Perspective Piece
An Improved Ward Architecture for Treatment of Patients with Ebola Virus Disease in Liberia
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Abstract. During the recent outbreak of Ebola virus disease (EVD) in west Africa, we established an Ebola treatment center (ETC) with improved ward architecture. The ETC was built with movable prefabricated boards according to infectious disease unit standard requirements. The clinical staff ensured their own security while providing patients with effective treatment. Of the 180 admissions to the ETC, 10 cases were confirmed with EVD of which six patients survived. None of the clinical staff was infected. We hope that our experience will enable others to avoid unnecessary risks while delivering EVD care.

INTRODUCTION
In late 2014, a Chinese Ebola treatment center (ETC) was established at the SKD Stadium in Monrovia, Liberia. This report summarizes recent lessons learned regarding appropriate Ebola care in Africa.

ARCHITECTURE AND PROCESSES OF THE ETC
Before the construction of the ETC, we visited other ETCs in Monrovia. Because of scarcity of resources, many scaled-down ETCs, referred to as community care centers, each with the capacity of about 30 patients in a tent, were built. The major structure was divided into a “hot zone” and “cold zone,” separating health-care workers (HCWs) and patients from the suspected ward with an orange fence. Containers of chlorine and taps for handwashing marked divisions between each section. In contrast to others, the Chinese ETC was constructed within 28 days and opened on November 25, 2014 (Table 1). The 5,000-m² structure was built with movable prefabricated boards according to infectious disease unit standard requirements. The functional sections consist of 16 buildings, including clinics, inpatient wards, a patient disinfection area, morgue, stock rooms, a distribution desk, and training centers. The main building is an E-shaped structure with one observation ward and two confirmed wards, containing 100 beds. The inpatient wards were constructed based on the standards established for a specialized severe acute respiratory syndrome (SARS) hospital built in Xiaotangshan, Beijing, China, during the SARS outbreak in 2003. The ward is divided into three “areas,” two “zones,” and two “lines.” The three areas include “contaminated,” “potentially contaminated,” and “clean” areas. The two zones consist of two buffering zones, and the two lines refer to the clean and contaminated pathways. A one-way flow from the clean to contaminated areas was included on the inpatient floor to limit cross-contamination (Figure 1). Each inpatient unit is equipped with a bed with adjustable head and foot sections. The rooms are air-conditioned and include a separate bathroom with chloride-containing disinfectant and clean water. The facility also includes a central video camera monitoring system, a multiparameter bed-side monitoring system, and in-room ultraviolet disinfection lamps.

The Chinese ETC had 240 HCWs including 160 Chinese People’s Liberation Army members and 80 Liberians. All of them were well equipped. Between November 2014 and May 2015, 180 cases were admitted, of which 10 were confirmed with Ebola virus disease (EVD) based on real-time fluorescence quantitative polymerase chain reaction in the Liberia National Reference Laboratory. The clinical staff ensured their own security while providing patients with effective treatment. Oral rehydration solution, parenteral fluid, electrolytes, and vitamin supplements were provided according to standard contact and droplet infection control precautions. Peripheral and central venous access, phlebotomy, dialysis, and mechanical ventilation were implemented safely. Of the 10 confirmed EVD cases, four patients died and six survived. It is important that none of the clinical staff was infected.

ADVANTAGES AND WEAKNESSES OF THE ETC
The Chinese ETC had advantages over simpler ETCs. It had a solid construction structure compared with tent-based ETCs. The structure prevented the effects of direct sunlight and severe weather conditions. The featured areas, zones, and lines design provided segregation to limit cross-contamination. In our experience, the buffering zone forced HCWs to slow down while removing personal protective equipment (PPE), ensuring sufficient time for disinfection, such as hand and boot washing, to be effective. We took full advantage of the two lines to transport medical and everyday supplies. Clean supplies and nursing equipment entered the contaminated area from the clean pathway, allowing direct transportation. We also had ample time to inventory the clean pathway when necessary. The contaminated material and trash were transported via the contaminated pathway. The air-conditioned room relieved the HCWs, who were equipped with thick layers of protection, but more importantly, it created a comfortable environment for the patients. The two monitoring systems allowed close monitoring of patients’ conditions. When HCWs were not in the patient unit, they could communicate with patients using the bedside intercom and alert system, aiding the patient by reducing anxiety and combating loneliness. For example, when we communicated with a young patient over the intercom system and later entered the patient unit, she recognized us by voice and was very
happy. One of the most important features of the ETC was the multifunctional central monitoring system. It monitored not only the entire process from admission to discharge, but also the activities of all HCWs in the contaminated zone. In particular, during the critical steps of removing PPE, we guided the process through the monitoring system by providing instructions and reminders whenever necessary. This guidance added a layer of safety to decrease the likelihood of errors that might endanger HCWs. The central monitoring system also had the ability to capture important events by

<table>
<thead>
<tr>
<th>Building materials</th>
<th>China ETC</th>
<th>Other ETCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrangements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three areas</td>
<td>Tent based</td>
<td></td>
</tr>
<tr>
<td>Two buffering zones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beds</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Hospital information system</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Patient call system</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Air-conditioner</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

ETC = Ebola treatment center; N/A = not applicable.

Table 1
Contrasting the elements of China ETC and other ones in Monrovia

- Building materials: Solid construction material vs. Tent based
- Arrangements: Three areas vs. Hot zone and cold zone, Two buffering zones vs. N/A, Two line vs. N/A
- Ancillary facility: Beds vs. N/A, Hospital information system vs. N/A, Real-time monitoring system vs. N/A, Patient call system vs. N/A, Air-conditioner vs. N/A

Figure 1. Schematic illustrations of the main building layout and procedures for the simple “tent type” Ebola treatment center (ETC) and the China ETC: (A) simple “tent type” ETC and (B) main “E-shaped” building of the China ETC with illustration of procedures in one of the three wards. The blue and pink lines show the routes of the inpatients and staff, respectively. The arrow shows the walking direction. A one-way flow from the clean to contaminated areas of the staff must be followed in the China ETC but not in the “tent type” ETC. In the China ETC, the staff need to put on basic personal protective equipment (PPE), including disposable scrub suit, the first one disposable head cover, N95 or N99 mask, goggles, protective gown, the second one disposable head cover, the inner pair of gloves, and rubber boots. After going across the buffering zone, the staff need to put on advanced PPE, including disposable waterproof apron, face shield, the outer pair of gloves, and shoe cover. The advanced and basic PPE should be taken off following strict rules. In the simple “tent type” ETC, the staff put on PPE in the cold area and take off PPE in the orange fence.
videotaping. Once, when we told a 7-year-old child with confirmed EVD that he was ready to be discharged, he was so happy that he danced in front of the video camera. The staff in the monitoring room taped this precious occasion for the patient and gave the tape to the patient as a gift when he left the ETC.

During our activities we recognized some weaknesses in our ETC. In the initial design, not enough attention was paid to the air flow and ventilation of the unit. Compared with the open-tent type of ETC, the air ventilation of our solid-structured unit was much worse. During the early use of the ETC, the chloride emission from the disinfectant caused irritation of the eyes and noses of the HCWs.

Consequently, we added a ventilation system to improve the air flow. The irritating odor disappeared, and the environment became comfortable for both the patients and HCWs. An obvious limitation of our ETC is its cost, which was much greater than that of tent-based ETCs.

CONCLUSION

At our ETC, we hired many local citizens and experts who had worked at other ETCs. After working with us for some time, there was a consensus that our ETC was comfortable and safe. Our staff especially appreciated the central monitoring system, which provided continuous real-time monitoring of patients. Our experience offers insight into optimal EVD care, and with necessary resources, advanced technology, and highly skilled expertise, efficient control of EVD was achieved.

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