Using Different Bioinformatics Software Tools for Determining the Carbon Dioxide (CO₂) Dependence in Staphylococcus aureus

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Abstract

Staphylococcus aureus (S. aureus) is a Gram-positive bacterium that occurs in microscopic bunches similar to grapes. In general, S. aureus shows two different colonies; on agar dishes S. aureus forms huge golden yellow colonies, while on blood agar dishes it has haemolytic properties. Recently, different major studies have discovered CO₂-dependent S. aureus strains that can be found as an inhabitant of small colony variants (SCV) S. aureus, which can cause recurrent and persistent infections. Although it has been investigated the mechanism of this CO₂ dependence, this paper aims to use different bioinformatics software tools, such as MUMmer, BLAST, Jalview and ClustalW, in order to compare and search for the differences in the enzymes involved in pathways that can be altered in the CO₂-dependent S. aureus strain. That is, the entire genome of CO₂-dependent S. aureus strain was compared against another strain, not CO₂-dependent using the software tool MUMmer. Based on this tool, the results show that the plots of the CO₂-dependent strain against the COL and Mu50 strains did not show any gaps, while the connected thick diagonal line reveals strong similarities between the sequences in comparison to the thin diagonal line. Surprisingly, the results of using BLAST alignment tool did not illustrate any obvious mutations. Besides, the comparison between a number of strains and the CO₂-dependent S. aureus strain was carried out using the ClustalW alignment tool and Jalview software; consequently it did not show any observable mutations, as well.

Keywords: Staphylococcus aureus; CO₂-dependent S. aureus strains; MUMmer; BLAST; Jalview; ClustalW

Introduction

Staphylococcus aureus (S. aureus) is a Gram-positive, immobile and spherically shaped (around 1 µm diameter) bacterium that occurs in microscopic bunches similar to grapes, as shown in Figure 1. In general, S. aureus shows two different colonies; on agar dishes S. aureus forms huge golden yellow colonies, while on blood agar dishes it has haemolytic properties. In addition, S. aureus has the ability to produce the lactic acid as it is considered to be an optional anaerobic, which grows either by aerobic respiration or by fermentation [2].

Commonly, S. aureus can be found on the skin, like part of the regular flora and in the respiratory tract of the human. Furthermore, this bacterium can be found as skin lesions or impetigo in the adult individual as an abscess in children or as mastitis in cattle [3,4]. It has been recorded that, around 20% of the populations are considered to have a long-term case of S. aureus. Moreover, there are different diseases that can be caused by S. aureus such as soft tissue infections, life-threatening septicemia, superficial skin, endocarditis and toxic shock syndrome [5]. In most cases β-lactam antibiotics, clindamycin, tetracycline and sulpha drugs are using as treatments for the S. aureus infections. In the past, before introducing penicillin as a treatment in 1949, the major cause of mortality in patients was the hospital-acquired (nosocomial) infections, which are caused by S. aureus. After that, the penicillin-resistant S. aureus isolates were first discovered in hospitals. Then the first discovery of the Methicillin-resistant nosocomial S. aureus isolates was in 1961 [6]. Afterwards, in hospitals and intensive care units the Methicillin-resistant S. aureus (MRSA) became common worldwide. Nowadays, more than 30% of the bacterial nosocomial infections occurring in intensive care units are caused by MRSA. Previously, MRSA was confined only to hospitals and then new strains of MRSA arose in the community causing different infections in healthy humans. In the 1990s, an extreme Community-Acquired Methicillin-resistant S. aureus (CA-MRSA) strain was discovered in Australia [7]. Normally, CA-MRSA has the ability to cause different infections such as a spontaneous abscess either on the skin or on the soft-tissues. In addition, the CA-MRSA strains can be spread quickly in a community, and can affect children and healthy individuals.

Pinto and Merlino found that the CO2-dependent S. aureus was detected for the first time in 1955 [8]. These organisms can be found as an inhabitant of small colony variant (SCV) S. aureus, which can cause recurrent and persistent infections. In addition, SCV S. aureus...
strains were found to be an antibiotic-resistant strain as it has a novel mechanism.

Furthermore, a study into SCVs found that they are naturally occurring and are considered to be a slow growing subpopulation of bacteria. Some of these SCVs are occasionally found as auxotrophs for CO\textsubscript{2}, whereas most of them are supposed to be mendionade, hemin or thymidine auxotrophy [9]. In terms of the CO\textsubscript{2}-dependent phenotype the same study found that the micro-colony phenotype is dependent on the gene expression level instead of the existence or absence of one or more particular genes. The reason for this might be because they demonstrated a significant decrease in the proportion of the microcolony phenotype stability. In addition, when multiple subcultures have been done, the micro-colony phenotype returned to normal colony morphology.

Another study by Rahman examined the CO\textsubscript{2} dependent strain both aerobically and anaerobically [10]. The results showed an obvious growth in colony size under both conditions, but with smaller sized colonies when produced anaerobically. Furthermore, after further tests, this study found several important characteristics of the CO\textsubscript{2} dependent strain. For example, this strain was found to be positive for coagulase, DNAse and phosphatase. Besides, it had a fermentative ability during fermentation/oxidation reactions and the organism was sensitive to all other antibiotics but not to tetracycline or penicillin.

Since there has been a little consideration given to the genetic and molecular basis for CO\textsubscript{2} dependence in S. aureus, this paper aims to examine the contribution of genomic re-arrangements to the CO\textsubscript{2} dependent phenotype by using different bioinformatics software tools. In particular, these tools will be utilised in order to compare and search for the differences in the enzymes involved in pathways that can be altered in the CO\textsubscript{2}-dependent S. aureus strain. That is, the entire genome of CO\textsubscript{2}-dependent S. aureus strain was compared against another strain, not CO\textsubscript{2}-dependent using the software tool MUMmer. By using this tool, it has been shown that the plots of the CO\textsubscript{2}-dependent strain against the COL and Mu50 strains did not show any gaps, while the connected thick diagonal line reveals strong similarities between the sequences in comparison to the thin diagonal line. Surprisingly, the results of using BLAST alignment tool did not illustrate any obvious mutations. Besides, the comparison between a number of strains and the CO\textsubscript{2}-dependent S. aureus strain was carried out using the ClustalW alignment tool and Jalview software; consequently it did not show any observable mutations, as well.

The rest of this paper is organized as follows, section 4 discusses the related work, methods are explained in section 5, section 6 shows the results; The results are discussed in section 7; section 8 concludes the paper with future works.

Related Work

One of the major studies in CO\textsubscript{2}-dependent S. aureus field was in (Gómez-González et al.) that investigated about 14 conditions of CO\textsubscript{2}- dependent S. aureus over a time of three years [9]. The clinical isolates in this study were confirmed to be Small Colony Variants (SCVs) of S. aureus as they displayed all the requisite characteristics. This study was aimed at verifying the importance of CO\textsubscript{2} dependent S. aureus as a significant pathogen, as well as illustrating the clinical characterisation of the 14 cases and the genetic and phenotypic characterisation of the SCVs isolated. The results of this study showed that 14 out of 14 (100%) of the clinical isolates were found to be CO\textsubscript{2} dependent.

Persson et al. discussed how CO\textsubscript{2} affects the growth of S. aureus at body temperature [11]. The S. aureus in this study was inoculated on both blood agar and brain--heart infusion broth. These plates were then exposed to either 100% CO\textsubscript{2}, or to air at body temperature (37°C) for a time of 8 to 24 hours. Their results showed that 100% CO\textsubscript{2} significantly reduced the growth of S. aureus at body temperature. Furthermore, they deduced that increasing the exposure duration considerably increased the inhibiting effect of CO\textsubscript{2}.

A study carried out by Arioli et al. focused on the genetic and proteomic analysis approaches to study the CO\textsubscript{2}-dependent metabolism of Streptococcus thermophilus, which was grown in either a CO\textsubscript{2} enriched atmosphere or in a N\textsubscript{2} rich atmosphere. The results of this study highlighted the importance of the CO\textsubscript{2}-dependent metabolism in the S. thermophilus physiology [12].

Different study by Bringel and Hubert has considered the range of genetic lesions in the pathways of both pyrimidine and arginine biosynthesis [13]. This was done on different strains of gram-positive lactobacilli, namely 32 strains of Lactobacillus pentosus, 150 strains of L. plantarum, 10 strains of L. casei and 15 strains of L. paraplanatarum. This study aimed to examine the arginine auxotrophs in L. plantarum and the important gene mutations. The results of this study showed that all L. casei strains, two of the L. pentosus strains and seven of the L. plantarum strains were arginine auxotrophs.

Another important study was in Nicolf et al. has shown that the wild-type Lactobacillus plantarum harbours two different efficient kinds of Carbamoyl-Phosphate Synthetases (CPS) [14]. Carbamoyl phosphate (CP) is considered to be an important intermediary in arginine and pyrimidine biosynthesis and requires ATP and CO\textsubscript{2} to be produced. This study found that the two important CPSs that are arginine-repressed CPS (CPS-A) and pyrimidine-inhibited CPS (CPS-P). Therefore, the results of this study demonstrated that the CP synthesis of the wild-type L. plantarum is reliant on higher levels of CO\textsubscript{2}.

Methods

This section describes the methods and software tools that have been used.

Comparative genomics using mummer

The MUMmer system was used to align the entire genomes of CO\textsubscript{2}-dependent S. aureus strain against other closely related strains (non CO\textsubscript{2}-dependet). MUMmer was run using a typical command line on the Biolinux terminal, namely: (mummer -mum -b -c genome1 genome2>output-file.mums) (where genome1 and genome2 indicate the sequences to be compared) [15]. This command was used to find all maximal unique matches (-mum) between genome1 and genome2 on both the forward and reverse strands (-b) and reports all the match positions relative to the forward strand (-c). A MUMmer plot program of all the MUMs between two sequences was run to identify the similarity between the different genomes. The MUMmer plot command line is (mummerplot -x ’[0, 275287]’ -y ’[0, 265111]’ -postscript -p mummer output-file.mums) (where genome1 and genome2 indicate the sequences to be compared) [15]. This command was used to plot all of the MUMs in the outputfile.mums file in postscript format (-postscript) between the given ranges for the X and Y-axes. The string specified with the -p option prefixed the output files. These plots are shown in the results section.

The alignment using BLAST

BLAST was used to align the CO\textsubscript{2}-dependent S. aureus nucleotide sequence against the most closely related sequence that is not CO\textsubscript{2} dependent. This was done by looking at the carbamoyl phosphate...
As shown in Figure 3, the postscript plot of all MUMs between the CO$_2$-dependent S. aureus strain and S. aureus Mu50 did not have any obvious gaps. In addition, the thick connected diagonal line reveals strong similarities between the sequences, in comparison to the thin diagonal line.

The alignment using BLAST

The carbamoyl phosphate (CP) requires CO$_2$ for synthesis and is encoded by two different genes: carA for the small subunit and carB for the large subunit. Therefore, these two genes from the S. aureus Mu50 strain were aligned against the CO$_2$-dependent S. aureus strain to find the closest contig. The results of the alignments using the BLAST alignment tool showed that the nearest to identical contig is 51. Next, this contig was translated into an amino acid sequence to be compared against the amino sequence from the carAB gene from the S. aureus Mu50 strain using BLASTP.

Multiple sequence alignment using Clustalw and Jalview

The small and large subunits for the CO$_2$-dependent S. aureus carAB genes were obtained from the results of aligning the same gene from different strains. The strains used were S. aureus COL, S. aureus Newman, S. aureus Mu50, S. aureus N315, S. aureus ED98, S. aureus ED133, S. aureus ST398, S. epidermidis ATCC 12228, S. carnosus TM300 and S. saprophyticus ATCC15305. The carAB small and large chain protein sequences for these strains were downloaded using the KEGG database. Additionally, the Jalview software was used to view the similarities and differences between these alignments.

Results

This section presents the results that have been obtained by using different bioinformatics software tools for determining the carbon dioxide (CO$_2$) dependence in Staphylococcus aureus. This section is divided into different subsections according to the used tools.

Comparative genomics using mummer

The entire genome alignments of CO$_2$-dependent S. aureus strain against non CO$_2$-dependent strains (Mu50 and COL) were performed using the MUMmer system to examine the similarities and differences occurring at the genomic level. The postscript plot of the whole genome alignment of the CO$_2$-dependent S. aureus strain against that of the S. aureus COL strain (Figure 2).

As shown in Figure 2, there are no gaps along the thin diagonal line. This represents a strong similarity between the two sequences. Further, the postscript plot of the entire genome alignment of the CO$_2$-dependent S. aureus strain, against that of the S. aureus Mu50 strain (Figure 3).

Multiple sequences alignment using Clustalw and Jalview

ClustalW was used to align the carAB large and small subunits for the CO$_2$-dependent S. aureus strain from the most identical contig against the same encoding genes from different protein strains [17-19]. These strains were S. aureus COL, S. aureus Newman, S. aureus Mu50, S. aureus N315, S. aureus ED98, S. aureus ED133, S. aureus ST398, S. epidermidis ATCC 12228, S. carnosus TM300 and S. saprophyticus ATCC15305. The carAB small and large chain protein sequences for these strains were downloaded using the KEGG database. Additionally, the Jalview software was used to view the similarities and differences between these alignments.

As shown in Figure 3, the postscript plot of all MUMs between the CO$_2$-dependent S. aureus strain and S. aureus Mu50 did not have any obvious gaps. In addition, the thick connected diagonal line reveals strong similarities between the sequences, in comparison to the thin diagonal line.

The alignment using BLAST

The carbamoyl phosphate (CP) requires CO$_2$ for synthesis and is encoded by two different genes: carA for the small subunit and carB for the large subunit. Therefore, these two genes from the S. aureus Mu50 strain were aligned against the CO$_2$-dependent S. aureus strain to find the closest contig. The results of the alignments using the BLAST alignment tool showed that the nearest to identical contig is 51. Next, this contig was translated into an amino acid sequence to be compared against the amino sequence from the carAB gene from the S. aureus Mu50 strain using BLASTP.
As illustrated in the results section, the entire genome nucleotide sequence of the CO₂-dependent S. aureus strain was compared against the Mu50 and COL strains to look for similarities and differences occurring at the genomic level. As demonstrated in Figures 2 and 3, the plots of the CO₂-dependent strain against the COL and Mu50 strains did not show any gaps. This might mean that the similarities between these sequences are very strong. Additionally, the connected thick diagonal line reveals strong similarities between the sequences in comparison to the thin diagonal line. As suggested by Delcher et al. the connected thick diagonal line between the two sequences represents high homologous relationships between the two sequences compared [20].

The BLAST alignment tool was used to align the S. aureus Mu50 carAB sequences against the whole genome of the CO₂-dependent S. aureus strain to find the most identical contig. The alignment results strongly supported contig 51 as being the nearest match. Then the amino acid sequence of this contig was aligned against the amino acid sequence from the carAB genes in the wild type strain Mu50. Surprisingly, the results of this comparison did not illustrate any obvious mutations, as shown in Figure 4. The possible explanation for this could be that the strains that were used for comparison against the CO₂-dependent S. aureus strain were from the same organism, namely staphylococci. Furthermore, these strains were very closely related to the CO₂-dependent S. aureus and therefore the group membership and the phylogenetic characteristics would be almost identical.

Due to the failure to find any mutations from the carAB comparison, the promoter DNA sequence for the carAB chains of the CO₂-dependent S. aureus strain needed to be compared against the same promoters from the Newman S. aureus strain. As demonstrated in the results section, the promoters of the carAB for S. aureus Mu50 were obtained using the microbesonline website. These promoters are PyrB for the carbamoyl phosphate small chain (carA or pyrA) and PyrC for the carbamoyl phosphate large chain (carB). In all organisms, there are two ways of synthesizing the pyrimidine nucleotides, either using the salvage pathways of preformed nucleosides and pyrimidine bases or from bicarbonate and intermediaries of the central metabolism using the de novo pathway (Ghim and Neuhard) [21]. The de novo
pathway is catalysed by ATP, glutamine (ammonia), aspartate and 5-phosphoribosyl-1-pyrophosphate (PRPP) and by bicarbonate and UMP when the exogenous pyrimidines are not present in the culture. This process is performed using six different enzymes that are encoded by the pyr operon: aspartate transcarbamoylase (pyrB), dihydroorotase (pyrC), dihydroorotate dehydrogenase (pyrD), carbamoylphosphate synthetase (carAB in enteric bacteria and pyrA in Bacillus spp.), orotate phosphoribosyltransferase (pyrE) and orotidine 5'-phosphate decarboxylase (pyrF) [21].

In the current study, the pyrB and pyrC promoters DNA sequences from the CO2-dependent S. aureus strain were compared against the same promoters from a non CO2-dependent strain, namely the Newman S. aureus strain. Because the results of comparing the promoters DNA sequences did not show any clear mutations either, as shown in Figure 6, the second theory needed to be tested.

Conclusion and Future Work

This paper applied numerous bioinformatics software tools in order to compare and search for the differences in the enzymes involved in pathways that can be altered in the CO2-dependent S. aureus strain. Therefore, the entire genome of CO2-dependent S. aureus strain was compared against another strain, not CO2-dependent using the software tool MUMmer. By this tool, the results that the Newman S. aureus strain was compared against another strain, not CO2-dependent did not illustrate any obvious mutations. Furthermore, the comparison of the CO2-dependent strain against the COL and Mu50 strains did not show any observable mutations, an alternative pathway of the CO2 enrichment needs to be achieved as one of our future works.

Since the results of comparing the carAB genes and their promoters of the CO2-dependent S. aureus strain against other closely related strains did not show any observable mutations, an alternative pathway of producing arginine, proline or pyrimidine from glutamate without CO2 enrichment needs to be achieved as one of our future works.

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