An outbreak of cutaneous abscesses caused by Panton-Valentine leukocidin-producing methicillin-susceptible Staphylococcus aureus among gold mine workers, South Africa, November 2017 to March 2018

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Abstract

Background: We aimed to describe an outbreak of cutaneous abscesses caused by Panton-Valentine leukocidin (PVL)-producing methicillin-susceptible Staphylococcus aureus (MSSA) among gold mine workers.

Methods: In February 2018, we retrospectively reviewed a random sample of 50 medical records from 243 cases and conducted face-to-face interviews using a structured questionnaire. Pus aspirates were sent to the National Institute for Communicable Diseases from prospectively-identified cases (November 2017–March 2018). Nasopharyngeal swabs were collected during a colonisation survey in February 2018. Staphylococcus aureus isolates were screened with a conventional PCR for lukS/F-PV. Pulsed-field gel electrophoresis (PFGE) was performed to determine the genetic relatedness among the isolates. A sample of isolates were selected for whole genome sequencing (WGS). We conducted an assessment on biological risks associated with mining activities.

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Background

*Staphylococcus aureus* is a Gram-positive bacterium that gives rise to a variety of infections, which include bloodstream, gastrointestinal, respiratory and skin and soft tissue infections (SSTIs) [1, 2]. *Staphylococcus aureus* forms part of the normal microflora of humans and approximately 20–30% of adult populations are colonized at any given time [3]. *Staphylococcus aureus* infections are common in both hospital and community settings [1]. Although a number of antimicrobial agents are used to treat staphylococcal infections, treatment remains a challenge due to antimicrobial resistance, particularly in healthcare settings [1, 2]. *Staphylococcus aureus* produces and expresses a range of exoproteins including the cytotoxin, Panton-Valentine leukocidin (PVL) [4]. The PVL is a pore-forming leukocidal toxin encoded by the *lukS-PV* and *lukF-PV* genes, which is known to cause leukocyte destruction and tissue necrosis [3–5].

In November 2017, the National Institute for Communicable Diseases (NICD) was alerted by a gold mining company in Gauteng province, South Africa of a large number of mine workers seeking care at their on-site occupational health clinic with skin infections, mostly cutaneous abscesses. From January through to September 2017, 243 mine workers had attended the occupational health clinic for the treatment of cutaneous abscesses. No deaths were reported. Following a stakeholders’ meeting involving management of the mining company, healthcare practitioners, occupational health practitioners and environmental health practitioners, we initiated epidemiological and laboratory investigations. In this study, we aimed to describe this outbreak investigation of cutaneous abscesses among gold mine workers and to characterise these PVL-producing methicillin-susceptible *S. aureus* (MSSA) isolates and relatedness with each other by using molecular methods.

Methods

Epidemiological investigations

*Medical record review*

On 6 February 2018, we retrospectively reviewed a random sample of medical records from 243 cases to describe the clinical management and treatment of mine workers with cutaneous abscesses. A standardised case report form was used to collect demographic, medical history and clinical data. A case was defined as any person employed at the mine who sought care at the occupational health clinic for cutaneous abscesses from 1 January through to 30 September 2017. A recurrent episode was defined when a cutaneous abscess recurred on a different part of the body or following the resolution of a previous episode.

*Interviews*

On 21 February 2018, we conducted face-to-face interviews using a structured questionnaire (Questionnaire S1). An eligible participant for an interview was defined as any person aged 18 years or older, engaged in underground mine work and employed for at least 1 month (as of the date of interview) at the gold mine. Written informed consent was obtained for interviews. An information sheet was provided to potential participants. We collected data on demographic characteristics, past medical history, exposure history and history of cutaneous abscesses. Eligible participants with cutaneous abscesses at the time of interview were examined by a medical doctor and a specimen (either pus aspirate and/or skin scrapings) was collected and submitted to the NICD for diagnostic testing. Written informed consent was obtained for specimen collection.

Conclusions:
PVL-producing MSSA caused an outbreak of cutaneous abscesses among underground workers at a gold mining company. To our knowledge, no other outbreaks of PVL-producing *S. aureus* involving skin and soft tissue infections have been reported in mining facilities in South Africa. We recommend that worker awareness of infection prevention and control practices be strengthened.

Keywords: Outbreak, Panton-valentine leukocidin, Methicillin-susceptible *Staphylococcus aureus*, Skin infection, Miners...
Laboratory investigations

Clinical specimens

From 17 November 2017 to 13 March 2018, clinic personnel at the on-site occupational health clinic obtained pus aspirates from mine workers with cutaneous abscesses and submitted specimens to the NICD.

Nasopharyngeal carriage of S. aureus

Colonisation with S. aureus was determined by collecting posterior nasopharyngeal swabs from mine workers working during the morning shift on 21 February 2018. Written informed consent was obtained for specimen collection. Nasopharyngeal swabs were tested at the NICD.

Microbiological assays

Pus aspirates, skin scrapings and nasopharyngeal swabs were cultured as per standard microbiological procedures [6]. Bacterial colonies were sub-cultured onto fresh 5% horse blood agar plates (Diagnostic Media Products, DMP), National Health Laboratory Service (NHLS), South Africa and identified to species level using a matrix assisted laser desorption ionization-time of flight mass spectrometer (MALDI-TOF) (Bruker Daltonik, Bremen, Germany). Antimicrobial susceptibility testing (AST) was performed on bacterial colonies using the Gram-positive panel PM33 on the MicroScan Walkaway system (Beckman Coulter, Inc., Atlanta, USA). Minimum inhibitory concentrations (MIC) were according to Clinical and Laboratory Standards Institute (CLSI) breakpoint recommendations [7].

Molecular characterisation of PVL-producing S. aureus

Genomic DNA from pure bacterial cultures grown on 5% horse blood agar plates (DMP, NHLS) was extracted using a crude boiling method and was then used as a template for polymerase chain reaction (PCR) amplification. Bacterial isolates were screened for the lukS/F-PV gene by a conventional PCR assay using the G-Storm thermal cycler (Somerton Biotechnology Centre, Somerton, UK), the Qiagen Multiplex PCR kit (Qiagen, Nordrhein-Westfalen, Germany) and previously published primers [8]. Staphylococcus aureus ATCC49775 was used as a positive control.

Pulsed-field gel electrophoresis

The genetic relatedness of the isolates was determined by pulsed-field gel electrophoresis (PFGE). Bacterial isolates cultured from pus aspirates, skin scrapings and nasopharyngeal swabs were selected based on the period of specimen collection. CDC-H9812 Salmonella enterica serotype Braenderup was included as a reference standard. PFGE for S. aureus was performed according to a published protocol [9]. PFGE banding patterns were analysed using BioNumerics (version 6.5) software (Applied Maths, Sint-Martens-Latem, Belgium). A dendrogram was created and compared using the unweighted pair group method with arithmetic mean analysis. Cluster analysis was conducted using a dice coefficient with both an optimization value and tolerance factor of 1.5%.

Whole-genome sequencing analysis

To supplement PFGE, whole-genome sequencing (WGS) analysis was performed for a sample of isolates. Staphylococcus aureus isolates were selected based on specimen type, AST and PFGE banding patterns. Bacterial isolates were grown in brain heart infusion (BHI) broth (DMP, NHLS) and genomic DNA from each isolate was extracted using the QIAamp DNA minikit (Qiagen, Germany). Samples were prepared using the Nextera XT library prep kit (Illumina, Inc., California, USA) and the MiSeq platform (Illumina) was used to carry out 2 × 300 base pair sequencing with 100x coverage. Raw sequencing data were trimmed and the trimmed reads were assembled on the De Novo Assembly Tool using the CLC Genomics Workbench Software version 11 (Qiagen, Germany). We used assembled genome data to identify isolates to species level and to characterise and compare these to genome assembly data of two S. aureus isolates, one hospital-associated (9336 HA) and one community-associated (9588 CA), obtained from the NICD/GERMS antimicrobial resistance surveillance study in 2015. The assembled genome data were evaluated using the Nullarbor pipeline and included: species identification; multi locus sequence typing (MLST) and identification of antimicrobial-resistant genes and virulence genes [10]. The spa types were determined using a web-based tool: Center for Genomic Epidemiology http://genomicepidemiology.org/. The assembled files were submitted to the National Center for Biotechnology Information GenBank and are available under BioProject numbers: PRJNA560164 and PRJNA548666.

Data analysis

Data were analysed using Stata version 14.2 (StataCorp LP, College Station, Texas, USA). Categorical data were expressed as frequencies, percentages and/or presented graphically. Characteristics of mine workers with and without cutaneous abscesses were evaluated using appropriate statistical measures (for example, a χ2 test and/or Fisher’s exact test were used to compare categorical variables). Nasopharyngeal colonisation was defined as S. aureus cultured from a nasopharyngeal swab. The nasopharyngeal colonisation rate of S. aureus was calculated by dividing the number of nasopharyngeal swab specimens that cultured S. aureus by the total number of nasopharyngeal swab specimens taken.

Bio-risk assessment

We conducted an assessment on biological risks associated with mining activities to determine possible exposure
sources for both surface and underground levels. Data were gathered by visual inspection and interviewing employees and management to obtain information on specific job tasks, work practices, engineering controls, water supply and personal protective clothing. The assessed areas included the male and female change rooms, laundry, occupational health clinic and the underground stope and tunnel. A Q-trak indoor air quality meter (dry bulb) and probe, model SN 7575 (TSI Instruments Ltd., UK) was used to measure ambient temperature in °C, percentage relative humidity and carbon dioxide simultaneously at underground sites on the day of risk assessment.

Results
From January 2017 to February 2018, 10% (350/3582) of gold mine workers sought care for cutaneous abscesses, with higher numbers being reported in the first 6 months of 2017 (Fig. 1).

Epidemiological findings from medical record review and face-to-face interviews
Of a random sample of 50 cases, 47 medical files were available for review. The totals represent the respective available data. Among the 47 symptomatic mine workers, 96% were male (45/47) with a mean age of 43 years (SD = 7) at their last clinic visit. Sixty percent (27/45) lived off-site, while the remaining 40% (18/45) stayed in hostels located on the mine premises. Four occupational fields identified, of which 52% (24/46) were involved in stoping (ore extraction activities underground) followed by 26% (12/46) in roving underground (mine workers are not assigned to one particular level). Symptomatic mine workers operated on five levels underground, of which 28% (13/47) worked on a particular level (results not shown due to confidentiality reasons) (Table 1). Forty-two percent (18/43) were HIV-seropositive, 47% (21/45) had a history of smoking (previous or current) and 46% (21/46) had a history of alcohol consumption (previous or current) (Table 1). The 47 workers had attended the occupational clinic for treatment of multiple episodes of cutaneous abscesses (data were collected on all episodes from 14 January 2011 to 15 January 2018). As of 06 February 2018, 130 episodes of cutaneous abscesses were recorded, 21% (27/130) in 2016 and 65% (84/130) in 2017 (Fig. 2). Sixty-four percent (83/130) were recurrent episodes. Of the 60 episodes with known information, the median duration of symptoms before presentation to the occupational clinic was 3 days (IQR 2–6). The location of the cutaneous abscesses was classified into eight anatomical sites, of which 31% (41/130) were located on the lower limbs and 24% (31/130) on the upper limbs (Table 1). For episodes with a recorded treatment history, 52% (62/119) were surgically drained (incision and drainage) and 83% (101/122) were treated with at least one oral antibiotic, of whom 65% (79/122) were treated with metronidazole. Of the 24 episodes with a known recorded outcome, the median duration of resolution was 12 days (IQR 9–17) and 98% (46/47) resolved (Table 1).

Fifty-eight interviews were conducted among mine workers who were eligible and gave consent to be interviewed. Seventy-six percent (44/58) of these mine workers worked the morning shift. Fifteen of the 58 mine workers reported current or prior cutaneous abscesses, of whom 80% (12/15) were from the morning shift. We found no differences among mine workers with and without cutaneous abscesses (Table 2).
Table 1: Demographic, medical history and clinical treatment of gold mine workers who presented with cutaneous abscesses at the on-site occupational health clinic from January through to September 2017, n = 47

| Characteristic                      | Number of symptomatic mine workers (n/N\(^a\)) | %    |
|------------------------------------|-----------------------------------------------|------|
| **Residence**                      |                                               |      |
| Mine hostel                        | 18/45                                         | 40   |
| Living out                         | 27/45                                         | 60   |
| **Work type**                      |                                               |      |
| Stoping                            | 24/46                                         | 52   |
| Roving underground                 | 12/46                                         | 26   |
| Development                        | 5/46                                          | 11   |
| Shaft and Services                 | 5/46                                          | 11   |
| **Medical history**                |                                               |      |
| Diabetes mellitus                  | 2/45                                          | 4    |
| Tuberculosis                       | 2/46                                          | 4    |
| HIV infection                      | 18/43                                         | 42   |
| Skin conditions                    | 2/27                                          | 7    |
| History of smoking                 | 21/45                                         | 47   |
| History of alcohol consumption     | 21/46                                         | 46   |
| Other medical conditions           | 3/46                                          | 7    |
| **Recurrence**                     |                                               |      |
| New                                | 47/130                                        | 36   |
| Recurrent                          | 83/130                                        | 64   |
| **Site of cutaneous abscess**      |                                               |      |
| Lower limbs                        | 41/130                                        | 31   |
| Upper limbs                        | 31/130                                        | 24   |
| Hands                              | 24/130                                        | 18   |
| Face                               | 16/130                                        | 12   |
| Buttocks and perianal              | 7/130                                         | 5    |
| Trunk and back                     | 6/130                                         | 5    |
| Groin                              | 2/130                                         | 2    |
| Other                              | 2/130                                         | 2    |
| Head and neck                      | 1/130                                         | 1    |
| **Treatment**                      |                                               |      |
| Incision and drainage              | 62/119                                        | 52   |
| Oral antibiotics\(^b\)             | 101/122                                       | 83   |
| Metronidazole                      | 79/122                                        | 65   |
| Amoxicillin/ampicillin             | 50/122                                        | 41   |
| Cloxacillin                        | 46/122                                        | 38   |
| Clindamycin                        | 14/122                                        | 12   |
| Amoxicillin-clavulanic acid        | 2/122                                         | 2    |
| Doxycycline                        | 2/122                                         | 2    |
| Topical antibiotics                | 48/120                                        | 40   |
| Dressings                          | 78/121                                        | 65   |
| **Resolved (yes)**                 |                                               |      |
|                                    | 46/47                                         | 98   |

\(^a\)Denominators are less than the column total because of missing data, \(^b\)Symptomatic mine workers often received a combination of antibiotics at the same time
Phenotypic characterisation of S. aureus isolates

From 22 November 2017 through to 13 March 2018, 29 pus aspirate specimens were received by the NICD. Of these, S. aureus was cultured from 86% (25/29), S. epidermidis from one and no bacterial growth for three. All 25 S. aureus isolates were susceptible to cloxacillin (based on a negative cefoxitin screen), trimethoprim/sulfamethoxazole and mupirocin. Eighty-four percent (21/25) were susceptible to clindamycin but resistant to penicillin (MIC ≥ 8 μg/ml). Twelve percent (3/25) were susceptible to both clindamycin and penicillin, while one isolate was resistant to clindamycin (erythromycin MIC > 4 μg/ml) (Table 3).

Of the 15 mine workers who reported to have cutaneous abscesses during interviews, 80% (12/15) were examined by the team of medical doctors from the NICD. Six skin scrapings and three pus aspirates were obtained from eight affected mine workers. Of these nine specimens, we cultured S. aureus from 56% (5/9) and S. haemolyticus from one. Three specimens were not tested due to poor specimen quality. All five isolates displayed similar AST profiles to specimens submitted to NICD from cases. All five S. aureus isolates were penicillin-resistant, but susceptible to cloxacillin, trimethoprim/sulfamethoxazole and clindamycin. One of the five isolates was resistant to mupirocin (MIC > 4 μg/ml) and penicillin (Table 3).

Eighty-three nasopharyngeal swabs were collected. Of these, we cultured S. epidermidis from 67% (56/83), S. aureus from 14% (12/83), S. haemolyticus from 10% (8/83), and other Staphylococcus species from 8% (7/83). Of the 83 mine workers who had nasopharyngeal swabs taken, 53% (44/83) were interviewed. Of the 15 mine workers who reported to have cutaneous abscesses, 11 had nasopharyngeal swabs taken. All 11 nasopharyngeal swabs cultured S. epidermidis. Of the 43 mine workers who reported not to have cutaneous abscesses, 33 had nasopharyngeal swabs taken. Five (NP6, NP7, NP16, NP17 and NP28) of the 33 nasopharyngeal swabs cultured S. aureus.

Genotypic characterisation of S. aureus isolates

Of the 42 S. aureus isolates (30/38 pus aspirates or skin scrapings and 12/83 nasopharyngeal swabs), 71% (30/42) were PCR-positive for the lukS/F-PV gene. PFGE analysis was performed on 37 S. aureus isolates, only isolates characterised from 22 November 2017 through to 22 February 2018 were included in the analysis. Six clusters (A-F) were identified, of which 57% (21/37) made up cluster A (isolates clustered together ≥ 90%). Two isolates, DRKM4 and NP71 had PFGE profiles that were distinguishable from the other isolates suggesting that these isolates were not related (Fig. 3). Based on WGS, a sequence type (ST) and spa type were assigned for 19 of the 20 outbreak isolates as shown in Fig. 3. Similarities in the ST and spa type were noted for three PFGE clusters except clusters B, D and E (Fig. 3). Six (DRKM, DRKM7, DRKM11, DRKM12, NP28 and NP46) of the 20 isolates chosen for WGS analysis belonged to ST152, all six isolates belonged to cluster A.

Findings from bio-risk assessment

A detailed summary of the bio-risk assessment is outline in Table 4.

Discussion

We describe a large outbreak of cutaneous abscesses among mine workers at a gold mine in Gauteng, South Africa. Skin diseases are common among South African mine workers [11]. However, they are seldom linked to a causative agent [11]. For instance, a medical record review of 507 patient files from a coal company (2005–2006) showed that 62% of skin disorders were diagnosed as infection-related [11]. In our study, findings from the medical record review showed that reports of cutaneous abscesses were identified prior to 2017, which may suggest that this outbreak had started earlier. Of the records evaluated, only one affected mine worker had a pus swab taken for testing: S. aureus, Klebsiella pneumoniae and Enterobacter cloacae were isolated (results not shown).
Table 2 Comparison of exposure characteristics of gold mine workers who presented with and without cutaneous abscesses, 21 February 2018, n = 58

| Characteristic                        | Mine workers without cutaneous abscesses (N = 43<sup>a</sup>) | Mine workers with cutaneous abscesses (N = 15<sup>b</sup>) | P-value |
|---------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------|---------|
| **n (%)**                             |                                                               |                                                           |         |
| Sex                                   |                                                               |                                                           |         |
| Female                                | 6 (100)                                                       | 0 (0)                                                      | 0.32    |
| Male                                  | 37 (71)                                                       | 15 (29)                                                    |         |
| Age                                   |                                                               |                                                           | 0.96    |
| Mean age (SD)                         | 39 (9)                                                        | 39 (9)                                                     |         |
| Residence                             |                                                               |                                                           | 0.24    |
| Mine hostel                           | 6 (67)                                                        | 3 (33)                                                     |         |
| Living out                            | 37 (77)                                                       | 11 (23)                                                    |         |
| Work type                             |                                                               |                                                           | 0.67    |
| Stoping                               | 29 (73)                                                       | 11 (27)                                                    |         |
| Roving underground                    | 1 (50)                                                        | 1 (50)                                                     |         |
| Shaft and services                    | 2 (100)                                                       | 0 (0)                                                      |         |
| Traming                               | 1 (100)                                                       | 0 (0)                                                      |         |
| Other                                 | 1 (50)                                                        | 1 (50)                                                     |         |
| HIV status                            |                                                               |                                                           | 0.87    |
| No                                    | 32 (71)                                                       | 13 (29)                                                    |         |
| Yes                                   | 7 (88)                                                        | 1 (12)                                                     |         |
| History of smoking                    |                                                               |                                                           | 1.00    |
| No                                    | 31 (74)                                                       | 11 (26)                                                    |         |
| Yes                                   | 12 (75)                                                       | 4 (25)                                                     |         |
| History of alcohol consumption        |                                                               |                                                           | 1.00    |
| No                                    | 22 (73)                                                       | 8 (27)                                                     |         |
| Yes                                   | 21 (75)                                                       | 7 (25)                                                     |         |
| Cuts/Scratches over the last week     |                                                               |                                                           | 0.64    |
| No                                    | 39 (75)                                                       | 13 (25)                                                    |         |
| Yes                                   | 4 (67)                                                        | 2 (33)                                                     |         |
| Frequency of wearing protective clothing |                                                               |                                                           | 1.00    |
| Always (100%)                         | 39 (75)                                                       | 13 (25)                                                    |         |
| Most of the time (80%)                | 3 (75)                                                        | 1 (25)                                                     |         |
| Sharing of protective clothing         |                                                               |                                                           | 1.00    |
| No                                    | 40 (74)                                                       | 14 (26)                                                    |         |
| Yes                                   | 1 (100)                                                       | 0 (0)                                                      |         |
| Sets of protective clothing used in one shift |                                                               |                                                           | 1.00    |
| One set                               | 10 (77)                                                       | 3 (23)                                                     |         |
| Two sets                              | 27 (73)                                                       | 10 (27)                                                    |         |
| More than two sets                    | 6 (75)                                                        | 2 (25)                                                     |         |
| Change into protective clothing<sup>b</sup> |                                                               |                                                           | 0.49    |
| Mine change rooms                     | 21 (78)                                                       | 6 (22)                                                     |         |
| Underground                           | 11 (65)                                                       | 6 (35)                                                     |         |
| Store protective clothing              |                                                               |                                                           | 1.00    |
| Mine change rooms                     | 23 (74)                                                       | 8 (26)                                                     |         |
Our findings showed that more than 60% of episodes were recurrent infections. It has been reported that identifying the causative pathogen may not be necessary for treating uncomplicated skin infections, but cultures can provide valuable information in patients with recurrent skin infections [12]. Our findings showed that more than 60% of episodes were treated with metronidazole. There is an Essential Drug List (EDL) at national level to guide clinicians for empirical treatment options for all organ systems including infectious causes. Each facility practitioner makes a decision based on assessment of possible cause of infection. Among our cases, mixed infections have been considered and number of antimicrobial agents were options including cover for anaerobic bacteria. Once unsuccessful with this treatment approach, NICD was consulted for investigation and assistance.

We showed that the causative agent responsible for this outbreak was PVL-producing MSSA. To our knowledge, no other outbreaks of PVL-producing MSSA SSTIs have been reported in mining facilities in South Africa. PVL is not necessarily associated with community-associated MRSA infections [13]. However, several outbreaks of skin infections due to PVL-producing MSSA have been previously described in community settings [14–16]. The presence of PVL was observed in a relatively high percentage of the MSSA isolates obtained from pus aspirates and skin scrapings (28/30 isolates were PCR-positive), but not from nasopharyngeal swabs (2/12 isolates were PCR-positive). This is consistent with findings from previous studies where the presence of PVL was low in specimens obtained from the nasopharynx [17].

PFGE and WGS analysis from this study revealed more than one cluster of *S. aureus* infections involving closely related isolates. More than half of the isolates clustered together indicating clonal spread and all six isolates chosen from cluster A for WGS belonged to ST152, making this the dominant outbreak isolate. In this study, the introduction of ST152 PVL-producing MSSA in the gold mine is still unknown. ST152 PVL-producing *S. aureus* was reported to be common in West and Central Africa [18].

High temperature and relative humidity measured at the underground level can support microbial growth,

### Table 2
Comparison of exposure characteristics of gold mine workers who presented with and without cutaneous abscesses, 21 February 2018, *n*= 58 (Continued)

| Characteristic                                      | Mine workers without cutaneous abscesses (N = 43<sup>a</sup>) | Mine workers with cutaneous abscesses (N = 15<sup>a</sup>) | P-value |
|----------------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------|---------|
| Underground                                        | 9 (75)                                                         | 3 (25)                                                   | 1.00    |
| Place of stay                                       | 11 (73)                                                        | 4 (27)                                                   |         |
| Rinse protective clothing with untreated water     |                                                                |                                                          |         |
| No                                                  | 8 (57)                                                         | 6 (43)                                                   |         |
| Yes                                                 | 7 (64)                                                         | 4 (36)                                                   |         |
| Bring protective clothing to surface                |                                                                |                                                          | 0.29    |
| After every shift                                   | 31 (79)                                                        | 8 (21)                                                   |         |
| Once a week                                         | 3 (60)                                                         | 2 (40)                                                   |         |
| Twice a week                                        | 2 (100)                                                        | 0 (0)                                                    |         |
| Never                                               | 2 (50)                                                         | 2 (50)                                                   |         |
| Daily wash of protective clothing                   |                                                                |                                                          | 0.66    |
| No                                                  | 6 (86)                                                         | 1 (14)                                                   |         |
| Yes                                                 | 30 (73)                                                        | 11 (27)                                                  |         |
| Place where protective clothing were laundered      |                                                                |                                                          | 1.00    |
| Place of stay                                       | 14 (74)                                                        | 5 (26)                                                   |         |
| Mine laundromat                                     | 26 (72)                                                        | 10 (28)                                                  |         |
| Wash at mine change rooms after a shift             |                                                                |                                                          | 1.00    |
| No                                                  | 4 (80)                                                         | 1 (20)                                                   |         |
| Yes                                                 | 36 (73)                                                        | 13 (27)                                                  |         |
| Worked in a different section of the mine<sup>c</sup> |                                                                |                                                          | 1.00    |
| No                                                  | 27 (73)                                                        | 10 (27)                                                  |         |
| Yes                                                 | 14 (78)                                                        | 4 (22)                                                   |         |

<sup>a</sup>Denominators are less than the column total because of missing data, <sup>b</sup>protective clothing used during a shift, <sup>c</sup>over the last 12 months
Table 3  Pus aspirates and skin scrapings submitted to the National Institute for Communicable Diseases for testing, 22 November 2017 to 13 March 2018, n = 35

| Isolate number | Specimen type | Collection date | Organism                  | PVL | Cefoxitin<sup>a</sup> | Pen<sup>MIC</sup> | Pen<sup>Interp</sup> | Eryth<sup>MIC</sup> | Eryth<sup>Interp</sup> | Clinda<sup>MIC</sup> | Clinda<sup>Interp</sup> | SXT<sup>MIC</sup> | SXT<sup>Interp</sup> | Mupirocin<sup>b</sup> |
|---------------|---------------|----------------|---------------------------|-----|------------------------|------------------|---------------------|-----------------|---------------------|-----------------|---------------------|-----------------|------------------|-------------------|
| DRKM1         | Pus aspirate  | 27/11/2017     | Staphylococcus aureus     | POS | NEG                    | > 8              | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM2         | Pus aspirate  | 23/11/2017     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM3         | Pus aspirate  | 22/11/2017     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM4         | Pus aspirate  | 22/11/2017     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM5         | Pus aspirate  | 04/12/2017     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM6         | Pus aspirate  | 29/11/2017     | No bacterial growth       |     |                        |                 |                     |                 |                     |                 |                     |                 |                 | NT                |
| DRKM7         | Pus aspirate  | 04/12/2017     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM8         | Pus aspirate  | 14/12/2017     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM9         | Pus aspirate  | 18/12/2017     | Staphylococcus aureus     | NEG | NEG                    | > 8             | R                   | > 4             | R                   | > 8             | R                   | ≤ 0.25          | S                   |                   |
| DRKM10        | Pus aspirate  | 19/12/2017     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM11        | Pus aspirate  | 20/12/2017     | Staphylococcus aureus     | POS | NEG                    | ≤ 0.12          | S                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM12        | Pus aspirate  | 20/12/2017     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM13        | Pus aspirate  | 18/01/2018     | Staphylococcus aureus     | POS | NEG                    | < 0.12          | S                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM14        | Pus aspirate  | 18/01/2018     | No bacterial growth       |     |                        |                 |                     |                 |                     |                 |                     |                 |                 | NT                |
| DRKM15        | Pus aspirate  | 18/01/2018     | No bacterial growth       |     |                        |                 |                     |                 |                     |                 |                     |                 |                 | NT                |
| DRKM16        | Pus aspirate  | 23/01/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM17        | Pus aspirate  | 06/02/2018     | Staphylococcus aureus     | POS | NEG                    | < 0.12          | S                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM18        | Pus aspirate  | 06/02/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM19        | Pus aspirate  | 06/02/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM20        | Pus aspirate  | 08/02/2018     | Staphylococcus epidermidis| POS | NEG                    |                 |                     |                 |                     |                 |                     |                 |                 | NT                |
| DRKM21        | Pus aspirate  | 12/02/2018     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM22        | Pus aspirate  | 12/02/2018     | Staphylococcus aureus     | POS | NEG                    | < 0.12          | S                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM23        | Pus aspirate  | 15/02/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM24        | Pus aspirate  | 21/02/2018     | Staphylococcus aureus     | POS | NEG                    | 8               | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM25        | Pus aspirate  | 22/02/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM26        | Pus aspirate  | 12/03/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM27        | Pus aspirate  | 12/03/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM28        | Pus aspirate  | 13/03/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM29        | Pus aspirate  | 13/03/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |
| DRKM30        | Pus aspirate  | 12/03/2018     | Staphylococcus aureus     | POS | NEG                    | > 8             | R                   | ≤ 0.5           | S                   | ≤ 0.25          | S                   | ≤ 2             | S              |                   |

<sup>a</sup> PVL: Presence of virulence locus

<sup>b</sup> Mupirocin: Sensitivity to Mupirocin
| Isolate number | Specimen type | Collection date | Organism                  | PVL | Cefoxitin<sup>b</sup> | Pen MIC | Pen Interp | Eryth MIC | Eryth Interp | Clinda MIC | Clinda Interp | SXT MIC | SXT Interp | Mupirocin |
|---------------|---------------|-----------------|---------------------------|-----|-----------------------|---------|-----------|-----------|-------------|-----------|-------------|---------|-----------|----------|
| DRKM24<sup>a</sup> | Skin scrapings | 21/02/2018      | *Staphylococcus haemolyticus* | NEG | POS                   | 8       | R         | > 4       | R           | > 2       | R           | > 4     | R         |          |
| DRKM25<sup>a</sup> | Pus aspirate   | 21/02/2018      | *Staphylococcus aureus*    | POS | NEG                   | > 8     | R         | ≤ 0.5     | S           | ≤ 0.25    | S           | ≤ 2     | S         |          |
| DRKM26<sup>a</sup> | Skin scrapings | 21/02/2018      | *Staphylococcus aureus*    | POS | NEG                   | > 8     | R         | ≤ 0.5     | S           | ≤ 0.25    | S           | ≤ 2     | S         | R        |
| DRKM27<sup>a</sup> | Skin scrapings | 21/02/2018      | *Staphylococcus aureus*    | POS | NEG                   | > 8     | R         | ≤ 0.5     | S           | ≤ 0.25    | S           | ≤ 2     | S         | S        |
| DRKM28<sup>a</sup> | Pus aspirate   | 21/02/2018      | *Staphylococcus aureus*    | POS | NEG                   | > 8     | R         | ≤ 0.5     | S           | ≤ 0.25    | S           | ≤ 2     | S         | S        |
| DRKM29<sup>a</sup> | Pus aspirate   | 21/02/2018      | *Staphylococcus aureus*    | POS | NEG                   | > 8     | R         | ≤ 0.5     | S           | ≤ 0.25    | S           | ≤ 2     | S         | S        |

<sup>a</sup> Specimens obtained from mine workers who reported to have cutaneous abscesses during interviews. <sup>b</sup>Cefoxitin screen, PVL Panton-Valentine leukocidin, POS Positive, NEG Negative, NT Not tested, MIC Minimum inhibitory concentration, Interp interpretation, Pen Penicillin, Eryth Erythromycin, Clinda Clindamycin, SXT Trimethoprim/sulfamethoxazole, S Susceptible, R Resistant
which can impact on employees’ health. Washing facilities (showers, hand wash basins) in all change rooms and the laundry was available at the gold mine. Infections can be acquired in settings where people interact through physical contact or with contaminated surfaces [19]. Although laundering practices appeared sufficient, damp towels used by employees were hanging on the lockers in the shared changing rooms during the survey and could expose workers to infectious agents. Re-used cloth towels can be contaminated with microorganisms. Sifuentes et al reported that re-usable hospital towels contained 93% viable microbes after laundering, with clean towels having the highest microbial load suggesting that the laundering practices were inadequate [20]. Employees with abscesses in particular can contribute to pathogen transmission and/or reinfection via human or surface contact. Sharing of protective clothing was evident and presents a potential source of transmission. Despite the in-house laundry service being accessible, some workers washed their protective clothing with raw water which previously yielded high TPC and faecal coliforms. Which were above the recommended limits [21]. We recommended that the administrative controls be strengthened by incorporating an awareness programme on infection prevention and control practices (IPC) for mine workers. The effectiveness of the disinfectant in reducing or inactivating the bacterial load is important in infection control [22, 23]. The bactericidal characteristics of the soap used for rinsing safety boots after shift work was not stated on the material safety data sheet except that it serves as a sanitizer and deodoriser. The dilution used was also not known during the assessment. The antibacterial performance of the disinfectant used should thus be considered and evaluated before application considering that the lower limbs were most affected. The medical hub occupational health clinic was well organised with administrative controls in place. These included separation of patients for cleaning and dressing.

**Fig. 3** Pulsed-field gel electrophoresis DNA fingerprint patterns (SmaI-digestion) of *Staphylococcus aureus* isolates, 22 November 2017 through to 22 February 2018, n = 37. Isolates were considered genetically related if the banding patterns showed ≥80% similarity. A cluster was defined if isolates showed ≥90% similarities. *Isolates selected for whole genome sequencing analysis*
infected sites, dedicated protective clothing, proper storage and disposal of medical waste, natural ventilation policy and maintenance of ultraviolet germicidal irradiation fixtures.

The study design was a weakness of this study; the sample size was small and could not detect differences among mine workers with and without cutaneous abscesses. Another limitation was the nasopharyngeal colonisation study, which was conducted at a single point in time for one group of mine workers only, thus excluding additional mine workers who may have been colonised.

**Conclusions**

In summary, PVL-producing MSSA caused an outbreak of cutaneous abscesses among underground workers at a gold mining company. We identified isolates with more than one ST that were responsible for this outbreak. Overall, we observed poor adherence to protective clothing use, and suboptimal administrative and engineering controls. The use of disinfectants, laundering of overalls and drying of towels should be critically re-evaluated to prevent cross contamination. Worker awareness of infection prevention and control practices should be strengthened.

**Supplementary information**

Supplementary information accompanies this paper at https://doi.org/10.1186/s12879-020-05352-5.

**Additional file 1:** Questionnaire S1. Data collection tool.
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**Authors’ contributions**

All authors contributed significantly to this paper. HI: design, data analysis, interpretation of results and manuscript preparation. NG, ASM, EVs, LS, IM, GF, RM1, WS, ML, RM2, SN, TM, GdA, FI, NI, MA, AI, TS, OM, TD, OP, editing, interpretation and manuscript preparation. All authors have read and approved the final manuscript.

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**Availability of data and materials**

Some restrictions will apply. Whole genome sequencing data is publicly available by accessing the following links: https://www.ncbi.nlm.nih.gov/bioproject?term=M100560164 and https://www.ncbi.nlm.nih.gov/bioproject?term=M100548666. However, line patient data cannot be shared publicly due to confidentiality concerns.

**Ethics approval and consent to participate**

The NICD has approval from the Human Research Ethics Committee of the University of the Witwatersrand to publish data from outbreak investigations. Ethics clearance number: M160667. Written Informed consent was obtained for all participants and written informed consent was obtained for specimen collection. Data collected for this study were delimited from participant identifiers.

**Consent for publication**

Permission was obtained from the executive committee of the mining company to report the findings of this outbreak.

**Competing interests**

The authors have declared that no competing interests exist.

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