours. The hospital of Coquimbo had significant damage in an elevator shaft of the oldest section of the hospital, and its use was prohibited as a precaution. In the hospital of La Serena, one of the three elevators could not be used after the earthquake. The hospital of Andacollo, Combarbala, Los Vilos, and Coquimbo had falling of computer-related items (e.g. screens, computers, printers, servers). Falling of laboratory supplies and/or medical equipment was observed in Andacollo, Combarbala, Illapel, La Serena, and Coquimbo. Furthermore, the falling of hard copies of medical records (Fig. 2b) was an important consequence of the earthquake in Coquimbo. Some minor

equipment (i.e. a microwave and a juice extractor) fell and was damaged in the hospital of Salamanca. In Combarbala, a blood coagulometer and a table fell down in a laboratory, and 8 computer screens and many books fell down in the administration office.

Table 2 – Type of non-structural and contents damage in the hospitals of the region of Coquimbo, Chile, 2015; the most commonly reported problem was the falling of building contents, and non-structural damage to glazing.

	Glazing	False ceilings	Partition walls	Plumbing	Elevators and stairs	Covering and coating	Hospital Contents
Coquimbo	X	X	X	X	X	X	X
La Serena		X	X		X	X	X
Ovalle	X	X	X	X	X	X	X
Illapel	X		X	X		X	X
Andacollo	X	X	X			X	X
Combarbala	X		X				X
Los Vilos							X
Salamanca	X						X
Vicuña							

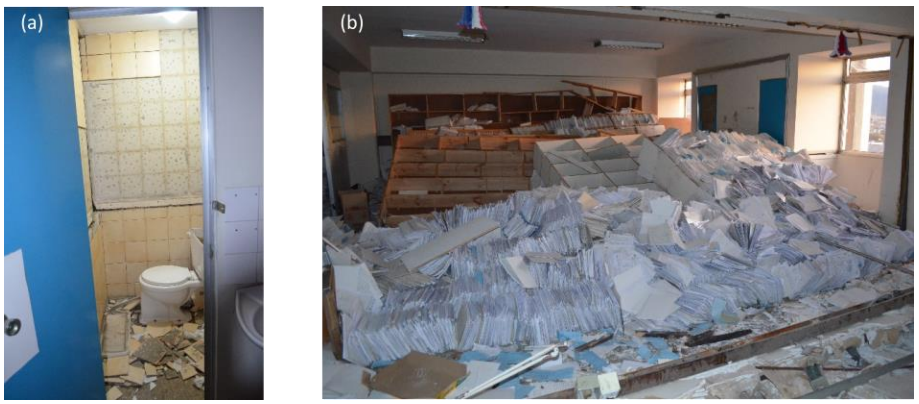

Fig. 2 – Non-structural and contents damage observed in the hospitals of Coquimbo: (a) fallen tiles in a bathroom, and (b) fallen stacks of medical records not digitally stored.

4.2 Lifelines issues

Municipal power was disrupted in several cities of the region. Backup systems were successfully used except in the facilities of Combarbala, La Serena, and Salamanca. The power generators of the hospitals of Combarbala and La Serena did not provide 100% of the energy needed by the hospitals during the electricity black-out which lasted 8 and 12 hours, respectively. The generator of the hospital of Salamanca did not work automatically after the municipal power went off; it was manually started 30 minutes later.

The only hospital losing municipal water supply was the Illapel Hospital. However, a backup water tank was successfully used to replenish water supply. No sewer damage was reported. All hospitals, except the one in Combarbala, reported difficulties in communication after the earthquake, mainly due to some interruptions produced by high congestions in the fixed and mobile phone networks in the affected areas. Alternatives consisted of using emergency backup systems such as high frequencies radios, written text messages using the internet, or direct calls using satellite phones.

4.3 Patients and staff flow after the earthquake

The characterization of hospital staff and patient flow after the earthquake is hard to describe quantitatively. Arrivals were not systematically registered and/or data were not provided by the surveyed facilities. The hospital of Andacollo and Coquimbo claimed to have had more hospital staff during the first 24 hours after the earthquake. The regional healthcare service of Coquimbo deployed additional physicians and support staff to support the hospital of Coquimbo. The hospitals of Ovalle and Vicuña described normal levels of attending staff reporting to work. The remaining hospitals observed a decrease of staff for a period of 24 hours to one week, mainly caused by staff with personal problems after the earthquake (e.g., damage in their houses and care of their relatives) or troubles to move within and between cities.

For all the hospitals, except the ones in Ovalle and Vicuña, the number of patient arrivals increased in the first 24 hours after the earthquake. A commonly reported symptom motivating the hospital visits was to have panic attacks and related symptoms. The flow of patients that were already admitted in the hospitals at the time of the earthquake was easier to track: hospitals of Coquimbo, La Serena, and Ovalle reported at least 14, 10, and 50 discharged and/or self-discharged patients, respectively. In the hospital of Andacollo, only one patient was discharged, while two patients were discharged in the hospital of Illapel. Transferred patients and evacuation are detailed in the following paragraphs.

Two types of transfers of patients were performed after the earthquake. The first transfer type aimed at increasing the number of available beds for new incoming patients by moving non-critical patients to other hospitals. The second type of transfer aimed at moving patients who first arrived to a facility that could not fulfil their healthcare needs. Figure 3 shows a summary of the patient transfers identifying the number of patients and the transportation modes. The transfer of patients was affected by the damage in the transportation network (e.g. slope failures, rock falls, and raveling of loose materials). Low-complexity hospitals in Andacollo and Combarbala transferred patients using their own ambulances to other more complex facilities of the network, in order to comply with their healthcare needs. Due to physical damage on the roads, it was noted that the transfer from the hospital of Combarbala to Ovalle took longer than usual in normal conditions. Two high-complexity hospitals transferred patients outside the Coquimbo regional healthcare network to other complex centers in Santiago and Valparaiso regions. The Coquimbo hospital transferred seven patients by a military plane and government vehicles outside the regional healthcare network, and four additional patients to the hospital in La Serena due to the damage affecting oncological beds. Besides, it received a critical patient from the La Serena hospital who needed specialized attention of neurosurgery only provided by the hospital in Coquimbo. This last transfer took more time than usual transfers in normal conditions because the main highway linking the two cities was overloaded.

Regarding the evacuation process, the hospital of La Serena was the only hospital in the network that did not evacuate. All the other eight hospitals evacuated, partially or totally, due to immediate security concerns of structural and/or non-structural damage, and/or following the post-earthquake protocol of the facility (Table 3). The hospital of Los Vilos, which is the only hospital of the region located within the tsunami inundation zone, evacuated completely to a kindergarten school located in the safety zone of the same city. The 28 hospitalized patients were successfully evacuated in approximately 25 minutes In spite of the fact that it is the host location stated by the evacuation plan of the hospital, the school does not have a backup electric generator or backup water supply. For the hospitals of Andacollo, Combarbala, and Vicuña, it only took 5 minutes to partially evacuate to meeting points located nearby the hospitals. It took a time between 25 minutes to 1 hour to evacuate the entire facilities or entire medical units in the hospital of Illapel, Los Vilos, and Salaman. Non-structural damage of false ceilings, windows, and partition walls were the reason why patients located in the 3rd story had to evacuate to the first story in the hospital of Ovalle (with the exception of three ICU patients that needed respiratory supports). The entire transfer took about 20 minutes; this short time can be explained by the fact that

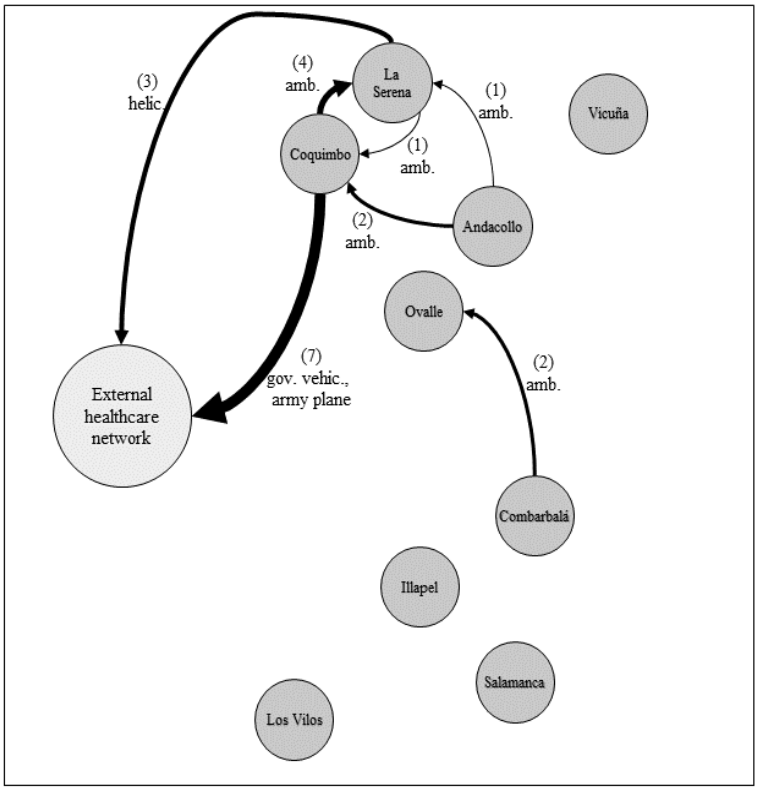

Fig. 2 – Patient transfers between facilities in the Coquimbo region (number of patients transferred in parenthesis) and the transportation mode, e.g. helicopter (helic.), ambulance (amb.), government vehicle (gov. vehic.), or army plane - arrow widths are proportional to the number of transferred patients.

Table 3 – Evacuation processes of Hospitals after the earthquake.

	Evacuation type	**Description**	**Reason**	**Time of evacuation**
Coquimbo	Partial	12 ICU/ITU, 12 non-ICU psychiatric patients evacuated to safe parts of the hospital	Structural and/or non-structural damage	6 hours
La Serena	None	NA	NA	NA
Ovalle	Partial	Entire 3rd floor, except 3 ICU patients, evacuated to 1st floor	Structural and/or non-structural damage	20 min.
Illapel	Total	Entire hospital (20 patients) evacuated to the patio	Protocol post-earthquake	35-40 min.
Andacollo	Partial	8 non-ICU hospitalized patients evacuated	Structural and/or non-structural damage	5 min.
Combarbala	Partial	7 hospitalized patients evacuated	Post-earthquake protocol	5 min.
Los Vilos	Total	All the hospital moved to safe zone, i.e. a kindergarten	Hospital in tsunami inundation zone	25 min.
Salamanca	Partial	Hospitalization and medical part evacuated outside	Post-earthquake protocol	<1hour
Vicuña	Partial	All the hospital employees and some patients evacuated	Post-earthquake protocol	5 min.

NA: not applicable.

a fire drill was conducted the week before. Finally, up to 6 hours were required to fully move 12 ICU/ITU patients and 12 non-ICU psychiatric patients from damaged to safe sections of the Coquimbo hospital.

4.4 Impacts on the healthcare services

A summary of the physical areas affected per service type is presented in Table 4. The following text is a description of how the healthcare services were affected in each hospital. This section describes the hospital impacts by complexity type (i.e. low, medium and high except the hospital of Coquimbo).

Table 4 – Physical areas affected by service type in the Coquimbo region's hospital network

	Inpatient wards	**Operating rooms**	**Laboratory**	**Radiology**	**Em. Dept.**	**Outpatient clinics**	**Psychiatry**	**Blood bank**	**Kitchen**	**Laundry**	**Administra.**	**Morgue**	**Total units lost**
Coquimbo	N	Y-P	N	N	N	Y	Y	N	N	N	Y	N	4
La Serena	Y-P	Y-P	Y-P	N	N	Y	N	N	N	N	N	N	4
Ovalle	Y-P	Y-P	N	N	N	N	NA	N	Y-P	N	Y-P	NA	4
Illapel	Y-P	N	Y-P	N	N	Y-P	NA	N	N	N	N	Y-P	4
Andacollo	Y-P	NA	N	N	N	Y-P	NA	N	N	NA	N	NA	2
Combarbala	Y	N	Y-P	Y	Y-P	N	NA	NA	Y-P	N	Y	N	6
Los Vilos	N	N	N	N	N	N	NA	N	N	N	N	N	0
Salamanca	Y-P	N	N	N	N	Y-P	NA	Y-P	Y-P	Y-P	Y-P	N	6
Vicuña	N	N	N	N	N	N	NA	NA	N	N	N	NA	0
Tot. units lost	6	3	3	1	1	5	1	1	3	1	4	1	30

NA: not applicable/service not provided, Y: total loss of the service, Y-P: partial loss of the service, N: No loss of the service.

The hospital of Los Vilos and Vicuña did not report losses of services after the earthquake. The case of the Los Vilos hospital is particularly noteworthy, since despite its complete evacuation, patients and staff after the earthquake (the hospital is within the tsunami inundation zone). The loss of capacity healthcare delivery lasted for only about 25 minutes, i.e. time required to evacuate the hospital. This can be explained by the fact that the hospital is facility with a low-complexity, i.e. it does not attend patients requiring complex treatment. Because only three extra patients arrived after the event, who had panic attacks and did not need medical equipment left in the evacuated hospital. In the hospital of Andacollo, the inpatient ward was affected: 7 beds out of 15 were unusable for 24 hours due to broken glazing, and one delivery room was unavailable for more than one week. In the hospital of Combarbala the radiology service and the administration were lost for 8 hours due to the lack of full coverage of the backup electricity generator. The administration was closed for 12 hours in total due to the limited capacity of the backup power supply, the broken windows and the falling of computers and books in the offices. In addition, the kitchen was affected by a gas failure, causing a partial food delivery interruption that lasted less than 24 hours. Due to non-structural damage that affected the hospital, the inpatient ward was closed until the following day. After a preventive evacuation, hospitalized patients were relocated to the parking lot of the hospital in an improvised emergency hospital that allowed continuity of healthcare services. In the hospital of Salamanca, the polyclinic, one hospitalization bed, and the laundry service were affected by breakages of windows glasses. The food preparation was affected by the loss of kitchen equipment, and disruption to the food supply chain (i.e., no vegetables were delivered to the hospital for one day). The administration office was also affected by the damage and falling of office equipment following the earthquake.

The laboratory of the hospital of Illapel diminished its capacity due to falling of minor equipment. Three attention rooms of the outpatient clinic were damaged and it took 4.5 months to recover them. The hospital morgue was also damaged and one decedent person could not be assisted due to water leaking. The

hospitalization service is still affected by the consequences of the earthquake, i.e. the maternity room and 4 medicine rooms are still closed at the time of the last call in the second week of March 2016.

In the La Serena hospital, detachments of filling material at expansion joints, failure of partition walls, falling of false ceilings and ceramic tiles, breakage of windows, flaking of stucco and covering, and the dismantling of the front door were observed in the polyclinic, affecting the pediatric surgery unit, the kinesiology unit, the sample collection room, and dental and ophthalmological rooms. Cracks were reported in the Intensive Care Unit (ICU), the Intermediate Treatment Unit (ITU), the ambulatory surgery unit, and in operating rooms. In Ovalle the hospitalization service was interrupted by the evacuation due to cracks in partition walls, which damaged areas assisted 42 medical beds for 17 hours. Three out of the five operating rooms were not usable for 12 days, i.e. the time for non-structural damage to be repaired in the rooms. Bread delivery was slightly reduced in food capacity for one day. The administration underwent covering and glazing damages but was not closed.

The hospital of Coquimbo is not only the largest facility of the region, but it is also the most damaged hospital. The day of the earthquake, 230 out of the 315 available beds were occupied with hospitalized patients. The affected areas of the hospital corresponded to those located in the oldest tower of the building, i.e., the ICU, the ITU, the psychiatric unit, the polyclinic (named Consultorio Adosado de Especialidades or CAE in Chile), the ambulatory surgery unit (UCA), the laundry service, the sterilization service, the endoscopy service, and some administrative offices. The administration was closed for more than one week. All the other services, except the laundry service, were partially or totally relocated in other parts of the hospital. Eight out of the eighteen ICU/ITU beds were relocated into the neurosurgical unit. Four out of twelve psychiatric beds and the entire sterilization service were relocated to undamaged parts of the hospital. The endoscopy service and the UCA were interrupted indefinitely, and were only restored when a military field hospital was installed next to the hospital on October 2nd, 16 days after the earthquake. Overall, 40 hospitalization beds were lost, the number of rooms of medical consultation decreased from 78 to 45, and the procedure rooms went down from 26 to 8, decreasing the capacity of addressing 38 different procedures to only 14. The military field hospital provided backup healthcare delivery until the third week of February 2016. It had the capacity to conduct 70 surgeries and more than 50 different procedures per week with 3 operating rooms, 20 post-operatory beds, and an endoscopy and sterilization room. Thus, the new healthcare facility composed by the damaged Coquimbo hospital and the field hospital reached the same capacity to provide healthcare attention as formerly sustained by the non-damaged Coquimbo hospital. According to an interview done in late February, when the field hospital was removed, the hospital of Coquimbo was not ready to take over the residual healthcare charge, which led to a new decrease of the healthcare capacity of the hospital. Since the hospital is the regional derivation center for the services of neurosurgery, complex traumatology, complex pediatric surgery, and psychiatric adult hospitalization, the functional losses in the facility impacted the healthcare delivery of the whole network.

5. Conclusions

This paper summarizes the impacts that the 2015 Illapel earthquake had on nine hospitals of the healthcare network of the Coquimbo region, which includes all public hospitals physically affected by the event. None of the hospitals had significant structural damage. However, non-structural and contents damages were widespread, affecting all but the farthest hospital from the epicenter. The functional loss of the hospitals was driven by non-structural damage and contents damage. The inpatient ward was the most commonly affected service area in the facilities, and was often relocated or closed due to glazing damage. Telecommunication failure was the most frequently reported loss in utility lifelines. All hospitals but one in La Serena were partially or totally evacuated. Overall, 10 patients were transferred within the Coquimbo regional healthcare network, and 10 other patients were transferred to other healthcare networks (i.e., Santiago and Valparaiso). The most affected facility was the Coquimbo hospital, which is the most important and largest hospital in the region. This hospital had the greatest amount of physical damage, leading to significant losses of medical records and healthcare services. A field hospital had to be added to the hospital premises for over 4 months in order to counter the reduction of medical attention capacity. The Coquimbo hospital still has significant functionality problems that have not been solved after the withdrawal of the field hospital.

The results presented are limited to short-term impacts of the earthquake on hospital functionality. Long-term effects such as the recovery of infrastructure and medical equipment, and the increase of patient arrivals due to post-traumatic stress disorder and water-related epidemics, are not captured by this work. A complete description of healthcare resilience would require several healthcare functionality assessment studies over time. Furthermore, the study did not include primary healthcare facilities of the region, which are numerous since do not provide complex treatment and derive any critical patient to hospitals.

The data presented in our study provides evidence ready to be used in future hospital or healthcare network models. The links between physical damage and functional losses are explained and can be exploited to predict future hospital seismic performance. Moreover, the information provided on patient transfers between hospitals can help develop healthcare network models. Finally, the information on hospital evacuations (e.g. times and causes) can be used to validate total or partial evacuation models of Chilean hospitals.

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