Experimental *Klebsiella pneumoniae* Burn Wound Sepsis: Role of Capsular Polysaccharide

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The role of *Klebsiella pneumoniae* capsular polysaccharide in relation to virulence in a murine burn wound sepsis model was investigated. Burn trauma markedly predisposed mice to lethal *K. pneumoniae* sepsis. A highly encapsulated variant (KP1-O) derived from *K. pneumoniae* KP1 was found to be extremely virulent for burned mice (50% lethal dose < 10 organisms), whereas another variant (KP1-T), which possessed a much smaller capsule, was comparatively nonvirulent (50% lethal dose > 10⁶ organisms). Production of large quantities of capsular material by KP1-O allowed for its rapid growth in vivo and persistence in the blood and liver. These traits were not demonstrated by KP1-T, which was effectively cleared after challenge.

Nosocomial infections due to *Klebsiella* species are a major cause of morbidity and mortality among several patient populations (5, 9). Of these groups, burn patients are particularly susceptible to life-threatening infections (8, 10, 13). In two reports, *Klebsiella* was second only to *Pseudomonas aeruginosa* as the cause of the bacteremia in burn patients (8, 10). Although several excellent experimental animal models exist for the study of pulmonary infections due to *Klebsiella* (2, 4), attempts to induce fatal burn wound sepsis have met with little success (15). Recent findings by Domenico et al. (4) demonstrating that the virulence of *Klebsiella pneumoniae*, both in a pulmonary and in an intraperitoneal challenge model, is greatly influenced by capsule size have led us to investigate this aspect in relationship to virulence in a murine burn model.

Two variants derived from *K. pneumoniae* KP1 (ATCC 8047, American Type Culture Collection, Rockville, Md.) were employed: KP1-O, which possesses a large capsule, and KP1-T, whose capsule is markedly smaller (approximately one-third that of KP1-O) were obtained from D. Straus, Texas Tech University Health Science Center, Lubbock, Tex. (4). Cultures were routinely grown on tryptic soy broth with dextrose (Difco Laboratories, Detroit, Mich.) at 37°C with shaking. The murine burn wound model of Stieritz and Holder (15) was used with slight modifications. The challenge organisms were grown to mid-log phase (absorbance at 540 nm = 0.3) and diluted in phosphate-buffered saline. Mice (18 to 20 g, Swiss-Webster white) were anesthetized with methoxyflurane (Penthrane, Abbott Laboratories, North Chicago, Ill.). Immediately after a 10-s ethanol burn over a 2-cm² area of the back, the bacterial challenge was given subcutaneously in 0.5 ml of phosphate-buffered saline. Mortality was recorded for 10 days postchallenge. The mean lethal dose (LD₉₀) was calculated by the method of Reed and Muench (14). Groups of six mice were used for each dilution. Quantitation of bacteria in the blood and in tissues was performed as previously described (3).

The effect of prior burn trauma on the virulence of *K. pneumoniae* was studied first. The LD₉₀ of KP1-O (highly encapsulated) for burned and for normal mice was determined (Table 1). KP1-O was found to be extremely virulent in burned mice with an LD₉₀ < 10 bacteria. However, it was comparatively nonvirulent for normal mice, as shown by a greater than 10,000-fold difference in the LD₉₀ value between the two groups. Therefore, burn trauma markedly predisposed mice to fatal infection with *K. pneumoniae*.

Next, the role that capsule size plays in the virulence of *K. pneumoniae* for burned mice was investigated by comparing the LD₉₀ values for KP1-O and KP1-T (Table 2). As in the previous experiment, the LD₉₀ for KP1-O was <10 bacteria. KP1-T was found to be far less virulent, with LD₉₀ values on the order of six magnitudes higher than KP1-O in both experiments. These findings indicate that the amount of capsular material produced by *K. pneumoniae* plays a critical role in virulence.

Bacterial growth and dissemination after challenge with KP1-O or KP1-T was monitored in an effort to better characterize the infectious process (Fig. 1). KP1-O proliferated rapidly in burned skin, with bacterial numbers exceeding 10⁷ per gram of skin by 48 h postchallenge. The bacterial load in the skin remained at this level throughout the course of the experiment. Bacteremia and liver colonization were first seen at 48 h postinfection. Deaths due to KP1-O sepsis occurred on days 3 through 5. In contrast, KP1-T displayed only limited multiplication in the skin, being cleared by day 3. Liver colonization and bacteremia were not observed. Therefore, possession of a large capsule allowed not only for sustained bacterial growth in the skin, but also for subsequent invasion of the bloodstream and organ colonization.

The present study demonstrates that the ability of *K. pneumoniae* to cause lethal burn wound sepsis in mice is dependent upon the amount of capsular polysaccharide produced. This is in agreement with previous studies using pulmonary or intraperitoneal challenge models (4, 6). Several hypotheses exist as to how *K. pneumoniae* capsular polysaccharide acts to increase virulence: (i) antiphagocytic activity (6, 16); (ii) induction of immune paralysis (1, 11); and

### TABLE 1. Effect of burn trauma on the virulence of *K. pneumoniae* KP1-O

<table>
<thead>
<tr>
<th>Burn trauma induced</th>
<th>LD₉₀</th>
<th>MTD (h)</th>
</tr>
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<tbody>
<tr>
<td>Yes</td>
<td>&lt;0.72 × 10⁶</td>
<td>158 ± 10.7</td>
</tr>
<tr>
<td>No</td>
<td>3.96 × 10⁵</td>
<td>136 ± 24.5</td>
</tr>
</tbody>
</table>

*a* Expressed as the number of viable infecting cells.

*b* Mean time to death ± standard deviation.

* Corresponding author.
TABLE 2. Virulence of K. pneumoniae KP1-O and KP1-T for burned mice

<table>
<thead>
<tr>
<th>Challenge strain</th>
<th>Expt 1</th>
<th>Expt 2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>LD₅₀</td>
<td>MTD ± SD*</td>
</tr>
<tr>
<td>KP1-O</td>
<td>&lt;0.75 × 10⁹</td>
<td>144 ± 33</td>
</tr>
<tr>
<td>KP1-T</td>
<td>&gt;3 × 10⁶</td>
<td>1.12 × 10¹⁷</td>
</tr>
</tbody>
</table>

* Mean time to death ± standard deviation.
* Lowest challenge dose tested. Less than 50% of animals survived.
* Highest challenge dose tested. All animals survived.

(iii) providing a barrier against nonspecific host defense systems (4). Which mechanism or mechanisms functioned in the animal model employed in the current study remains to be determined.

The animal model used in the current study was initially developed to investigate the pathogenesis of P. aeruginosa burn wound sepsis (15). The LD₅₀ for K. pneumoniae KP1-O was comparable to that seen for highly virulent strains of P. aeruginosa (<10 bacteria) (15). However, infection with P. aeruginosa is much more rapidly fatal compared with infection with KP1-O (15). Whereas the mean time to death with P. aeruginosa is approximately 30 h, that for KP1-O was found to be 150 h. This difference is most likely due to the production of extracellular enzymes (proteases and toxins) by P. aeruginosa which enhance bacterial growth in burned skin, allowing for evasion of the bloodstream (7, 12). Production of similar virulence factors by K. pneumoniae has not been reported. The use of a murine burn wound model with highly virulent challenge strains of K. pneumoniae may prove to be useful in evaluation of immunophrophylactic/immunotherapeutic agents for the prevention of fatal sepsis.

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