First Staphylococcal Cassette Chromosome mec Containing a mecB-Carrying Gene Complex Independent of Transposon Tn6045 in a Macrococcus caseolyticus Isolate from a Canine Infection

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A methicillin-resistant mecB-positive Macrococcus caseolyticus (strain KM45013) was isolated from the nares of a dog with rhinitis. It contained a novel 39-kb transposon-defective complete mecB-carrying staphylococcal cassette chromosome mec element (SCCMecKM45013). SCCMecKM45013 contained 49 coding sequences (CDSs), was integrated at the 3' end of the chromosomal orfX gene, and was delimited at both ends by imperfect direct repeats functioning as integration site sequences (ISSs). SCCMecKM45013 presented two discontinuous regions of homology (SCCMec coverage of 35%) to the chromosomal and transposon Tn6045-associated SCCmec-like element of *M. caseolyticus* JCSC7096: (i) the mec gene complex (98.8% identity) and (ii) the ccr-carrying segment (91.8% identity). The mec gene complex, located at the right junction of the cassette, also carried the β-lactamase gene *bla*Zm (* mecRm-mecI-mecB-bla*Zm). SCCMecKM45013 contained two cassette chromosome recombinase genes, *ccrAm2* and *ccrBm2*, which shared 94.3% and 96.6% DNA identity with those of the SCCmec-like element of JCSC7096 but shared less than 52% DNA identity with the staphylococcal *ccrAB* and *ccrC* genes. Three distinct extrachromosomal circularized elements (the entire SCCMecKM45013 + SCCMecKM45013 lacking the *ccr* genes, and SCCKM45013 lacking *mecB*) flanked by one ISS copy, as well as the chromosomal regions remaining after excision, were detected. An unconventional circularized structure carrying the mecB gene complex was associated with two extensive direct repeat regions, which enclosed two open reading frames (ORFs) (ORF46 and ORF51) flanking the chromosomal mecB-carrying gene complex. This study revealed *M. caseolyticus* as a potential disease-associated bacterium in dogs and also unveiled an SCCmec element carrying mecB not associated with Tn6045 in the genus *Macrococcus*.

The genus *Macrococcus* is composed of seven species of Gram-positive bacteria closely related to staphylococci, including *Macrococcus caseolyticus* (formerly identified as *Staphylococcus caseolyticus*) (1). Unlike staphylococci, macroccoci do not usually cause human or animal diseases and are typically isolated from animal skin and food products, such as milk and meat (1, 2). The only association of *M. caseolyticus* with an infection was observed in abscesses from slaughtered lambs in 1992 (3). Even though *M. caseolyticus* is not primarily targeted by antibiotic treatment as an infectious agent, a few strains have acquired antibiotic resistance mechanisms identical or similar to those found in staphylococci, such as cfr-mediated multidrug resistance (4) and mecB-mediated methicillin resistance (5), respectively.

In staphylococci, methicillin resistance is caused by the synthesis of a modified penicillin binding protein (PBPs) with low affinity to virtually all β-lactams. This protein is encoded by either the *mecA* or the *mecC* gene (6, 7), whose expression is often regulated by the presence of MecR1 (sensor/signal transducer *mecR1* gene) and MecI (*mec* transcription repressor *mecI* gene). These genes are arrayed in an operon designated the *mec* gene complex, which is located within the staphylococcal cassette chromosome mec (SCCmec) element. Cassette chromosome recombinases (Ccr), the second essential component of the SCCmec element, encoded by different allotypes of the *ccrAB* and *ccrC* genes, are responsible for site-specific integration and excision of the element at the integration site sequence (ISS) of SCCmec located at the 3' end of the chromosomal orfX gene. The combination of the different allotypes defines the ccr gene complex. SCCmec elements are flanked by characteristic direct repeats (DRs) containing the ISSs that define the transferable unit (8).

The *meca* and *mecC* homologue mecB genes have been identified in *M. caseolyticus* in two plasmids as well as on a macroccocal chromosomal primordial form of the SCCmec element, designated a SCCmec-like element due to the location of the *mecB* gene complex (*mecR1m-mecI-mecB-blaZm*) within a transposon-driven genetic element (5). In this element, transposon Tn6045 was shown to be responsible for the excision of the region peripheral to *mecB* (5). While the SCCmec-like element exhibited characteristic 18-bp DRs that potentially also enable spontaneous excisions of *ΨSCCMec*7096 (SCCMec lacking the *ccr* genes) and SCC7096 (SCC lacking the *mecB* gene) as independent units in...
strains JCSC7096, the two mecB-containing plasmids lacked ccr genes (5).

In 2013, a 9-year-old male neutered Bernese mountain dog was presented several times to a veterinary practice with coughing and signs of rhinitis, including sneezing, nasal and ocular discharge, and swelling of the tonsils and regional lymph nodes. Bacteriological analysis of a nasal sample revealed massive growth of hemolytic Gram-positive cocci which exhibited resistance to penicillin as well as to oxacillin and cefoxitin, which are used for the prediction of the mec genes in staphylococci (9, 10). This prompted us to further identify this bacterium and characterize the genetic background of the β-lactam resistance, revealing a novel mecB-containing SCCmec element not associated with a transposon in a hemolytic *Macrococcus*.

**MATERIALS AND METHODS**

**Bacterial identification.** Strain KM45013, obtained from our diagnostic unit, was identified as *M. caseolyticus* by 16S rRNA gene PCR amplification of cell lysates and sequence analysis (11). *M. caseolyticus* was routinely grown on either Trypticase soy agar containing 5% sheep blood (TSA-S; Becton, Dickinson and Company, Franklin Lakes, NJ) or in LB broth at 37°C with aeration.

**Determination of antimicrobial resistance profile.** MICs were measured in Mueller-Hinton broth by the microdilution technique using custom-made Sensititre susceptibility plates (NLEUST; Trek Diagnostics Systems, East Grinstead, United Kingdom) and following the Clinical and Laboratory Standards Institute (CLSI) guidelines (9). The production of β-lactamase was tested on nitrocefin dry slides (Becton, Dickinson and Company).

DNA extraction and determination of mecB location.** Genomic DNA was isolated using a phenol-chloroform method with the following modifications for improved cell lysis (12). Five milliliters of overnight culture in LB broth was centrifuged for 10 min at 15,000 rpm, and cells were resuspended in 100 μl Tris-EDTA buffer containing 2 mg/ml lyssozyme and 0.5 mg/ml lysozyme and incubated for 20 min at 37°C. Plasmid DNA was obtained by phenol-chloroform extraction as described by Anderson and McKay (13), also including a lysis step with lysozyme and lysostaphin. The integrity and concentration of the extracted DNA were assessed by agarose gel electrophoresis and spectrophotometric measurement (Quibit; Invitrogen), respectively.

Southern blot hybridization was performed on both genomic and plasmid DNA of strain KM45013 using a digoxigenin-labeled mecB probe obtained using primers mecB-Fw and mecB-Rv (see Table S1 in the supplemental material) following the manufacturer’s protocol (Roche, Switzerland). Hybridization signals were visualized on the membrane using a ChemiDoc detection system (Biorad, Hercules, CA).

**Whole-genome sequencing, assembly, and annotation of the novel SCCmec element.** High-throughput whole-genome sequencing (WGS) of *M. caseolyticus* KM45013 was performed with Roche 454 GS Titanium chemistry according to the manufacturer’s standard protocols (GS Junior System; Roche Diagnostics, Switzerland). Resultant contigs were analyzed for the presence of characteristic genetic elements of the SCCmec-like element (mecB, meclm, mecRim, ccrAm, ccrBm) and surrounding chromosomal sequences (orfX, transposase gene of Tn6045, MCCL_0033, and MCCL_0034) of *M. caseolyticus* JCSC7096 (5) (GenBank accession no. AB498756) using a BLAST search (http://www.ncbi.nlm.nih.gov) and specific PCRs (see Table S1 in the supplemental material). Sanger sequencing of PCR products was performed using BigDye Terminator cycle sequencing and an ABI Prism 3100 genetic analyzer (Applied Biosystems, Foster City, CA) to fill the gaps between SCCmec-containing contigs and to define their specific orientations. Open reading frames (ORFs) were defined with the help of Prodigal (14), GeneMark (15), and ORF Finder (NCBI) software. Only those with plausible ribosomal binding sites were considered. Annotation of the ORFs was performed by BLAST homology, and motif analysis of the translated reading frames was performed against the ScanProsite database (16), the Pfam database (only significant matches were considered for annotation) (17), and the National Center for Biotechnology Information conserved domain database (CDD) (18).

Detection of ISSs was achieved by searching for the consensus sequence GA[AG][T/G][ATG]/TATCATAAGTGA (positions with possible alternative nucleotides are indicated within square brackets, and the possible nucleotides are separated by slashes) in all contigs. Characteristic inverted repeats (IRs), typically found after element insertion catalyzed by Ccrs, were also examined directly upstream and downstream of the ISSs.

**Characterization of the chromosomal SCCmec structure and detection of spontaneous extrachromosomal excisions.** Primers designed for the detection of the mec and ccr gene complexes of SCCmec45013 and the SCCmec-like element of JCSC7096 are shown in Table S1 in the supplemental material. In addition, primers used for identification of the chromosomal orfX gene of *M. caseolyticus* strain KM45013, as well as the conserved regions of MCCL_0033 and MCCL_0034 located at the 3’ end of orfX in the previously described mecB-carrying macrococcus strains (5), are also described (see Table S1). BamHI and BglII restriction analysis of different regions of the SCCmec element amplified by long-range PCR (GoTaq long PCR master mix; Promega) was performed for assembling and scaffolding confirmation (see Table S1). The presence of potential circular intermediates (CIs) of SCCmec segments delimited by ISS sequences, as well as other possible extrachromosomal circularized structures, was tested by specific PCR and sequenced by primers reading outward from the ISSs or a corresponding region (for an ISS-independent excision event). The chromosomal region, where segment excision was expected to have occurred, was also amplified by PCR using adapted elongation times and was sequenced (see Table S1).

**Phylogenetic relationship of ccr genes and blaZ-containing mec gene complexes.** The phylogenetic relationships of one representative of each type of mec gene (19) and the mec gene complexes containing the blaZ gene (5–7, 20) were investigated by the construction of a maximum likelihood phylogenetic tree using the SeaView program, version 4.4.0 (21), with nucleotide sequences deposited in the ENA/GenBank databases. Sequences were aligned using MUSCLE, and the trees were built with PhyML using a general time-reversible (GTR) model.

**Nucleotide sequence accession number.** The 41,563-bp nucleotide sequence of *M. caseolyticus* strain KM45013 containing the complete 38,941-bp SccMec545013 and its 602-bp upstream and 2,020-bp downstream chromosomal regions has been deposited in the GenBank/ENA/ DDBJ databases under the accession number HG970732.

**RESULTS AND DISCUSSION**

**Identification of *M. caseolyticus* KM45013.** Strain KM45013 was identified as *M. caseolyticus* based on the 16S rRNA gene sequence, which exhibited 99.7% nucleotide identity with that of *M. caseolyticus* type strain ATCC 13548T and *M. caseolyticus* JCSC5402, the only macrococcus strain whose genome has been completely sequenced (2). Decreased susceptibility to β-lactams was confirmed by the determination of the MICs for penicillin (MIC, >2 μg/ml), oxacillin (MIC, >8 μg/ml), and cefoxitin (MIC, >8 μg/ml). *M. caseolyticus* KM45013 differed from other members of *Macrococcus* species by the formation of a complete hemolysis on a sheep blood plate. Hemolysins are known virulence factors in staphylococci which have been associated with different types of infections (22, 23). Whether the hemolytic property of strain KM45013, which is so far unique among *Macrococcus caseolyticus*, represents a virulence factor in dogs still remains to be clarified. Nevertheless, the massive presence of *M. caseolyticus* in the nasal sample may be

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indicative of an association with the disease, even if other causes cannot be excluded. Since this discovery, 2 additional hemolytic M. caseolyticus isolates were obtained in our laboratory from 2 dogs diagnosed with otitis and dermatitis, indicating that more attention should be paid to this microorganism.

Characterization of the novel SCC\textit{mec}_{KM45013} element and comparison with other mec\textit{B}-carrying elements. WGS of strain KM45013 resulted in 92,893 filter reads and coverage equivalent to 14.3\times. Sequence reads were \textit{de novo} assembled using Newbler 2.6 (Roche) at the Vital-IT Center for High-Performance Computing at the Swiss Institute of Bioinformatics (http://www.vital-it.ch), yielding 116 contigs (86 contigs \textgreater 500 bp) with an \textit{N}_{50} (length-weighted median) of 46,794 bp, a mean contig size of 19,287 bp, a maximum contig length of 227,824 bp, and a contig sum of 2,275,932 bp. WGS of \textit{M. caseolyticus} KM45013 as well as Southern blot hybridization experiments allowed the identification and characterization of the novel SCC\textit{mec}_{KM45013} element. A total of 49 coding sequences (CDSs) were identified in SCC\textit{mec}_{KM45013}. The genome of strain KM45013 presented a GC content of 37.0\%, while that of SCC\textit{mec}_{JCSC7096} was 31.5\%, suggesting that SCC\textit{mec}_{KM45013} was integrated as an exogenous element. SCC\textit{mec}_{KM45013} was located at the 3\textsuperscript{\text{rd}} end of the chromosomal orf\textit{X} gene and was demarcated at both extremities by DRs with the following ISSs: 5\textsuperscript{\text{\textprimet}}-GAAAGTTATCATAAGTGA-3\textsuperscript{\textprimet} (ISS1) and 5\textsuperscript{\textprimet}-GAAAGTTATCATAAGTGA-3\textsuperscript{\textprimet} (ISS3) (Fig. 1). An additional ISS, ISS2 (5\textsuperscript{\textprimet}-GAAAGTTATCATAAGTGA-3\textsuperscript{\textprimet}), was detected 26,883 bp downstream of the orf\textit{X} gene and 6,842 bp upstream of the mec\textit{B} complex. Imperfect inverted repeats (IRs), which have been shown to play a role in the excision but not the integration of SCC\textit{mec} (8), were detected adjacent to the three ISS elements (data not shown). These IRs had similar sequences to those detected in staphylococcal SCC\textit{mec} elements and in the SCC\textit{mec}-like element of \textit{M. caseolyticus} JCSC7096 (5, 24). SCC\textit{mec}_{KM45013} also shared the highest identity with the SCC\textit{mec}-like element of JCSC7096 (BLAST hit of 35\% query cover and 92\% sequence identity) (Fig. 1). The high nucleotide identity value was mainly due to the presence of two discontinuous regions: the mec gene complex and a ccr-carrying segment. The mec gene complex shared 98.8\% DNA identity with the corresponding segments of the three mec\textit{B}-carrying macrococcal strains, and the ccr-carrying region shared 91.8\% DNA identity with that detected in the SCC\textit{mec}-like element of JCSC7096 (5). The ccr genes were absent in the mec\textit{B}-carrying plasmids of \textit{M. caseolyticus} strains JCSC5402 and JCSC7528, which instead contained transposon-associated transfer mechanisms (5) (Fig. 1). The mec gene complex was located at the right-end junction of the cassette and carried a functionally active \beta-lactamase resistance gene, \textit{blaZm}, as determined by the nitrocefin test. No other \beta-lactamase gene was detected in the remaining genomic sequence. In strains JCSC7096, JCSC5402, and JCSC7528, the mec gene complex (\textit{mecR1m-mecIm-mecB-blaZm}) formed part of transposon Tn6045, which contains two adjacent transposase genes immediately upstream of the mec gene complex and is

![FIG 1 Schematic presentation of the orf\textit{X} downstream region in the \textit{M. caseolyticus} KM45013 chromosome, including the novel SCC\textit{mec}_{KM45013} (ENA accession no. HG970732), and a comparison with the previous mec\textit{B}-carrying genetic structures detected in macrococci: \textit{M. caseolyticus} strain JCSC7528 (GenBank accession no. AB498758), JCSC5402 (GenBank accession no. AP009486), and JCSC7096 (GenBank accession no. AB498756) and their correspondent chromosomal orf\textit{X} downstream regions (GenBank accession no. AB498757, AP009484, and AB498756, respectively). The arrows indicate the extent and direction of transcription of the open reading frames. All annotated regions of \textit{M. caseolyticus} KM45013 are colored as follows: yellow (orf\textit{X}), pale pink (\textit{orp}), pale green (\textit{ccrAm}, \textit{ccrBm}), dark green (\textit{mecAm}), green (\textit{mecAm}), red (mec\textit{B}, mec\textit{Am}), blue (\textit{blaZm}), purple (orf\textit{F}), pale purple (orf\textit{S1}), magenta (MCCL\_0033) and pink (MCCL\_0034). The different integration site sequences (ISSs) for SCC (ISS1 to ISS4) are shown within boxes. The direct repeats (CTGAA) of transposon Tn6045 in strains JCSC7528, JCSC5402, and JCSC7096 are shown within dashed boxes. Shadowed areas indicate regions with more than 84\% nucleotide sequence identity. Tn6045 in strains JCSC7528, JCSC5402, and JCSC7096 (green horizontal curly brackets) and the joining regions J1 to J3 (red horizontal bar) in KM45013 are also shown. B andBg indicate the BamHI and BgIII restriction sites, respectively, within SCC\textit{mec}_{KM45013}. A size scale in kb is displayed in the upper right-hand corner.](https://aac.asm.org/figs/1.png)
flanked by a set of short DRs (5'-CTGAA-3'), presumably generated by transposon integration (5). Neither transposons nor transposable genes were detected in the entire SCCmecKM45013 element. In contrast, the mec gene complex was flanked by two 775-bp to 777-bp duplicated sequence fragments that shared 93.2% identity. This duplicated DNA fragment comprised two active metabolic functions (GenBank accession no. HG970322) and was therefore outside SCCmecKM45013. Analysis of the putative functional domains of the ORF46 and ORF51 proteins revealed a helix-turn-helix (HTH) domain of the XRE family (CDD accession no. cd00093) but has two additional integrase domains of the rve superfamily (rve CDD accession no. pfam13276) and a HipB domain profile (CDD accession no. COG1396), both belonging to the class E mec complex. Phylogenetic comparison of the mec gene complex from macrococci with the class E mec gene complexes revealed 57.4% nucleotide identity to that of S. xylosus.

The mec gene complex of SCCmecKM45013 contained three joining (J) regions (Fig. 1). Two of them (J3 and J2) carried additional CDSs, encoding hypothetical proteins for the vast majority but also proteins with putative metabolic functions (GenBank accession no. HG970322). Neither additional antimicrobial nor heavy-metal resistance genes were detected within SCCmecKM45013.

Variable regions downstream of the integration site of SCCmec have been previously observed in staphylococci (25, 26). In M. caseolyticus strains JC7528, JC5402, and JC7528, the orfX downstream region contains two adjacent conserved ORFs, named MCCL_0033 and MCCL_0034, coding for proteins of unknown function. These ORFs were not detected downstream of SCCmecKM45013 in the entire KM45013 genome. Instead, orf51 was present, sharing 72% identity with a sequence downstream of orfX of the methicillin-resistant Staphylococcus pseudintermedius strain 57395 (comprising a CDS named mrsp-29) (24) and of methicillin-susceptible S. pseudintermedius ED99 and HKU10-03 (27, 28), all encoding putative transcriptional regulators.

**Phylogenetic analysis of ccr and mec gene complexes.** The mecB complex of SCCmecKM45013 presented structural similarities to the mecC complexes detected in SCCmec elements of Staphylococcus aureus LGA251 (mecl-mecR1-mecC-blaZ) (6) and of Staphylococcus xylosus S04009 (mecl-mecR1-mecC1-mecI1-blaZ) (20), both belonging to the class E mec complex. Phylogenetic comparison of the mec gene complex from macrococci with the class E mec gene complexes revealed 57.4% nucleotide identity to that of S. xylosus.
and 56.8% to that of \textit{S. aureus} (Fig. 2A). However, since the current nomenclature of the International Working Group on Staphylococcal Cassette Chromosome elements (IWG-SCC) is set for staphylococcal species, in particular for \textit{S. aureus}, this \textit{mecB} complex was not assigned to a specific class (19).

Integration and excision of SCC\textit{mec} at the \textit{orfX} gene is mediated by CcrAB or CcrC, which are responsible for catalyzing DNA cleavage, strand exchange, and recombination between the two attachment sites, one within the SCC element (\textit{attSCC}) and the other on the bacterial chromosome (\textit{attB}) (8). The \textit{ccr} genes detected in SCC\textit{mec}\textsubscript{KM45013} showed 94.3% and 95.6% identity with the \textit{ccrAm1} and \textit{ccrBm1} genes, respectively, from the SCC\textit{mec}-like element of \textit{M. caseolyticus} JCSC7096 and were designated \textit{ccrAm2} and \textit{ccrBm2} according to the nomenclature first described by Tsu-

FIG 3  Graphical representation of the spontaneous circular chromosomal excisions detected in SCC\textit{mec}\textsubscript{KM45013}. (A) Display of the circular intermediates (CIs) designated to those with integration site sequences (ISSs) as delimiting region (SCC\textit{mec}\textsubscript{KM45013}, SCC\textsubscript{KM45013}, and \textit{ψSCCmec}\textsubscript{KM45013}), and the resulting chromosomal regions after spontaneous loss. The arrows indicate the extent and direction of transcription of \textit{orfX}, \textit{orf6}, and \textit{orf51}, the site-specific recombinase genes (\textit{ccrAm2}, \textit{ccrBm2}), and the genes comprising the \textit{mecB} operon (\textit{mecIm}, \textit{mecRm}, \textit{mecB} and \textit{blaZm}). ISS1 to ISS3 are boxed. Bases in blue indicate divergences from ISS1, while letters in red indicate the presence of double peaks (Sanger sequencing) in the sequence chromatograms: R (G or A), W (A or T), S (G or C), and K (T or G). A size scale in kb is displayed in the upper left-hand corner. (B) Spontaneous chromosomal excision of an unconventional circularizable structure (UCS) carrying the \textit{mecB} complex. The left panel shows the potential homologous recombination event between \textit{orf6} and \textit{orf51} in \textit{M. caseolyticus} strain KM45013. The right panel shows the resulting UCS and the chromosomal region after excision. The recombinated area is colored in purple with white dots. The imperfect direct repeats (DR\textsubscript{1}, DR\textsubscript{2}) flanking \textit{orf46} and \textit{orf51} are indicated as blue (DR\textsubscript{-51}) or green (DR\textsubscript{-46}) blocks. The suggested recombination sites (\textit{\textsuperscript{3′}TTACAG-\textsuperscript{3′}}) and the ISS3 are indicated within black boxes. Primers used to detect the different circularized elements and the excision sites are indicated as dashed arrows, with the arrowhead indicating the direction of amplification. They are named 0 to 5 for the named CIs and A to D for the designated UCS. See Table S1 in the supplemental material for nomenclature.
bakishita et al. (5) with the agreement of the members of the IWG-SCC (see reference 19 for a list of the members). The ccrAm2 and ccrBm2 genes showed the closest identity to the staphylococcal ccr genes from methicillin-resistant 
S. aureus strain HDE288 (GenBank accession no. AF114935), with an overall nucleotide identity of 51.6% to ccrA4 and 47.3% to ccrB4, respectively (Fig. 2B). Phylogenetic comparative analysis of the ccr genes from the macrococcal SCCmec elements with the other ccr types revealed that the macrococcal ccr genes formed two separate branches outside the staphylococcal ccrA, ccrB, and ccrC clades (Fig. 2B).

Analysis of spontaneous chromosomal excision of different SCCmecKm45013 element units. PCR and sequence analysis detected four distinct extrachromosomal CIs, three of them carrying one ISS copy as joining regions, which is characteristic of Cre-mediated excision. These three ISS-associated CIs have been named with the same nomenclature as that described for the SCCmec-like element of JCSC7096 (5): (i) SCCmecKm45013 (entire cassette), (ii) SCC*Km45013 (SCC lacking the mec gene) (26.9 kb, 37 CDSs, GC content of 32.7%), and (iii) ΨSCCmecKm45013 (SCCmec lacking the ccr genes) (12 kb, 12 CDSs, GC content of 29%) (Fig. 3A). This excision ability was also observed for the SCCmec-like element of JCSC7096 (5), indicating a high functional activity of the ccrABm gene complex. In addition, all corresponding chromosomal segments remaining after excision were detected (Fig. 3).

The fourth CI (6,279 bp, GC content of 28.1%) consisted of the mec gene complex (mecR1m-mecIm-mecB-blaZm) joined by one recombinated copy of the putative transcriptional regulator genes orf64 and orf51 (Fig. 3B). The GC content of this CI was remarkably lower than that in the genome of M. caseolyticus KM45013 (37.0%), indicating that it probably originated from another bacterial species with a lower GC content. Additionally, the presence of long DRs as a joining region instead of ISSs suggested a ccrABm2-independent mechanism for excision, categorizing this CI as an unconventional circularized structure (UCS). UCSs have been recently described as particular genetic structures, mostly carrying antimicrobial resistance determinants (29) which, despite the lack of their own recombinase genes, are able to be excised in circular forms thanks to extensive flanking DRs (29). Moreover, UCSs are frequently carried by conventional mobile elements. Mobilization via site-specific recombination and usage of host trans-acting functions has been suggested for UCSs; however, an active role of the ccrABm2 genes in the excision of this UCS cannot be excluded.

Nucleotide sequence alignment of the recombined region located in the UCS element, the recombinated copy that remains in the chromosome after excision, and the individual orf64 and orf51 genes revealed that the CDS located in the UCS and the one that remained in the chromosome after excision resulted from a recombination event between orf64 and orf51, with a 6-bp sequence DR [5′-TTACAG-3′] present at the 5′ and 3′ ends of both CDSs as a presumptive homologous recombination site (see Fig. S1 in the supplemental material). Both extensive repeated regions on each side of mecB may still play a role in the UCS integration/excision. Additionally, this UCS contained ISS3 (Fig. 3B) and thus retained the potential to be integrated by Ccrs.

In conclusion, a mecB-carrying SCCmec element was discovered in a clinical hemolytic M. caseolyticus strain of canine origin. The mecB gene complex was not associated with transposases of Tn6045, revealing for the first time a true SCCmec element in Macrooccus. The high sequence and structure similarity between Tn6045 and the mecB complex of KM45013 within two structurally different elements gives new insight into the acquisition of mecB and the birth of SCCmec in Macrooccus. The detection of several excised circularized elements may also contribute to the further diversification of SCCmec elements in M. caseolyticus. This study underlines the role of commensal bacteria both as potential opportunistic animal pathogens and as reservoirs for novel and primordial forms of SCCmec with high potential genetic plasticity.

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