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RESEARCH ARTICLE

REVISED Polycistronic transcription of fused cassettes and identification of translation initiation signals in an unusual gene cassette array from *Pseudomonas aeruginosa* [version 2; peer review: 1 approved, 1 approved with reservations]

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Abstract

The gene cassettes found in class 1 integrons are generally promoterless units composed by an open reading frame (ORF), a short 5' untranslated region (UTR) and a 3' recombination site (*attC*). Fused gene cassettes are generated by partial or total loss of the *attC* from the first cassette in an array, creating, in some cases, a fusion with the ORF from the next cassette. These structures are rare and little is known about their mechanisms of mobilization and expression. The aim of this study was to evaluate the dynamic of mobilization and transcription of the *gcu14-bla_{GES-1}/aacA4* gene cassette array, which harbours a fused gene cassette represented by *bla_{GES-1}/aacA4*. The cassette array was analyzed by Northern blot and real-time reverse transcription-polymerase chain reaction (RT-PCR) in order to assess the transcription mechanism of *bla_{GES-1}/aacA4* fused cassette. Also, inverse polymerase chain reactions (PCR) were performed to detect the free circular forms of *gcu14*, *bla_{GES-1}* and *aacA4*. The Northern blot and real time RT-PCR revealed a polycistronic transcription, in which the fused cassette *bla_{GES-1}/aacA4* is transcribed as a unique gene, while *gcu14* (with a canonical *attC* recombination site) has a monocistronic transcription. The *gcu14* cassette, closer to the weak configuration of cassette promoter (PcW), had a higher transcription level than *bla_{GES-1}/aacA4*, indicating that the cassette position affects the transcript amounts. The presence of ORF-11 at *attI1*, immediately preceding *gcu14*, and of a Shine-Dalgarno sequence upstream *bla_{GES-1}/aacA4* composes a scenario for the occurrence of array translation. Inverse PCR generated amplicons corresponding to *gcu14*, *gcu14-aacA4* and *gcu14-bla_{GES-1}/aacA4* free circular forms, but not to *bla_{GES-1}* and *aacA4* alone, indicating that the GES-1 truncated *attC* is not substrate of integrase activity and that these genes are mobilized

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Any reports and responses or comments on the article can be found at the end of the article.

together as a unique cassette. This study was original in showing the transcription of fused cassettes and in correlating cassette position with transcription.

Keywords

gene cassette, clase 1 integrons, fused gene cassette, transcription

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REVISED Amendments from Version 1

Doubts and questions made by reviewers have been answered in the comments section, and whenever possible an explanation was made in the manuscript in order to make it clear to readers.

- A new figure (Figure 2) was provided showing the alignment of canonical and truncates GES-1 *attC* site as requested by Dr. Berçot.
- We contacted the GenBank staff in order to alter the start codon of *aacA4* gene cassette, which was erroneous annotated in the original DQ236170 accession number, as noticed by Dr. Berçot. The correct gene annotation has already been performed and the GenBank accession number provided in the second version of the manuscript is already updated.
- As requested by Dr. Partridge, the sequence showing that the free circular form was composed by the entire gene cassette arrangement was properly annotated and submitted to GenBank under the accession number KT336477. As such, we have removed this information from the appendices. In order to help and guide reviewers and readers, a new figure (Figure 3) showing the inverse PCR approach and the sequence resulted from it was provided.
- As suggested by Dr. Partridge, some parts of the results and discussion was moved to the introduction section, as highlighted, and the conclusion section was expanded.
- Since new and more informative data concerning the presence and configuration of cassette circular forms (Figure 3 and the releasing of the deposited sequence KT336477) were provided in the second version, the presentation of figshare widget would not be necessary anymore, and it was removed from this second version.

See referee reports

Introduction

Class 1 integrons are capable of inserting, excising and rearranging gene cassettes by a site-specific recombination mechanism. These assembly platforms can also act as expression systems due to the presence of a promoter region (Pc), which drives the expression of genes captured by integron¹. Moreover, naturally occurring integrons may have a second promoter (P2), which is activated by the insertion of three G residues between -35 and -10 hexamers¹. Gene cassettes are generally promoterless units associated with a recombination site (*attC* or 59-be), which confers the ability of each structure to be mobilized independently², and the Left Hand (LH – 1L and 2L core sites) and Right Hand (RH – 1R and 2R core sites) domains from *attC* sites are crucial for this mobilization³. Studies focusing on gene cassette translation in the context of integrons are rare, however, it was recently showed that *attC* sites regulate the translation of downstream cassettes due to their peculiar sequences composed by imperfect inverted repeats that form stem-loop structures. These secondary structures prevent ribosome progression throughout mRNA, reflecting in a decreased expression of more distal genes regarding Pc⁴. Conversely, TIR (Translation Initiation Region)-deficient gene cassettes could have their expression promoted by the presence of ORF-11⁵. This ORF, when present, is found at the *attI* site preceding the gene cassette array. It codes for 11 amino acids and harbours its own Shine-Dalgarno (SD) sequence. Therefore, the ORF-11 recruits the ribosomes and, through an event of coupled translation, the subsequent TIR-deficient

gene cassette could be expressed^{4,5}. Gene cassettes can be found inserted in integrons or in other secondary sites, or free in the cytoplasm as a closed circle, in which the 5' end (5' UTR) and the *attC* recombination site are covalently linked⁶.

As demonstrated previously, several stress conditions could evoke the activation of the SOS response resulting in integron-integrase expression⁷. Therefore, under stress, the integrase activity increases, favoring the occurrence of integration/excision/rearrangements events.

Although rare, fused cassettes may be generated by partial or total loss of the first *attC*, retaining both complete coding regions and, therefore, creating permanent gene arrays comparable to bacterial operons⁸. The functionality of such structures has been indirectly inferred by the resistance profile of transformants carrying the fusion⁹; however, the transcription itself has never been verified.

This study showed the dynamics of fused cassette mobilization, the co-transcription of the *gcuI4-bla_{GES-1}/aacA4* cassette array and the effect of cassette position on transcription levels in *Pseudomonas aeruginosa* wild lineages carrying class 1 integrons. Moreover, the presence of translation signals in this gene cassette array was determined.

Material and methods

An unknown Open Reading Frame (ORF), *gcuI4* (gene cassette of unknown function), followed by the fused cassette *bla_{GES-1}/aacA4*, created by partial loss of GES-1 *attC* were present in integrons from clinical *P. aeruginosa* isolates (PS1 and PS26)¹⁰. Total RNA was extracted and purified according to the manufacturer's instructions with the SV 96 Total RNA Isolation System (Promega). Northern blot using 7 µg of total RNA from PS1 and PS26 was performed in order to detect the transcript originated from *gcuI4-bla_{GES-1}/aacA4* cassette array. After electrophoresis in a denaturing-formaldehyde 1.5% agarose gel, the total RNA was transferred to the Hybond-N⁺ nylon membrane (GE Healthcare) by upward capillary transfer. An amplicon of 519bp corresponding to part of the *bla_{GES-1}* gene was used as a probe (Table 1) in hybridization assay. The GES probe was labeled with the AlkPhos Direct Labelling kit (GE Healthcare) and hybridized with the target RNA immobilized on the Hybond-N⁺ membrane as recommended. The chemiluminescence was detected with the CDP-Star detection reagent (GE Healthcare) according to manufactures. Immediately after applying the detection reagents, the blot was drained, incubated five minutes at room temperature and exposed to the Hyperfilm ECL (GE Healthcare) for 60 minutes at room temperature.

In order to verify whether the relative position of gene cassettes on the variable region plays a role in transcription level, real-time RT-PCR reactions using the TaqMan System (Applied Biosystems) were performed with primers and probes detailed in Table 1. The *rpsL* gene of the *P. aeruginosa* chromosome was amplified by PCR (Table 1) and used as a reference gene for normalization. The relative quantification (RQ) results were presented as ratios of gene transcription between the target gene (cassettes) and the reference gene (*rpsL*), which were obtained according to the following equation: $RQ=2^{-\Delta CT}$, where CT is the value corresponding to the crossing point of the amplification curve with the threshold and $\Delta CT=CT$

Table 1. Primers used in conventional, inverse and real-time PCR reactions.

Primer	Primer sequence (5' – 3')	Size (bp)	Target
Primers for conventional PCR			
Ges F Ges R	GCGTTTTGCAATGTGCTC CCAGTTTTCTCTCCAACAACC	519	Internal fragment of <i>bla_{GES}</i> gene
Primers for inverse PCR			
Gcu14 FSQ Gcu14 RSQ	AGCAATCAACACACAGGGG CTCGCGTAAATGCACCGCTT	130	<i>gcu14</i> circular form
GES FSQ GES RSQ	CAAGTTATTACACAATCAT AGTGCGTGAATGAAGCGCAT	110	<i>bla_{GES-1}</i> circular form
AAC4 FSQ AAC4 RSQ	GCCAGGCATTCGAGCGAACAC ATTTAGCCACTCACATAGAGC	188	<i>aacA4</i> circular form
Primers and probes for real time PCR (TaqMan)			
RpsL F RpsL R Probe	GCCTGCGCTGCAAACT TTTCGGCGTGGTGGTGAT TCGTGGCGTATGCACC	67	<i>rpsL</i> transcripts
Gcu14 F Gcu14 R Probe	CATGCGCTTCTTGGTTCGT ACGCCAGCTTGGATGCAA ATGCCACGAGACCTT	56	<i>gcu14</i> transcripts
Ges F2 Ges R2 Probe	GTGCAGCTTAGCGACAATGG CACAGAGTCGCCAATTTACGA AATTGCAGCAGGTCCGCC	99	<i>bla_{GES-1}</i> transcripts
AacA4 F AacA4 R Probe	CAAGCGTTTTAGCGCAAGAGT TCGGCTCTCCATTCAGCATTG CCGTCACCTCCATACATTG	59	<i>aacA4</i> transcripts
Ges F3 AacA4 R2 Probe	TCCTGAGCACGGACAAATAG TCATAGAGCATCGCAAGGTC TTCCGTCACACTGCGCCTCA	134	Polycistronic transcripts

target gene minus CT reference gene. The effect of cassette position on gene transcription was considered significant when the ratios obtained between RQ values (RQ value of cassette 1/RQ value of cassette 2) were ≥ 2.0 , taking into account the standard deviation intervals.

In order to induce cassette excision from integrons, PS1 and PS26 strains¹⁰ were submitted to thermal stress during the log growth phase to induce integrase activity. Cells were grown on Luria-Bertani (LB) broth medium (OXOID) at 37°C for two hours. Subsequently, the bacterial cultures were submitted to a heat shock at 4°C for 30 minutes and immediately incubated at 42°C for another 30 minutes. Briefly, the total DNA from PS1 and PS26 cultured under thermal stress were obtained with the Wizard Genomic DNA purification kit (Promega) following manufacturer recommendations and used as templates in inverse PCR reactions. The inverse PCR was performed with primers facing outwards towards the ends of *gcu14*, *bla_{GES-1}* and *aacA4* so that only circular gene cassette configurations would be amplified. The reactions targeting the circular forms of *gcu14*, *bla_{GES-1}*, *aacA4* and *bla_{GES-1}/aacA4* fusion was performed with primers and combinations described in Table 1. The inverse PCR was performed using Platinum *Taq* DNA Polymerase reagents (Invitrogen), and the following components were added to a sterile 0.2-mL tube: 5 μ L of 10X PCR buffer (1X final concentration);

1 μ L of 10mM dNTP mixture (0.2 mM each); 1.5 μ L of 50mM $MgCl_2$ (1.5 mM final concentration); 2 μ L of 15 μ M of each primer (30 μ M each); 100 ng of template DNA; 0.3 μ L of Platinum *Taq* DNA Polymerase (1U final concentration). The tubes were incubated in the Eppendorf MasterCycler (Eppendorf) at 94°C for 2 minutes and PCR amplification was performed in 40 cycles consisting of: 94°C for 30 seconds; 55°C for 30 seconds; and 72°C for 3 minutes. The amplicons generated with the inverse PCR were purified using Wizard SV Gel and PCR Clean-Up system kit (Promega) and directly sequenced on both strands. Sequencing reactions were performed with Big Dye Terminator RR Mix (Applied Biosystems) in an ABI 3730 XL DNA Analyzer (Applied Biosystems). Nucleotide sequences were compared to those available in the GenBank database accessible on the National Center for Biotechnology Information website (<http://www.ncbi.nlm.nih.gov>). All primers used in PCR, sequencing and real time RT-PCR are described in Table 1.

Analyses *in silico* were performed to search for a potential promoter for *gcu14* gene cassette. The 5'UTR from *gcu14* were submitted to the promoter predictor programs Neural Network for Promoter Prediction version 2.2 (Berkeley Drosophila Genome Project, <http://www.fruitfly.org/index.html>) and BPROM (SoftBerry, <http://linux1.softberry.com/berry.phtml>). Results with the highest scores were selected as candidates for a putative promoter.

Results and discussion

The integrons analysed in this study harbored the weak Pc configuration (PcW)¹¹, and they carry the *gcu14* as the first gene cassette (see reference 12 for nomenclature), which has not been reported so far. Considering that transcription initiates from the Pc promoter placed upstream the cassette array, both monocistronic and full length polycistronic transcripts could be identified. In fact, Northern blot and hybridization assays revealed a unique signal of approximately 2,300 bases, which corresponds to the co-transcription of the entire array (*gcu14-bla_{GES-1}/aacA4*) (Figure 1). This result is in agreement with previous work in which the occurrence of transcripts containing more than one gene cassette was observed by Northern blot analysis¹. Moreover, this finding gives support to the lack of *attC* function in terminating transcription of downstream gene cassettes as demonstrated previously⁴.

This fusion retained both entire coding regions and, due to a possible erroneous recombination event, the *bla_{GES-1} attC* site was replaced by part of the *attII* site (DQ236170)¹⁰, reducing it to the 6bp from the 1L core site (Figure 2). Taking into account that the region responsible for stem-loop formation was missing in GES-1 *attC* and the participation of this site in terminating translation⁴, our findings indirectly suggested that *bla_{GES-1}* and *aacA4* translation is occurring in a unique step.

The strains were submitted to thermal stress conditions in order to verify the dynamics of mobilization of *gcu14-bla_{GES-1}/aacA4* gene cassettes. Since the excision event depends on the recognition of the LH and RH domains of the *attC* site, and that the 2L core site and the entire RH domain are missing in GES-1 *attC* (Figure 2), it is expected that the *bla_{GES-1}/aacA4* excision occurs only at the *aacA4 attC* site, and that this structure is excised together as a unique cassette.

Figure 1. Northern blot analysis of *gcu14-bla_{GES-1}/aacA4* gene cassette array from *P. aeruginosa* class 1 integron. The full length transcript (2,300 bases), corresponding to the entire gene cassette array, hybridized with the GES probe (arrow). The fragment sizes of the RNA marker (Promega) used in RNA electrophoresis are indicated.

	815		864
GES1 (THIS STUDY)	GTATACAACG GCCCGGAAAC TATCGGCCGT AGAACGTGAC GAATTAGTTG		
GES1 (AF355189)	GTATACAACG GCCCGGAAAC TATCGGCCGT AGAACGTGAC GAATTAGTTG		
	865		914
GES1 (THIS STUDY)	cctctgtcgg tcaagttatt acacaactca tcttgagcac ggacaaatag		
GES1 (AF355189)	cctctgtcgg tcaagttatt acacaactca tcttgagcac ggacaaatag		
	915		964
GES1 (THIS STUDY)	ttgacgcccg tctaaaacaa agttaggcat cacaaagtac agcatcgtga		
GES1 (AF355189)	ttgacgcccg <u>tctaaca</u> aatt <u>cgttcaagc</u> c gacgttgctt cgtggcggcg		
		1L	2L
	965		1014
GES1 (THIS STUDY)	ccaac.agca acgattccgt cacactgcgc ctc~~~~~ ~~~~~		
GES1 (AF355189)	cttgctgtgct acgctaagct tcgcacgccg cttgccactg cgcaccgcg		
	1015		1033
GES1 (THIS STUDY)	~~~~~ ~~~~~		
GES1 (AF355189)	<u>cttaac</u> tcag gc <u>gttagat</u>		
	2R		1R

Figure 2. Alignment of the truncated and the complete/canonical *bla_{GES-1} attC* sites. Underlined capital letters represent the *bla_{GES-1}* coding region. The *attC* site is indicated in lower case; the core sites 1L, 2L, 2R and 1R are in boldface and underlined.

Positive results were obtained for the *gcu14*, *gcu14-aacA4* and *gcu14-bla_{GES-1}/aacA4* circular forms, but not for *bla_{GES-1}* and *aacA4* alone. This finding indicates that the GES-1 *attC* is not functional and that the fused gene cassette is excised as a unique cassette. Moreover, the presence of *gcu14-aacA4* circular form suggests that this strain carries a second integron containing this gene cassette arrangement. Sequencing assessed the recombination point where excision occurred, confirming the occurrence of free circular forms (Figure 3). This is in agreement with the presence of the PcW configuration, in which the corresponding *intI1* gene codes for a high efficient integrase¹¹. The lack of activity of a truncated *attC* had also been observed before when associated

with *aadA10*¹³. However, Ramirez and colleagues¹⁴ showed that the integrase was able to recognize and mediate excision of a truncated site associated to *aadA1*, indicating that the genetic context of such truncated sites could influence their role in *IntI1* recognition and mobilization.

The relative quantification performed by real time RT-PCR revealed that PS1 and PS26 presented very similar RQ values for *gcu14-bla_{GES-1}/aacA4* transcription (Figure 4). This result was expected since integrons from these two strains have the same backbone, including the Pc promoter, and are at the same genetic environment¹⁰.

Figure 3. Schematic representation of the free circular form cassette array resulted from the inverse PCR assay. (A) inserted/linearized form of integron harbouring the fused cassettes. Arrows show the gene transcription orientation. Thin arrows represent the annealing sites of the inverse PCR and sequencing primers whose generated product corresponded to the cassette circular form illustrated in (B). (B) Illustration of the free circular form of gene cassettes represented in (A). Thin arrows show the primers used to obtain the inverse PCR product (*GES FSQ* and *GES RSQ*) and the primers used in sequencing (*AACA4 FSQ* and *GES RSQ*) that revealed the excision in block of the entire gene cassette arrangement (*gcu14-bla_{GES-1}/aacA4*) from integron (red curved line).

Figure 4. Transcription level of *gcu14*-*bla*_{GES-1}/*aacA4* gene cassette array. The relative quantification values obtained by real time RT-PCR are indicated for each gene cassette and for the fusion *bla*_{GES-1}/*aacA4* when considered as a unique gene.

gcu14, the first cassette in integrons with the weak PcW configuration, presented approximately two-fold higher transcription when compared to *bla*_{GES-1} and *aacA4* separately or when the fused cassette *bla*_{GES-1}/*aacA4* was considered (Figure 4). The same RQ value obtained for *bla*_{GES-1}/*aacA4* and the fusion reveals that these two ORFs are transcribed as a unique gene. The lower transcript amount of *bla*_{GES-1}/*aacA4* compared to *gcu14* lies on the distance between these gene cassettes and Pc, which is one of the determinants influencing cassette transcription^{1,7}, and it shows the effect of cassette position on expression levels.

A putative promoter for *gcu14* (-35 TTGATG [17 bp] -10 TGTTAC) was found 45 bp upstream from its start codon, which has the potential to influence transcription. Moreover, the ORF-11, which enhances the translation efficiency of downstream TIR-deficient cassettes inserted in integrons⁵, was found at the *attI1* region preceding the TIR-deficient *gcu14* gene cassette. This ORF contained its own Shine-Dalgarno (SD) sequence placed 8 bp upstream of the ATG codon. The ribosome at the ORF-11 stop codon could, therefore, be carried along the mRNA by lateral diffusion, reinitiating translation at the *gcu14* start codon. A potential SD sequence was identified 10 bp upstream of the fused cassette *bla*_{GES-1}/*aacA4*. In addition, the loss of the GES-1 *attC* region, which is involved in stem-loop formation, may enhance the chances of *aacA4* translation, since this *attC*, reduced to the 6bp of the 1L core site, no longer constitutes a physical barrier to ribosome progression⁴. Together, these findings create a scenario for the occurrence of *gcu14*-*bla*_{GES-1}/*aacA4* expression in PS1 and PS26, which then provides a possible explanation for their resistance profile to β -lactams and aminoglycosides that has been observed elsewhere¹⁰.

RQ fused cassette raw data for *Pseudomonas aeruginosa* isolates PS1 and PS26

2 Data Files

<http://dx.doi.org/10.6084/m9.figshare.651717>

Conclusions

Fused cassettes have been found in class 1 integrons^{9,13-18}; however, the transcription of such structures has rarely been addressed. This work showed the transcription pattern of a fused cassette as a polycistronic mRNA and that these unusual structures are excised as a unique cassette. The mobilization in block of the entire *gcu14*-*bla*_{GES-1}/*aacA4* array together with its active transcription, and the presence of translational signatures demonstrate the potential for dissemination and expression of multidrug resistance, in a one-step fashion, to other bacteria. Therefore, such events could represent a threat to public health and to the establishment of efficient antibiotic regimens.

Nucleotide sequence accession number

The sequence of the cassette array composed by the fusion has been deposited in the GenBank database under accession number **DQ236170**. The sequence obtained from the inverse PCR amplification, showing the circular form gene organization, was submitted to GenBank under accession number **KT336477**.

Data availability

Figshare: Polycistronic transcription of fused cassettes and identification of translation initiation signals in an unusual gene cassette

array from *Pseudomonas aeruginosa* doi: <http://dx.doi.org/10.6084/m9.figshare.651717>¹⁹

Author contributions

ELF and ACPV conceived the study and designed the experiments. ELF carried out the research and prepared the first draft of the manuscript. All authors were involved in the revision of the draft manuscript and have agreed to the final content.

Competing interests

No relevant competing interests were disclosed.

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Sally Partridge

Sydney West Area Health Service, Sydney, NSW, Australia

This manuscript has been improved and the points I raised have been addressed, but I have some comments about the new Fig. 2:

1. The underlined uppercase letters indicating the blaGES-1 coding region should extend until the stop codon at position 914.
2. ttgat of the IR site shown for the complete blaGES-1 attC is really part of the adjacent 3'-CS in AF355189 (most of the 1R core site belonging to the blaGES cassette (TTAGAC) is found at the start of the linear cassette). I would suggest ending this sequence after the first g of this site.
3. The partial 1L of the truncated blaGES cassette (924-9), the nucleotides derived from the attI1 site (930-6) and 1R of the aacA4 cassette (937-42) should be indicated. I would suggest ending the sequence of the truncated cassette after 1R of aacA4, as the alignment of the complete attC with the start of the aacA4 cassette beyond this point is not really useful.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 19 Nov 2015

Erica Fonseca, Instituto Oswaldo Cruz, Rio de Janeiro, Brazil

Reviewer: The underlined uppercase letters indicating the blaGES-1 coding region should extend until the stop codon at position 914.

Response: Reviewer is right. This was corrected in the figure. Actually, the figure was modified in order to make clearer the differences between the canonical GES-1 attC and the truncated GES-1 attC found in this study.

Reviewer: ttagat of the IR site shown for the complete blaGES-1 attC is really part of the adjacent 3'-CS in AF355189 (most of the 1R core site belonging to the blaGES cassette (TTAGAC) is found at the start of the linear cassette). I would suggest ending this sequence after the first g of this site.

Response: We agree and this was corrected in the new figure.

Reviewer: The partial 1L of the truncated blaGES cassette (924-9), the nucleotides derived from the attI1 site (930-6) and 1R of the aacA4 cassette (937-42) should be indicated. I would suggest ending the sequence of the truncated cassette after 1R of aacA4, as the alignment of the complete attC with the start of the aacA4 cassette beyond this point is not really useful.

Response: We agree and this was modified in the new figure.

Competing Interests: There is no competing interests

Reviewer Report 28 September 2015

<https://doi.org/10.5256/f1000research.3720.r10563>

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Béatrice Berçot

Service de Bactériologie-Virologie, Hôpital de Bicêtre, Paris, France

I have read the updated paper which is clear and well written. Little is known in transcription of fused cassettes and these experimental data highlighted that the two genes are cotranscribed and mobilized together. The author answered all my request and I have not supplementary remarks

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 21 May 2013

<https://doi.org/10.5256/f1000research.903.r961>

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Béatrice Berçot

Service de Bactériologie-Virologie, Hôpital de Bicêtre, Paris, France

This work is conducted to address the transcription of the fused gene cassette *bla*_{GES-1}/*aacA4*. This arrangement is rare but not exceptional in a class 1 integron. In this work, the experimentation confirmed that the three gene cassettes harbored in this class 1 integron were expressed together from a unique polycistronic transcript.

It seems that the authors have observed a circular form containing the *gcu14* gene cassette associated with the *aacA4* gene cassette. Could they explain this arrangement? Is it possible that the *Pseudomonas* isolates harbored another class 1 integron containing the *gcu14* gene followed by the *aacA4* gene?

The authors have to provide in the paper the classical length of the *bla*_{GES-1} *attC* site, which is 110bp and contained the 1L, 2L, 2R and 1R sequences-shown in bold.

TTGACGCCC **GTCTAAC** AATTC **GTTCAAGC**
CGACGTTGCTTCGTGGCGGCGCTTGCGTGCTACGCTAAGCTTCGCACGCCGCTTGCCACTGCGCACC GCG
GCTTAAC TCAGGC **GTTAGNC**

In the *Pseudomonas* SP26 and PS1 isolates, the *bla*_{GES-1} *attC* site is reduced to the 6 bp of 1 L box.

TTGACGCCC **GTCTAA** AACAAAGTTAGGCATCACAAAGTACAGCATC **GTG**

So, the distance from of the stop of *bla*_{GES-1} to the start codon of the *aacA4* gene is 46bp. The translational start codon of *aacA4* gene is erroneous in the Genbank data base ([DC236170](#)). Indeed, it has been determined by N-terminal amino acid sequencing to be a GTG (in italic in the sequence above) and the beginning of the cassette was 24 bp before [[Hanau-Bercot B. et al., 2002](#)].

- Could the Genbank annotation be modified as explained above?
- The Appendix is not necessary and should be deleted.
- In the sentence page 4, line 13, "The single copy of *rpsL* gene of *Pseudomonas*...", should be replaced by "the *rpsL* gene of *Pseudomonas* (see [Bodilis et al., 2012](#))"
- In the conclusion, page 6, change "never" to "rarely".

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 05 Aug 2015

Erica Fonseca, Instituto Oswaldo Cruz, Rio de Janeiro, Brazil

It seems that the authors have observed a circular form containing the *gcu14* gene cassette associated with the *aacA4* gene cassette. Could they explain this arrangement? Is it possible that the *Pseudomonas* isolates harbored another class 1 integron containing the *gcu14* gene followed by the *aacA4* gene?

Response: Yes, the presence of the *gcu14*-*aacA4* circular form indicates that this strain harbours a second integron composed by the *gcu14*-*aacA4* arrangement. However, this result does not invalidate our main conclusion, which is that the truncated GES-1 *attC* site is not functional and this gene is only mobilized when recombination occurs in *aacA4 attC*. A brief explanation was included in the text (Results section).

The authors have to provide in the paper the classical length of the *bla*_{GES-1} *attC* site, which is 110bp and contained the 1L, 2L, 2R and 1R sequences-shown in bold.

Response: A figure showing the truncated and the complete canonical *attC* from GES1 was included in the new version.

So, the distance from of the stop of *bla*_{GES-1} to the start codon of the *aacA4* gene is 46bp. The translational start codon of *aacA4* gene is erroneous in the Genbank data base (DC236170). Indeed, it has been determined by N-terminal amino acid sequencing to be a GTG (in italic in the sequence above) and the beginning of the cassette was 24 bp before [Hanau-Bercot B. et al., 2002].

-Could the Genbank annotation be modified as explained above?

Response: We performed this modification and the updated sequence regarding the beginning of *aacA4* gene is already accessible on GenBank database under the same accession number (DQ236170).

-The Appendix is not necessary and should be deleted.

Response: The appendix is only for helping referees in their evaluation. It will not be published.

-In the sentence page 4, line 13, "The single copy of *rpsL* gene of *Pseudomonas*...", should be replaced by "the *rpsL* gene of *Pseudomonas* (see Bodilis et al., 2012).

Response: this was modified in the new version of the manuscript.

In the conclusion, page 6, change "never" to "rarely".

Response: this was modified in the new version of the manuscript.

Competing Interests: There is no competing interests

Reviewer Report 02 May 2013

<https://doi.org/10.5256/f1000research.903.r920>

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Sally Partridge

Sydney West Area Health Service, Sydney, NSW, Australia

This paper looks at expression of genes in a gene cassette array that includes a fused cassette and at the excision of cassette from this array. Polycistronic transcripts from cassette arrays and the excision of other fused cassettes have previously been noted by others, as cited in this paper. The sequences in Appendix 1 need to be annotated properly, rather than just the results of searches given, and the point illustrated by each sequence needs to be explained to make it possible to assess whether they support the conclusions drawn in the paper.

Some reorganisation (moving some information in the Results and Discussion to the Introduction) would help to make the paper easier to follow and the Conclusions section is very short and could be expanded. The English could also be improved and the manuscript checked for typos etc.

A few specific points also need correcting or clarifying:

- Abstract Line 5- fused cassettes do not always have fused orfs (e.g. *aacA1/orfG*)
- Abstract 6th Line from end and Results and Discussion p. 5 1st Line of 2nd paragraph – what is in the *gcu14-aacA4* circular form? Should this be *blaGES-1/aacA4*?
- Materials and Methods Line 1 – this needs rewording to explain that *gcu* is a gene cassette of unknown function.
- Results and Discussion p. 4 – the fusion here is the type where part of the *blaGES-14 attC* site is replaced by part of the *attI1* site (see ref. 14). The LH and RH domains are part of the *attC* site, rather than flanking it. The 5' UTR contains 6 bp of the *attC* site.
- Results and Discussion p. 5 – most of the 1L core site and the 1R core site of the *blaGES attC* site are present.
- Results and Discussion p. 6 – the deletion of part of the *attC* site doesn't bring the *aacA4* gene much closer to *Pc* and ref. 14 makes slightly different point (that expression of the downstream cassette may be enhanced).

Formatting “14” of *gcu14* and “A4” of *aacA4* should be in italics. Transposon, gene and species names etc are not correctly formatted in the references.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 05 Aug 2015

Erica Fonseca, Instituto Oswaldo Cruz, Rio de Janeiro, Brazil

The sequences in Appendix 1 need to be annotated properly, rather than just the results of

searches given, and the point illustrated by each sequence needs to be explained to make it possible to assess whether they support the conclusions drawn in the paper.

Response: The sequence resulted from inverse PCR product, showing the circular form of the *gcu14-blaGES-1-aacA4* array, was submitted to GenBank under accession number KT336477. This information was included in the text. Moreover, we provided a new figure showing a schematic representation of primer targeting sites used in inverse PCR in order to make easier for the reviewers comprehend our strategy and results.

Some reorganisation (moving some information in the Results and Discussion to the Introduction) would help to make the paper easier to follow and the Conclusions section is very short and could be expanded. The English could also be improved and the manuscript checked for typos etc.

Response: We agree that some points from results and discussion section would be more adequate in the introduction section, and they were moved in the new version of the manuscript (Page 3, lines 59-60 and 65-70; page 4, lines 71-76 in the new version). The English was reviewed by a native spoken-English, and the conclusion was expanded.

A few specific points also need correcting or clarifying:

Abstract Line 5- fused cassettes do not always have fused orfs (e.g. *aacA1/orfG*)

Response: We agree and it was modified: We affirmed that only in some cases fused orfs can be created.

Abstract 6th Line from end and Results and Discussion p. 5 1st Line of 2nd paragraph – what is in the *gcu14-aacA4* circular form? Should this be *blaGES-1/aacA4*?

Response: The presence of the *gcu14-aacA4* circular form indicates that this strain harbours a second integron composed by the *gcu14-aacA4* arrangement. However, this result does not invalidate our main conclusion, which is that the truncated *GES-1 attC* site is not functional and this gene is only mobilized when recombination occurs in *aacA4 attC*. A brief explanation was included in the text (Results section).

Materials and Methods Line 1 – this needs rewording to explain that *gcu* is a gene cassette of unknown function.

Response: It was included in the text.

Results and Discussion p. 4 – the fusion here is the type where part of the *blaGES-1 attC* site is replaced by part of the *attI1* site (see ref. 14). The LH and RH domains are part of the *attC* site, rather than flanking it. The 5' UTR contains 6 bp of the *attC* site.

Response: We change the text emphasizing that the *attC* was replaced by part of *attI1*. The referee is right; LH and RH domains are part of the *attC* site, rather than flanking it. This general idea concerning *attC* site and its domains was modified throughout the text.

Results and Discussion p. 5 – most of the 1L core site and the 1R core site of the *blaGES attC* site are present.

Response: In fact, only the 1L core site is present in the truncated *attC*. We included a figure (figure 2) in this new version showing this.

Results and Discussion p. 6 – the deletion of part of the attC site doesn't bring the aacA4 gene much closer to Pc and ref. 14 makes slightly different point (that expression of the downstream cassette may be enhanced).

Response: The referee is right. This statement was removed.

Formatting "14" of gcu14 and "A4" of aacA4 should be in italics. Transposon, gene and species names etc are not correctly formatted in the references.

Response: All formatting errors were properly corrected.

Competing Interests: There is no competing interests

Comments on this article

Version 1

Author Response 05 Aug 2015

Erica Fonseca, Instituto Oswaldo Cruz, Rio de Janeiro, Brazil

Dear Authors,

Besides the comments already made by the reviewers, I would like to specify some points:

- The C to G mutations that converts the usual weak PcW variant into PcWTGN-10 has been shown to increase (instead of 'decrease', first part of the Results section).

Response: This sentence was removed.

- I have not checked which IntI1 had been used for the excision assay, usually these are made with the most efficient "PcW" IntI1 (IntI1R32_H39); note that in our PLoS Genetics paper ([Jove et al. 2010](#)) we evidenced the IntI1 "PcWTGN-10" (IntIP32_H39) were much less efficient for excision of gene cassettes, which could had been taken into account in your discussion.

Response: As properly noticed by you, our Pc configuration is the weak one, and this was changed in the text. However, we agree that including this discussion we will improve our manuscript (lines 182 and 184).

- The hypothesis of a synergistic effect between the Pc and P(gcu14) tandem promoters does not fit the observed phenotypes: since the resulting level of transcription observed for the downstream genes is lower I suggest that some transcriptional interferences occur rather than synergistic interactions. By the way in absence of any experimental evidence for the

functionality of the *gcu14* promoter, such hypothesis is overstated. It would have been interesting to check the level of transcription of the *bla*GES-1,*aacA4* gene cassette when *gcu14* is deleted.

Response: we totally agree with this observation, in fact our conclusion is overstated since no experimental assay was performed to test the promoter synergy. Therefore, we remove this part from the text. We also agree that would be interesting to verify the expression of the fused cassette in the absence of *gcu14*, however it was not the focus of this paper.

- First, the class 1 integron sequence of the PS1 strain in Genbank DQ236170 does not display the rare C to G mutation that converts a weak "PcW" promoter into a stronger "PcWTGN-10" as stated in the paper. Consequently you should write "the weak PcW configuration" instead of "weak PcWTGN-10". Also it means that its own *IntI1* integrase is likely to be optimally efficient.

Response: Dr. Jové is absolutely right, the DQ236170 accession number presented the PcW configuration and not the PcWTGN-10 as stated in the manuscript, we apologize about this mistake. This was corrected in the text.

- Then, the sequence of the class 1 integron as deposited in the Genbank does not display the complete array of gene cassette (the end of the *attCaacA4* is not available) which means that it is ambiguous whether there is a downstream third gene cassette or not. Consistently this array of gene cassette, although a novel one, has not been numbered in the INTEGRALL database (<http://integrall.bio.ua.pt/?acc=DQ236170>)

Response: We know that *aacA4* was the last cassette in the array because this variable region was obtained using primers annealing in the *attI1* and in the beginning of *qacEΔ1* from 3'CS. It is true that the *aacA4 attC* is not completed in the GenBank accession number DQ236170. Therefore, spite of the incomplete *attC* sequence we are sure that the *aacA4* is the last cassette from this array.

- Lastly, as an element of reply to the reviewer Dr Bercot, I would like to notify that the so-called *gcu14* GC has not been reported in other reports except in an environmental strain of *Citrobacter* (and the sequence is not 100% identical, Genbank FM998050).

Response: thanks for this observation. It was included in the text.

Competing Interests: There is no competing of interests

Reader Comment 23 May 2013

Thomas Jové, LGPB, Belgium

Dear authors,

I would like to add some further comments:

- First, the class 1 integron sequence of the PS1 strain in Genbank DQ236170 does not display the rare C to G mutation that converts a weak "PcW" promoter into a stronger "PcWTGN-10" as stated in the paper. Consequently you should write "the weak PcW configuration" instead of "weak

PcWTGN-10". Also it means that its own IntI1 integrase is likely to be optimally efficient.

- Then, the sequence of the class 1 integron as deposited in the Genbank does not display the complete array of gene cassette (the end of the attCaacA4 is not available) which means that it is ambiguous whether there is a downstream third gene cassette or not. Consistently this array of gene cassette, although a novel one, has not been numbered in the INTEGRALL database (<http://integrall.bio.ua.pt/?acc=DQ236170>)

- Lastly, as an element of reply to the reviewer Dr Bercot, I would like to notify that the so-called gcu14 GC has not been reported in other reports except in an environmental strain of *Citrobacter* (and the sequence is not 100% identical, Genbank FM998050).

Competing Interests: None

Reader Comment 17 May 2013

Thomas Jové, LGPB, Belgium

Dear Authors,

Besides the comments already made by the reviewers, I would like to specify some points:

- The C to G mutations that converts the usual weak PcW variant into PcWTGN-10 has been shown to increase (instead of 'decrease', first part of the Results section).
- I have not checked which IntI1 had been used for the excision assay, usually these are made with the most efficient "PcW" IntI1 (IntI1R32_H39); note that in our PLoS Genetics paper ([Jové et al. 2010](#)) we evidenced the IntI1 "PcWTGN-10" (IntIP32_H39) were much less efficient for excision of gene cassettes, which could had been taken into account in your discussion.
- The hypothesis of a synergistic effect between the Pc and P(gcu14) tandem promoters does not fit the observed phenotypes: since the resulting level of transcription observed for the downstream genes is lower I suggest that some transcriptional interferences occur rather than synergistic interactions. By the way in absence of any experimental evidence for the functionality of the gcu14 promoter, such hypothesis is overstated. It would have been interesting to check the level of transcription of the blaGES-1,aacA4 gene cassette when gcu14 is deleted.
- Some years ago [Jacquier et al. \(2009\)](#) published data suggesting that attC sites rather influence the level of translation between each gene cassette while the level of transcription was unaffected.

Competing Interests: None

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