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14. ABSTRACT
Control of anthrax toxin and capsule synthesis, the two major virulence factors of Bacillus anthracis, has been associated with two regulatory genes, atxA and acpA, located on virulence plasmids pX01 and pX02, respectively. We used DNA microarrays to determine which genes in the B. anthracis genome are controlled by atxA and/or acpA. The regulation of numerous genes present on the virulence plasmids was documented and both positive and negative effects were observed. Certain atxA-regulated genes were affected synergistically in an atxA, acpA double mutants. AcpA appears to be a minor regulator with fewer targets than atxA. The newly discovered atxA-regulated targets include genes predicted to encode secreted proteins and proteins with roles in transcriptional regulation and signaling.

15. SUBJECT TERMS
DNA microarrays, gene expression, sporulation, virulence gene regulators

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ABSTRACT:

Control of anthrax toxin and capsule synthesis, the two major virulence factors of Bacillus anthracis, has been associated with two regulatory genes, atxA and acpA, located on virulence plasmids pXO1 and pXO2, respectively. We used DNA microarrays to determine which genes in the B. anthracis genome are controlled by atxA and/or acpA. The regulation of numerous genes present on the virulence plasmids was documented and both positive and negative effects were observed. Certain atxA-regulated genes were affected synergistically in an atxA, acpA double mutants. AcpA appears to be a minor regulator with fewer targets than atxA. The newly discovered atxA-regulated targets include genes predicted to encode secreted proteins and proteins with roles in transcriptional regulation and signaling.

KEY WORDS:

DNA microarrays, gene expression, sporulation, virulence gene regulators

OBJECTIVE:

We wished to determine which genes in the B. anthracis genome are transcriptionally regulated by either atxA and/or acpA beyond those previously identified, namely the toxins, pagA, lef, and cya and various genes encoding for capsular biosynthesis functions. Taken together, this repertoire of genes comprise the most important virulence determinants for B. anthracis pathogenicity. We also wished to explore the functional similarities (if any) that exist between the two transcription factors under investigation.

APPROACH:

The approach undertaken at TIGR was to construct a DNA microarray containing PCR amplified fragments of the open reading frames (ORFs) present within the partially completed B. anthracis genome sequence. In total PCR products representing 3,428 ORFs (3,290 chromosomal and 138 plasmid) were successfully amplified and spotted onto microarrays used in subsequent studies. This DNA microarray was to serve as the substrate for performing whole genome transcriptional profiling of B. anthracis in relevant environmental contexts that mimic the host environment
during early stages of infection. However, given the limitation of experimentally relevant RNAs provided from Dr. Hanna's laboratory, we were permitted, in collaboration with Theresa Koehler's laboratory, to validate the newly created DNA microarray using alternative RNAs bearing substantial interest to the B. anthracis research community. We used transcriptional profiling to determine whether atxA and/or acpA control genes other than those already described, and whether functional similarities exist between these two regulators. Transcription was assessed in a pXO1+ pXO2+ parent strain and in isogenic mutants deleted for one or both regulatory genes.

ACCOMPLISHMENTS:

We were successful in identifying the set of genes in the B. anthracis genome that are regulated by the transcriptional regulators, atxA and/or acpA. AtxA, regulates the majority and certainly the most important virulence determinants required for B. anthracis virulence and pathogenicity. The importance of the known targets of atxA suggest that identifying the complete set of genes regulated by this transcription factor will point interested investigators towards a greater set of genes with similarly important function in virulence and host infection. The atxA and acpA regulons have been defined through this effort.

CONCLUSIONS:

Our analysis of the transcriptional profiles of a genetically complete (pXO1+ pXO2+) toxigenic capsulated B. anthracis strain and isogenic mutants deleted for the regulatory genes indicates that these regulators affect expression of numerous B. anthracis genes on the plasmids and on the chromosome. The newly discovered atxA-regulated genes may have direct or indirect roles in B. anthracis pathogenesis. Some of the highly-regulated target genes on the plasmids are predicted to encode proteins associated with the B. anthracis cell membrane or cell wall biosynthesis. Our data reveal two significant findings regarding the relationship between these regulators. First, atxA positively regulates acpA expression, while acpA does not affect atxA expression. Second, the two regulators have a synergistic effect on expression of certain target genes. Our data expand the list of atxA and acpA-regulated genes in B. anthracis. Considering that all previously known targets of atxA are under positive regulation, it is somewhat surprising that atxA also negatively regulates a number of genes. AtxA may function as both a repressor and an activator, as has been reported for some transcriptional regulators. Moreover, some or all of the target genes may be controlled by an unidentified downstream regulator. Certain atxA-regulated genes identified in our experiments are predicted to encode proteins with similarity to known regulators. For example, the atxA-regulated gene pXO2-53, is predicted to encode a protein with sequence similarity to AtxA and AcpA. Another candidate for a downstream regulator is pagR. There is increasing evidence suggesting that the distinct phenotypes of the species with regard to pathogenesis may be due in some part to differential gene expression related to the presence or absence of functional regulatory proteins. The chromosomal regulator plcR of B. thuringiensis and B. cereus is a transcriptional activator that controls expression of a number of known and potential virulence genes, including those encoding lecithinase, proteases and hemolysins. B. anthracis harbors homologues of many plcR-regulated genes, some of which are proceeded by consensus sites for PlcR-binding. However, these genes do not appear to be highly expressed in
B. anthracis because B. anthracis lacks a functional PtcR protein. In an analogous manner, B. cereus and B. thuringiensis do not appear to harbor atxA or acpA homologues. However, these species contain homologues of the atxA target genes on the chromosome. Although the roles of the newly-identified atxA-regulated genes described here are not known, we view the species-specific regulators as important players in the transcriptomes of the species.

Our results represent a snapshot of the B. anthracis transcriptome for one time point in one specific growth condition. Certainly the transcription profile of B. anthracis will vary during growth in other conditions, including infection. It is noteworthy that in a mouse model for anthrax, a pXO1\(^+\) pXO2\(^-\) atxA-null mutant is avirulent and the antibody response to all three toxin proteins is decreased significantly. These data indicate that atxA function is important in vivo. No studies of acpA function during infection have been reported. In light of results presented here, studies of gene expression in B. anthracis and other plasmid-containing species should be interpreted with caution when cured strains are employed. It will be of interest to test the pXO1\(^+\) pXO2\(^+\) parent and regulatory gene mutants in animal models to determine relative virulence and to compare toxin and capsule synthesis in vivo. The significant cross-talk between the B. anthracis plasmids and chromosome is likely to be important for virulence and other aspects of B. anthracis physiology.

SIGNIFICANCE:

The identification of the atxA and acpA regulons provide researchers with a refined set of genes from the B. anthracis genome that represent novel virulence gene candidates that may be validated as potential therapeutic targets. It will be of interest to determine whether the proteins under atxA and acpA control are immunoreactive with sera from infected animals. The data generated also establish the first step in defining the atxA/acpA regulatory circuitry that likewise provides a unique basis and opportunity for therapeutic approaches in which attempts to “short circuit” the proper regulation of atxA and acpA target genes by interfering with their expression and functional impact to the cells virulence potential.

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