Houston's Medical Disaster Response to Hurricane Katrina: Part 1: The Initial Medical Response From Trauma Service Area Q

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After Hurricane Katrina hit the Gulf Coast on August 29, 2005, thousands of ill and injured evacuees were transported to Houston, TX. Houston's regional disaster plan was quickly implemented, leading to the activation of the Regional Hospital Preparedness Council's Catastrophic Medical Operations Center and the rapid construction of a 65-examination-room medical facility within the Reliant Center. A plan for triage of arriving evacuees was quickly developed and the Astrodome/Reliant Center Complex mega-shelter was created. Herein, we discuss major elements of the regional disaster response, including regional coordination, triage and emergency medical service transfers into the region's medical centers, medical care in population shelters, and community health challenges. [Ann Emerg Med. 2009;53:505-514.]

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INTRODUCTION

Hurricane Katrina, which hit the Gulf Coast on August 29, 2005, was one of the costliest and deadliest natural disasters in US history, killing 1,836 people.[1] The hurricane and flooding caused by the breach of the levee system in New Orleans required as many as 373,000 New Orleanians and Gulf Coast residents to flee their homes.[1] Remaining New Orleans residents sought emergency shelter in the New Orleans Superdome and Convention Center. After a decline in the living conditions in these temporary shelters,[2] government officials in Texas were asked to provide shelter in Houston/Harris County to thousands of Gulf Coast evacuees.[1] On September 1, 2005, evacuees were transported by bus to Houston.

Reliant Park, Harris County's football stadium and convention center, was designated by the Harris County judge to serve as a mega-shelter for evacuees. This facility, consisting of the Astrodome, Reliant Convention Center, and Reliant Arena, became known as the Astrodome/Reliant Center Complex and was operated under the leadership of a unified area command, with Medical Branch operations led by Harris County Public Health & Environmental Services, in concert with the Harris County Hospital District.

Based on the concept of evacuee care, rather than acute mass casualty care, the vacant Astrodome was designated the initial receiving point for arriving evacuees, where those in need of medical intervention were identified. The Astrodome became the primary shelter within Reliant Park; the Red Cross supplied water, cots, bedding, and logistic support. The Reliant Park facilities management provided food.

As the buses continued to arrive, it became apparent that the Astrodome alone could not safely house all evacuees. The City of Houston's fire marshal set the Astrodome's capacity at 8,000; however, Houston's mayor authorized this limit to increase to 12,000.[1] Eventually, the population inside the Astrodome reached 16,000, whereupon the neighboring Reliant Arena and Reliant Convention Center were opened to house 4,500 and 2,300 evacuees, respectively.[1] It is estimated that the Astrodome/Reliant Center Complex housed approximately

27,000 evacuees at its peak in operations, with a total of 65,000 evacuees processed there before being sent to other Texas shelters.

When Astrodome/Reliant Center Complex reached its capacity, the City of Houston opened another large shelter at the George R. Brown Convention Center. The center sheltered 2,800 and registered 28,000 evacuees for services, including medical care provided by the University of Texas Health Science Center at Houston School of Medicine's Family and Community Medicine Department.[3] Additionally, another 40,000 homeless evacuees were housed in Harris County hotel rooms. The number of evacuees who eventually came to Houston/Harris County numbered slightly more than 250,000.

The data presented in this article were derived from electronic patient encounter data (August 31, 2005, to November 1, 2005), collected from Harris County Hospital District emergency departments (EDs) (n=1,304), Harris County Hospital District inpatient floors (n=264), Harris County Hospital District outpatient clinics (n=17,208, of whom 12,219 were at the Katrina Clinic), and the Catastrophic Medical Operations Center (n=1,093). These encounters were analyzed for type of service, diagnosis, disposition, age, sex, and date of service. Paper-based medical records were maintained at the Astrodome/Reliant Center Complex shelter treatment sites (n=4,013) and retrospectively entered into a database by professional Harris County Hospital District data entry personnel. Baylor College of Medicine and Red Cross staff manually collected data during evening Astrodome/Reliant Center Complex operations. The accuracy of the Astrodome/Reliant Center Complex population data is limited and should be considered with caution. However, because they are the only data available, they are presented here. The authors were given access to this data after Catastrophic Medical Operations Center and Harris County Hospital District institutional review board approval.

During the last 2 years, interviews were conducted with medical professionals, Red Cross workers, emergency medical services (EMS) agency personnel, Houston Fire Department, and Houston Police Department staff who worked in Astrodome/Reliant Center Complex or with the Catastrophic Medical Operations Center. Much of the anecdotal data included in this report came directly from the observations of the authors, all of whom worked in Astrodome/Reliant Center Complex or the Catastrophic Medical Operations Center during the Katrina operations. In this article, we describe the sequence of events that took place from September 1 to 20, 2005, from the perspective of civilian medical personnel and describe the challenges posed to the Texas Trauma Service Area-Q, as well as the response of Houston/Harris to help Katrina evacuees. (The Texas Department of State Health Services has implemented a statewide EMS and trauma care system, designating trauma facilities and creating a trauma registry. Texas is divided into 22 trauma service areas, accounting for all of the 254 counties in Texas. Each trauma service area is required to maintain a regional advisory council with appropriate representation from local EMS agencies and trauma hospitals.)

The article is structured according to the sequence of activated medical capabilities, the unique challenges of providing medical care for approximately 27,000 evacuees, and the conclusions, which cites key recommendations.

DESIGN OF THE CATASTROPHIC MEDICAL OPERATIONS CENTER

Harris County comprises 1,756 square miles and is home to 4.5 million residents, making it more populous than 23 states.[1,4] There are 34 municipalities within Harris County, including the City of Houston, the fourth largest city in the country. More than 1.2 million residents rely on Harris County as their primary health care provider.[1] The region covered by the Catastrophic Medical Operations Center includes Houston and Harris Counties, as well as 8 other Texas counties. With 2 Level I trauma centers, one freestanding pediatric emergency facility, 51 acute care facilities with EDs, 12 public community health centers, and 40 nonacute/specialty hospitals without an ED, the Texas Trauma Service Area-Q emergency health care infrastructure is routinely saturated. In 2004, a "normal" year requiring no major regional disaster management operations, the region's EDs experienced more than 1,750,000 patient encounters, and paramedic traffic was diverted almost 10% of the time.[4]

Soon after the official request to shelter Katrina evacuees, Harris County officials began to organize the Hurricane Katrina Disaster Unified Area Command under the City of Houston and Harris County Emergency Management Basic Plan. A command center was created on the second floor of the Reliant Convention Center inside the Astrodome/Reliant Center Complex in accordance with principles of the National Incident Management System. The Unified Area Command structure included representatives from the federal government, the state of Texas, Harris County—including both Harris County Public Health & Environmental Services and the Harris County Hospital District—the City of Houston, and nongovernmental agencies such as the Baylor College of Medicine, the Reliant facilities management, food and security service contractors, EMS contractors, and the Red Cross. The Unified Area Command Medical Branch operations were led by Harris County Public Health & Environmental Services, in conjunction with the Harris County Hospital District and Catastrophic Medical Operations Center. Within the Medical Branch, the Southeast Texas Trauma Regional Advisory Council assisted in coordinating onsite transportation and staging EMS with the Montgomery County Hospital District. The latter served as the transportation sector of the Catastrophic Medical Operations Center, which had been activated by the Regional Hospital Preparedness Council at the request of the City of Houston Office of Emergency Management. This regional entity was responsible for disaster planning and

response coordination for more than 100 of the region's health care facilities in 9 counties surrounding Houston.[4]

Many members of the Hurricane Katrina Unified Area Command staff had first worked as a team during 2001 for Tropical Storm Allison, which was the costliest tropical storm in US history, flooding 72,000 homes,[1] and property damage countywide estimated at more than $5.0 billion.[3-5] Three large health care facilities were evacuated, with the loss of more than 2,500 inpatient beds. The region learned much from responding to this disaster and rebuilding the devastated communities. This experience was critical to organizing the Houston/Harris County community's disaster management operations, in particular the Catastrophic Medical Operations Center.

Located as a permanent section within the City of Houston Emergency Operations Center, the Catastrophic Medical Operations Center is an integral component of the regional medical response. It serves as the central point for redistribution of staff and supplies, identifies and utilizes surge capacity, and coordinates the transportation and assignment of patients into health care facilities according to the patient's medical need and the facilities' concurrent capability and capacity. The Catastrophic Medical Operations Center also identifies additional capacity in regional health care facilities by reviewing patient status for possible early discharge or transfer to an extraregional facility and by delaying elective surgical procedures. This single-point coordination allows for safe and effective surge capacity into the region's health care facilities and the proper and efficient utilization of the region's health care resources.

Although the Regional Hospital Preparedness Council has no regional jurisdictional authority, the Catastrophic Medical Operations Center works with governing entities in the coordination of disaster response, mitigation, and preparedness/planning to ensure that emergencies do not adversely affect the quality, capacity, and continuity of regional health care operations. The coordination of all medical responses and assets is vetted through the Catastrophic Medical Operations Center.

During Katrina Operations, Catastrophic Medical Operations Center functioned from the City of Houston Emergency Operations Center and its structure was National Incident Management System compliant, consisting of a medical operations chief, deputy chief, public health sector, special needs sector, transportation sector, and five corridor chairs within Texas Trauma Service Area-Q who were responsible for the coordination of 20 to 40 health care facilities within the 9-county geographic regions of Texas Trauma Service Area-Q. Because of previous planning efforts, memorandums of understanding, and regional relationships within Texas Trauma Service Area-Q,[4] the Catastrophic Medical Operations Center had the ability to coordinate the transfer and placement of patients triaged from the Astrodome/Reliant Center Complex, George R. Brown Convention Center, and Ellington Field. The Catastrophic Medical Operations Center facilitated patient transports to appropriate health care facilities, notified hospitals of incoming patients, collected bed availability from regional health care facilities, instituted patient tracking mechanisms, identified emerging trends in patient presentations, and coordinated placement of patients from incoming National Disaster Medical System flights. Real-time matching of all regional health care facilities' resources with patient conditions created additional hidden surge capacity within Texas Trauma Service Area-Q. During disasters, EMS transfers assume the facilities' ability to manage the arriving condition, although this may not be the case. The Catastrophic Medical Operations Center, however, confirmed that hospitals had the necessary resources to receive and treat patients.

The Harris County Unified Area Command[6] at the Astrodome/Reliant Center Complex focused on controlling the resources needed to accomplish their mission within the Astrodome/Reliant Center Complex and George R. Brown Convention Center, whereas the Catastrophic Medical Operations Center vectored EMS transfers from the Astrodome/Reliant Center Complex, George R. Brown Convention Center, and Ellington Field into Texas Trauma Service Area-Q medical facilities. As mentioned, the Southeast Texas Trauma Regional Advisory Council coordinated Unified Area Command Astrodome/Reliant Center Complex Medical Branch activities with EMS transfers through the Catastrophic Medical Operations Center. The partnership was essential to maintaining medical infrastructure and coordination of care.

Although the Houston/Harris County response community learned important lessons responding to Allison and analysis of previous disasters,[7] a medical and public health response to a disaster on the scale of Hurricane Katrina was not among these, because the Katrina response was markedly larger than predicted. Many of the local medical personnel within the Astrodome/Reliant Center Complex were not trained in disaster response or evacuee care.[8] Thus, many physicians were unaccustomed to command and control organization models or National Incident Management System and Incident Command System principles. No one anticipated that Houston/Harris County would ever need to rapidly shelter, feed, and provide medical care for so many evacuees for an indefinite period by using such a large number of untrained civilians.

EVACUEE ARRIVAL TO THE ASTRODOME/RELIANT CENTER COMPLEX

As the first buses arrived from New Orleans, it became obvious that a large-scale, high-flow, patient redirection system was required to direct evacuees requiring medical care to the most appropriate facility. Because of the extreme temperatures during the day, evacuees required efficient and appropriate care to prevent further deterioration in their already compromised condition. Thus, steps were put into place to process evacuees as quickly as possible, preferably indoors.

During the first 12 hours of initial triage, wheelchair supply was limited, resulting in the exposure of several disabled evacuees to extreme outdoor conditions for several hours.

Relative humidity regularly reached 100%, and temperatures in downtown Houston sometimes exceeded 100°F (37.8°C) around the black asphalt Astrodome/Reliant Center Complex disembarkation sites. To provide transport into the Astrodome, Catastrophic Medical Operations Center staff and Red Cross used ambulances and office and other furniture with wheels.[9]

The buses from Louisiana arrived earlier than anticipated. Houston Fire Department was called to the triage sites 3 hours after the arrival of the first buses from New Orleans because EMS resources were overwhelmed. Houston Fire Department executed mass casualty procedures and erected inflatable structures and large air fans to provide relief to patients undergoing immediate medical care or awaiting EMS transport. Hydration in the heat during the long shifts was essential to sustaining an around-the-clock operation.

No information about the health status of incoming patients was received before the arrival of the buses. Typically, 5 buses at a time were disembarked inside a secure area. One physician, 2 emergency medical technicians (EMT), and 2 paramedics met each bus and the evacuees. Baylor and Houston Fire Department physicians and paramedics rapidly classified patients by severity of illness. Evacuee medical conditions commonly fell into one of 3 categories:

- EMS: Severely ill patients (on average, 1 or 2 persons per bus) needing immediate stabilization and transport to designated regional medical facilities by ambulances vectored by the Catastrophic Medical Operations Center;
- Urgent: Patients not requiring treatment in a tertiary care facility (about 2 per bus) who continued on the bus to the Katrina Clinic for further assessment and treatment, subsequent housing in the Astrodome/Reliant Center Complex shelters, and registration with the Red Cross; and
- Stable: Patients with more stable conditions, such as non–insulin-dependent diabetic patients who had been without medication for several days, elderly requiring mental status assessments, and evacuees with rashes as a result of sun and unsanitary water exposure, who were directed into the Astrodome/Reliant Center Complex. These patients would typically receive medical care within 48 hours, once their other needs (eg, clothing, food, water, bathing) were met.

An "expectant" category was not used, because all critical patients were transported immediately to a tertiary care facility. The remainder of the evacuees were directed into the Astrodome/Reliant Center Complex shelter, where they received water, a hot meal, clothing, toiletries, and bedding, as well as first aid–type medical care.

The Houston Fire Department set up a command post inside the bus disembarkation zone to control the rate at which buses entered the Astrodome/Reliant Center Complex. The queue of buses sometimes numbered more than 100, making the wait time for disembarkation after Astrodome/Reliant Center Complex arrival as long as 6 hours (a bus was emptied about every 5 minutes; almost all buses were air conditioned). The disembarkation areas were set up directly in front of the shelter to minimize walking distance and decrease exposure to hot summer temperatures. It was necessary to reassemble and relocate the disembarkation area in front of the next Astrodome/Reliant Center Complex shelter when the previous shelter reached capacity. Some evacuees disembarked the buses, registered, changed clothes, and had a meal but did not stay overnight and therefore were not included in the nighttime headcounts.

Several disembarkation relocations were required because the primary Astrodome shelter filled within 28 hours of the arrival of the first bus (16,000 accommodated overnight of 20,000 disembarked), followed by the Reliant Arena, which filled within 4 hours (2,500 accommodated overnight of 3,000 disembarked). The remaining evacuees were sent to the Reliant Convention Center during the next 2 days (5,000 accommodated overnight of 6,500 disembarked).

When the Astrodome/Reliant Center Complex shelters were at full capacity, the Astrodome/Reliant Center Complex Unified Area Command secured a disembarkation area in a large Astrodome/Reliant Center Complex parking lot (yellow lot) outside the security perimeter of the Astrodome/Reliant Center Complex shelters (Figure 1). Initial bus triage at the yellow lot was performed by the Disaster Medical Assistance Teams and National Medical Response Teams.[10] Bus security was handled by the Houston Police Department, and security at the perimeter of Astrodome/Reliant Center Complex was provided by the Houston Police Department and the Metropolitan Transit Authority of Harris County. Inside the shelters, security was provided by the Houston Police Department and the Harris County Sherriff's Office. An unarmed National Guard presence was visible during the Astrodome/Reliant Center Complex response. Physicians triaged patients to be transported to the Texas Trauma Service Area-Q medical facility or to remain with the Astrodome/Reliant Center Complex/Harris County Hospital District medical support. The Red Cross assisted disembarking passengers needing food and clothing. Showers were constructed, as well. The yellow lot for triage at the Astrodome/Reliant Center Complex and its support by out-of-state disaster response teams/volunteers allowed the Astrodome/Reliant Center Complex to utilize fewer local fire and law enforcement resources than otherwise would have been required. The yellow lot triage site on Astrodome/Reliant Center Complex premises continued to operate for the first week as buses destined for Dallas, San Antonio, and the George R. Brown Convention Center arrived. These evacuees who arrived at the yellow lot were triaged, registered, fed, given a clothing change, and then reloaded onto the bus for their final destination. This process ensured that any ill or injured evacuees would receive necessary treatment before reaching their final Texas destination. To keep family members in the same community, any family member of a patient requiring hospital admission in Texas Trauma Service Area-Q was disembarked and admitted to the Astrodome/Reliant Center Complex shelters. Within the first 4 days of evacuee arrivals, the

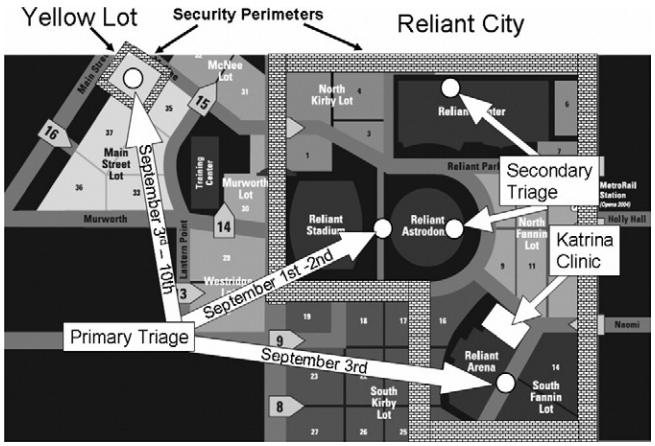

Figure 1. Reliant City and the yellow lot triage area. Map of the Astrodome/Reliant Center Complex, showing the location of the evacuee arrival triage sites and the Katrina Clinic.

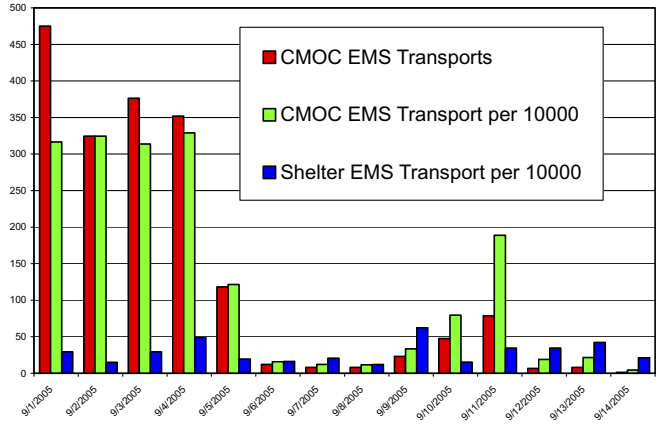

Figure 2. Catastrophic Medical Operations Center EMS transfers by date. Total EMS transports are represented by red bars. Total Astrodome/Reliant Center Complex EMS transports are normalized to a rate per 10,000 shelter inhabitants (green bars). EMS transports per 10,000 shelter inhabitants from shelter facilities only are represented by the blue bars. The majority of EMS transports occurred during the initial evacuee triage at bus arrival. (Astrodome/Reliant Center Complex population data are limited and should be considered with caution, especially from a comparative perspective.) *CMOC*, Catastrophic Medical Operations Center.

complementary roles of the Catastrophic Medical Operations Center, Southeast Texas Trauma Regional Advisory Council, Katrina Clinic, and the initial Astrodome/Reliant Center Complex triage area kept low-acuity patients from seeking medical attention in Houston-area hospitals. It also allowed the on-site Katrina Clinic to treat and return patients directly to the Astrodome/Reliant Center Complex shelter without having to involve external community health care facilities.

The Catastrophic Medical Operations Center documented more than 1,000 EMS transfers during the 2-week period, with 75% occurring during the first 72 hours (Figure 2). On the first day of Astrodome/Reliant Center Complex operations, 80 unstable patients with diabetes, who had been without insulin for more than 5 days, were transported by Catastrophic Medical Operations Center–directed EMS to appropriate community medical facilities. After September 5, 2005, when the bulk of transported evacuees had already arrived and settled in the shelter facilities, subsequent EMS transfers came directly from inside the Astrodome/Reliant Center Complex shelter areas and the Katrina Clinic.

INITIAL SHELTER MEDICAL CARE

It soon became apparent that treating evacuees at their bedsides inside the shelters was not medically or logistically possible. Consequently, treatment sites were created on the floor of the Astrodome and the Reliant Convention Center, where limited primary care and basic first aid were provided. There, physicians and nurses determined whether a patient required transfer to the Katrina Clinic or an off-site facility by EMS. This medical capability inside the shelters was essential; otherwise, the Astrodome/Reliant Center Complex's Katrina Clinic would have been overwhelmed with patients with low-acuity illness and injury.

The shelter treatment areas consisted of separate nurse and physician assessment areas, a psychiatric and crisis counseling "clinic," and a pharmacy with over-the-counter medications. Patients requiring prescription medications were referred to the Katrina Clinic pharmacy, which was managed initially by Harris County Hospital District by courier service. The CVS Pharmacy volunteered to take over this function and to send 2 large disaster response trailers. This unsolicited offering by CVS Pharmacy supplied essential medications after the first 2 days because Harris County Hospital District could not simultaneously support the Katrina Clinic pharmacy and the Harris County Community Health Clinic volume. Generously donated medications came from many countries, such as Japan, and were given to the Katrina Clinic pharmacy because often they were not approved for use in the United States or were not on the Harris County Hospital District formulary. To meet the sudden demand for medications, other Texas regions treating evacuees used pharmaceuticals from the Disaster Medical Assistance Team, the local community health program, and commercial pharmacies.

Figure 3 presents the distribution of new prescriptions written in the Katrina Clinic, Harris County Hospital District hospitals, and Harris County Hospital District clinics by date (data from other Texas Trauma Service Area-Q health care facilities were not available at this article's publication). Prescriptions filled in the Katrina Clinic exceeded 1,600 on the second day of Astrodome/Reliant Center Complex operations and averaged more than 500 a day during the next 5 days. Any disaster response mounted for a similar type of large-scale population displacement should consider the surge capacity

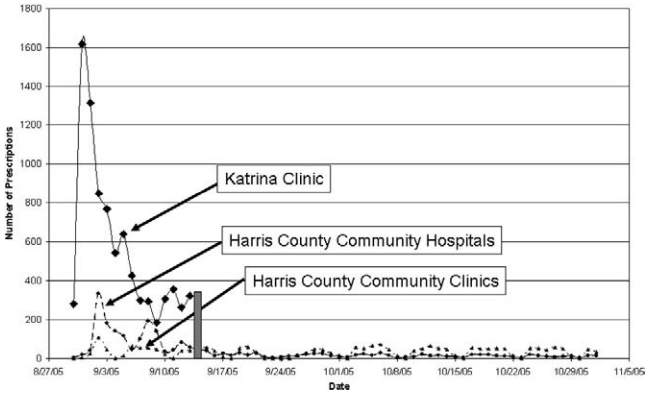

Figure 3. Solid line (diamonds) showing the total number of Katrina Clinic prescriptions, which peaked during the initial arriving evacuee triage. Dashed line (circles) showing the total number of prescriptions from Harris County Hospital District hospitals, which also peaked during the initial arriving evacuee triage. Dotted line (triangles) showing the total number of prescriptions from Harris County Hospital District clinics, which increased 3 to 4 weeks after Astrodome/Reliant Center Complex operations closed, corresponding to the 30-day refill limit on all prescriptions.

needed to accommodate immediate pharmacy needs. Of note is the rapid decrease in prescriptions filled by Harris County Hospital District hospitals as the Katrina Clinic became more functional over time. Eventually, a steady state was reached, leaving approximately 400 prescriptions to be filled daily at the Katrina Clinic pharmacy until its closure on September 15, 2005 (Figure 3, gray bar).

The Katrina Clinic pharmacy delivered most evacuee medications. A crest in prescriptions can be observed in the Harris County Hospital District hospitals during September 3 and 4. Another similar peak was observed in Harris County Hospital District community clinic prescriptions as the total evacuee numbers sheltered in Astrodome/Reliant Center Complex decreased, indicating that evacuees had begun to seek services at Harris County community health centers. After the closure of the Katrina Clinic pharmacy, the number of prescriptions filled at Harris County Hospital District clinics became cyclic because of weekend clinic closures and Harris County Hospital District hospital pharmacies' long weekend waits.

Initially, nonpharmacy personnel handled over-the-counter medications distributed in the shelter areas. Physicians and nurses brought many samples, including some expired medications not listed on the Harris County Hospital District formulary. Later, Harris County Hospital District pharmacy staff took over the shelter pharmacy because they were no longer responsible for the Katrina Clinic pharmacy. Over-the-counter medications were provided to 54% of patients at the shelter treatment sites.

Because refrigeration was not available in the shelter, initial arrangements were made for insulin cold storage and administration through a shelter care site diabetes clinic. Many patients also did not have up-to-date insulin delivery systems or recent training on sliding scales. Because of limited law enforcement inside the shelters during the first 5 days of shelter operations, some medical personnel were concerned about medication and needle theft. As the population thinned, patients were permitted to carry their own unrefrigerated insulin to shelter treatment site follow-up visits. Logistic issues such as the use of sharps containers for safe disposal of needles had to be balanced with safety concerns for others, such as children. Providing diabetic patients with insulin and needles encouraged self-managed patient care, which was facilitated with use of the "sharps" boxes, as well as teaching of the use of new devices, such as glucose meters and insulin injectors. Katrina Clinic pharmacy prescriptions were limited to 30 days, and therefore diabetic patients who left the Astrodome/Reliant Center Complex needed to engage in Harris County Hospital District community health programs (or other area providers) for refills or dose adjustments. This policy limited the number of needles and drugs lost or stolen.

Just 10 days after Katrina evacuees arrived at the Astrodome/Reliant Center Complex, almost every school-aged child was enrolled in school and bused daily to their classrooms from the Astrodome/Reliant Center Complex. Because most children registering at Houston Independent School District campuses initially had no proof of vaccination, Harris County Public Health & Environmental Services & Harris County Hospital District set up immunization sites next to the shelter triage sites to administer childhood vaccinations.[1] When possible, the Louisiana state immunization registry was accessed to confirm patient vaccination status. Because of concerns about evacuee exposure to waste matter from overflowing sewage facilities and toxic substances from agricultural and industrial systems,[11] tetanus vaccinations were administered. The Medical Branch also provided tetanus vaccinations for workers about to deploy to affected Gulf Coast areas.

Although the composition of the shelter treatment area medical teams varied, they typically consisted of 3 physicians, 5 nurses, 3 EMTs or paramedics, and a pharmacist or pharmacy assistant. Red Cross or local volunteers helped gather data from paper-based patient encounter forms. A 24-hour pediatric/maternal support service, managed by pediatric nurses, was located inside the shelters to assist mothers with children younger than 5 years. Evacuees needing EMS services inside the shelters were usually identified by Red Cross volunteers and brought to the attention of medical personnel. A code team from the shelter care areas was also in place and consisted of shelter treatment area personnel and paramedics. These personnel responded to potential emergencies after notification by shelter personnel, such as law enforcement or shelter staff. To synchronize EMS activities requested by Astrodome/Reliant Center Complex medical personnel, Southeast Texas Trauma Regional Advisory Council—within the Medical Branch Operations—communicated to the Catastrophic Medical

Operations Center the need for patient transportation to health care facilities.

Many residents sheltered at the Astrodome had chronic medical problems such as diabetes, renal disease, and hypertension. Evacuees with preexisting renal disease requiring dialysis were triaged directly to hospitals. When area health care facilities could not accommodate the increasing population of dialysis patients, the Catastrophic Medical Operations Center established a Dialysis Network program to provide scheduled dialysis appointments and transportation to and from dialysis centers. (Since the 2005 Hurricane Katrina response, this program has developed into the Texas End Stage Renal Disease Emergency Coalition and remains a partner with the Regional Hospital Preparedness Council. The Texas End Stage Renal Disease Emergency Coalition/Regional Hospital Preparedness Council program development has further expanded since Katrina and is currently under development nationwide.)

Figure 4 shows the nighttime headcount in the Astrodome/Reliant Center Complex shelters by date (Red Cross and Catastrophic Medical Operations Center personnel performed headcounts after midnight when most evacuees were asleep), with the overall Astrodome/Reliant Center Complex population steadily decreasing during the 2 weeks. Total population peaked at 16,000 on the first night of the headcount, mostly in the Astrodome. As discussed previously, all attempts at obtaining precise Astrodome/Reliant Center Complex shelter population numbers must be considered in the context of the sheer scope and size of this disaster response. These estimates may be low because several thousand evacuees registered to receive daytime medical assistance but slept outside Astrodome/Reliant Center Complex. Many also left the Astrodome after securing other housing.

Designation of refugee status is an internationally accepted definition with specific meaning, distinct from the term *internally displaced persons*, which better defined Katrina evacuees. The Unified Area Command staff, including the Joint Information Center personnel, worked diligently to avoid use of the term *refugee* when referring to these internally displaced persons. Approximately 75% of the Astrodome/Reliant Center Complex evacuee population was given the Harris County Hospital District financial class designation of "Katrina Refugees" to identify those Katrina evacuees without medical insurance (Table). Patients with Medicaid and Medicare represented only 17% and 6% of the registered evacuees, respectively. Managed care patients were usually from an institution with an unknown source of medical funding, whereas no eligibility–self-pay patients were insured but would need to pay all costs and later seek reimbursement from insurance. Regardless of their ability or inability to pay, no evacuee was refused treatment.

When the daily EMS transfers from Astrodome/Reliant Center Complex are divided by the estimated daily population census at Astrodome/Reliant Center Complex, the mean EMS event rate for the whole Astrodome/Reliant Center Complex can be derived (Figure 2). There are 2 cautionary notes in using the mean EMS event rate date: (1) although the Catastrophic Medical Operations Center activation was initiated on August 31, total integration with Astrodome/Reliant Center Complex operations was not complete until September 2, and as many as 700 EMS transfers may have been undocumented; and (2) although the Astrodome/Reliant Center Complex's daily population census was believed to be the best estimate of the Astrodome/Reliant Center Complex population, the possibility of over- or undercounting exists. According to disembarkation personnel observations that EMS transfers were highest on September 1 and 2, EMS transfers were corrected to equal the same normalized EMS transfer rates as occurred on September 3 and 4. On September 4, the bus disembarkation rate began to decrease after Astrodome/Reliant Center Complex reached full occupancy, yet the EMS event rate was sustained at 329 transfers per 10,000 evacuees for the next day. This sustained

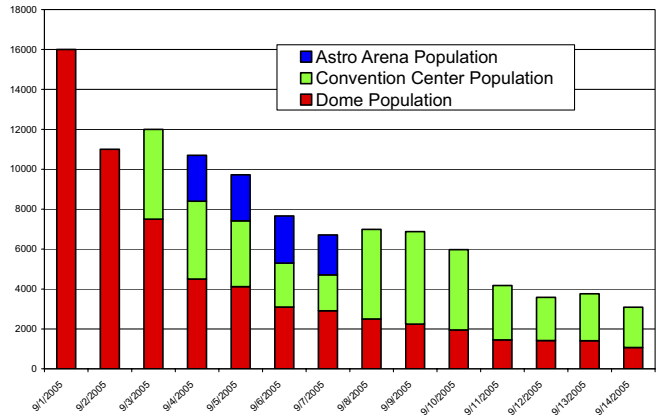

Figure 4. Total Astrodome/Reliant Center Complex headcount is shown. As the Astrodome population (red) decreased, the population in the Reliant Arena (blue) and Reliant Convention Center (green) increased. The arena was closed during the early morning of September 8 after the transfer of 2,000 evacuees to the convention center from the arena. Some evacuees still arrived by bus for disembarkation and triage through the yellow lot and were transported to the convention center during this time. (Astrodome/Reliant Center Complex population data are limited and should be considered with caution, especially from a comparative perspective.)

Table. Medical funding/insurance distribution of arriving evacuees.

Medical Insurance	% Of Evacuees
Blue Cross Texas	0.2
Commercial	1.0
Managed care, no contract	1.2
Self-pay, no eligibility	1.2
Medicare	5.5
Medicaid	16.6
No insurance	74.5

EMS transfer rate is likely due to the norovirus outbreak at Astrodome/Reliant Center Complex because EMS transfers as a result of gastrointestinal symptoms peaked at more than 100 per day before surveillance/containment areas were implemented.

Analysis of the Astrodome Houston Fire Department transport officer records shows a peak EMS transfer rate of 60 per 10,000 evacuees on the night of September 8, when 2,000 evacuees were relocated in hot, humid weather from the Reliant Arena to the Reliant Center, a distance of about one-half mile. The relocation resulted in further triage in the parking lot for some evacuees and the eventual transport of 10 patients to Harris County hospitals in a matter of 2 hours. A number of factors hampered relocation efforts: (1) several evacuees had acquired many possessions since arrival, impeding their ability to make a physical transport; (2) some evacuees with poorly controlled chronic disease conditions (eg, congestive heart failure, chronic obstructive pulmonary disease, arthritis) were impeded by disease exacerbations.

Because communication between the Unified Area Command and these medical personnel was limited, civilian medical personnel were not ready for this unexpected move, necessitating increased reliance on the Red Cross or other means for current information about overall Astrodome/Reliant Center Complex activities. Nevertheless, shelter care medical personnel rapidly responded to stabilize and transport by EMS the medically affected evacuees to Texas Trauma Service Area-Q facilities. With limited communication capabilities between Unified Area Command Medical Branch Operations and civilian medical personnel, exacerbation of evacuee medical conditions was a definite possibility. The large number of cell telephones within the Astrodome/Reliant Center Complex also continued to affect the network performance throughout the 3-week period of shelter operations.

CONCLUSIONS

This article describes the initial medical response of the City of Houston, Harris County, Harris County Public Health & Environmental Services, Harris County Hospital District, the Catastrophic Medical Operations Center, and Texas Trauma Service Area-Q. Ninety-five percent of the evacuees arrived during the first 5 days, and the emergency response component of this disaster soon evolved from a more subacute to chronic community health challenge (see Part 2: Transitioning From Emergency Evacuee Care to Community Health Care).

Implementation of Evacuee Tracking System

The Astrodome/Reliant Center Complex disaster response would have benefited from a triage tracking system for evacuees unable to provide identifying information, as in the case of a child, elder, or disabled person, and for all evacuees in general. The volume of evacuees arriving at the Astrodome/Reliant Center Complex—at one point the population increased by 9,000 evacuees in a 12-hour period—made initial registration and tracking very difficult. (Because of recognition of the need for better patient tracking, the Regional Hospital Preparedness Council, in partnership with the City of Houston, South East Texas Trauma Regional Advisory Council, and regional EMS agencies, has purchased a patient tracking system for use in future large-scale responses.)

Recommendation. We recommend deploying a region-wide evacuee tracking system providing a unique identifier (and ability to include a photograph). This system should track individuals, both patient and evacuee, from the initial contact site, throughout health care facilities, and back into any shelter, the medical examiner's office, or alternative living situation by means of facility-based and deployable field kits. The tracking system should be able to interface with a basic electronic medical record and track belongings, families, and pets for reunification purposes.

Use of Integrated Patient Medical Record System

At the Astrodome/Reliant Center Complex, patient encounter forms for the shelter treatment sites were supplied by the Harris County Hospital District community health clinics because the Harris County Hospital District electronic medical record system was deployed only in the Katrina Clinic. Total counts of patient encounter forms from the shelter triage areas numbered 4,500. Additionally, at least 1,500 encounters were not recorded in the first 2 days inside the Astrodome and, later, in the Reliant Convention Center. During the first days of the Astrodome/Reliant Center Complex shelter activation, using formal encounter forms was difficult; however, some data were recovered from informal records. Properly trained "intake" personnel are needed before the arrival of the first bus to gather demographic and identification information, which may later be added to the medical encounter form, facilitating patient tracking.

Recommendation. We recommend the use of the local region's medical record system, especially an integrated electronic version to enable integration and tracking of displaced persons into the larger system.

Use of Waste Management/Hygiene Facilities

Waste management and ensuring personal hygiene during Astrodome/Reliant Center Complex Operations was daunting. Many evacuees, after receiving new clothing, discarded large garbage bags of personal items soaked with flood water, leaving an estimated 20,000 bags of clothing at the Astrodome/Reliant Center Complex shelters. Cleaning crews were recruited to handle this potential health hazard and clean the shelter while evacuees slept. Waste management personnel became even more critical during the peak of gastrointestinal symptoms. The cleanup of emesis, loose stool, etc, was critical to help prevent the spread of infection. Planning for cleaning personnel is essential to prevent serious health and toxic hazards inside evacuee sheltering areas.

Recommendation. Bathing and hygiene facilities should be provided for all evacuees, including those with medical special needs, such as the disabled and the elderly. Most potential

shelter facilities are designed to deal with human waste for a more limited time (a few-hour sporting event or a day-long convention). Provision of around-the-clock waste management and hygiene requires proactive consideration to enable continuous facility use for weeks to months.

Availability of Transportation Within Shelter Facilities for Evacuees

Many evacuees required wheelchairs to move across the long parking lots between the shelter sites and the Katrina Clinic. Initially, only a limited number of wheelchairs were available. Transportation in and around shelter areas is as important as ambulance transport around the city. Local modes of transportation—wheelchairs or golf carts—within shelter facilities are critical and should be included in the regional plan. It is challenging to predict the number of persons with special needs, but advanced planning is critical. Given the potential for extreme weather, the regional shelter plan should consider large portable shelters for wind, sun, rain, or even snow, depending on the area. In the case of the Astrodome/Reliant Center Complex, the Houston Fire Department deployed large water mist fans to cool patients waiting for an ambulance or assistance into the shelters.

Recommendation. We recommend that the shelter plan include care for evacuees with special needs. This recommendation applies to the shelter and clinic facilities. Adequate transport and weather protection capability should be predeployed. Additional consideration for such medical special needs throughout the length of sheltering should be part of any preresponse planning.

Utilization of Communication Networks During Disasters

During disasters, cellular networks may experience increased call volumes or damage, severely impairing the ability of medical and National Security/Emergency Preparedness personnel to make emergency calls. Because the location of disaster areas is unpredictable and the number of medical and National Security/Emergency Preparedness personnel relying on cell telephones while performing emergency duties increases during a disaster response, the Wireless Priority Service (available at http://wps.ncs.gov/) was developed to provide emergency telephone call prioritization for emergency cellular calls for responders.

Although Wireless Priority Service was enabled for the greater Houston Area and the Astrodome/Reliant Center Complex, no Harris County Hospital District managers or Catastrophic Medical Operations Center Astrodome/Reliant Center Complex clinic/shelter personnel had a Wireless Priority Service–enabled cell telephone. The Harris County Hospital District, Harris County Public Health & Environmental Services, Houston Police Department, Houston Fire Department, and EMS teams had their own independent command and control communication assets; these were linked to the Unified Area Command. As in the Hurricane Andrew experience,[12,13] the civilian medical support staff could not use the cell telephone system and relied on "human couriered paper message systems" provided by Red Cross workers for the first 2 days of the response. We estimate that more than 150 messages were transferred by this system in the first 24 hours of Astrodome/Reliant Center Complex operations. With the installation of ubiquitous, free, landline phones to Katrina evacuees, decreased cell telephone congestion permitted civilian medical support to use cell telephones for the duration of the Astrodome/Reliant Center Complex shelter and clinic activities.

Recommendation. We recommend local civilian medical and logistical organizations be equipped with Wireless Priority Service–enabled cell telephones and landline telephone priority designation while performing their emergency/disaster management duties (Wireless Priority Service, available at http://wps.ncs.gov/). The Regional Hospital Preparedness Council, in partnership with the Southeast Texas Trauma Regional Advisory Council, has designed and deployed a mobile communication vehicle with satellite capabilities and radio interoperability.

Utility of Advanced Establishment of a Regional EMS/Hospital System

Regional EMS/hospital system coordination, such as Catastrophic Medical Operations Center provided to the Astrodome/Reliant Center Complex must be fully planned and ready before a disaster response. The Catastrophic Medical Operations Center's ability to monitor hospitals' capabilities and capacities while directing EMS resources and monitor patient presentation trends proved that a coordinated, patient-focused, collaborative health care response can help a region maintain its medical infrastructure, manage the usual population's emergencies, and care for a massive surge of evacuees with medical special needs. The Catastrophic Medical Operations Center was significantly aided by the Astrodome/Reliant Center Complex's shelter care and triage sites, which handled thousands of nonemergency conditions while diverting patients requiring more acute care to the Katrina Clinic (rather than into the community).

Summary

The Southeast Texas Trauma Regional Advisory Council served as the single point of contact for Unified Area Command's Medical Branch operations at Astrodome/Reliant Center Complex for Catastrophic Medical Operations Center provided a single point of contact for all Texas Trauma Service Area-Q hospitals, eliminating duplicate information requests. The same duties were performed for George R. Brown Convention Center and Ellington Field. Coordinating placement of patients according to hospital capability, capacity, and current patient volume prevented hospitals from becoming overwhelmed. This system also eliminated hospital diversions even when Astrodome/Reliant Center Complex EMS transfers were sustained at an average of 15 to 20 per hour during the first 3 days of shelter operations. Posthurricane quality assurance surveys indicated that only 2 (0.08%) patients were diverted to

an alternative erroneously triaged to the wrong medical facility. Thus, any region creating a disaster response plan to care for a large displaced population with similar medical maladies as those of Katrina evacuees may be assured that it is possible. However, activation of the Catastrophic Medical Operations Center model should be proactively developed and tested long before an actual event.

Recommendation. We recommend the implementation of a Catastrophic Medical Operations Center–like regional medical resource management model to coordinate regional health care assets and resources and to optimize patient outcomes.

Based on the Houston/Harris County Katrina experience, we are confident any community can mount a rapid response to a disaster such as Hurricane Katrina. Houston/Harris County was fortunate to have hundreds of health care professionals who worked long hours in a collegial manner. These medical care providers were successful both because of the support of their superiors and the thousands of other volunteers who showed up at the Astrodome/Reliant Center Complex to "do what needs to be done!"

On September 20, 2005, Harris County officially announced that the Katrina Response Operations had been completed and the Katrina Unified Area Command at the Astrodome/Reliant Center Complex was standing down after 3 weeks of around-the-clock operations. Lt. Joe Leonard of the US Coast Guard, who led the operations, said, "Our success is directly attributable to the strong personal relationships developed long before the Hurricane in Louisiana."[1] Any community should be able to do what Astrodome/Reliant Center Complex did, if advanced planning is used. When fellow communities are involved, doing less is unacceptable.

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