Carbapenem-resistant bacteria on hand-held and hands-free electronic devices of healthcare workers and non-healthcare workers in Delhi, India

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ARTICLE INFO

SUMMARY

Background: Monitoring sensitivity profiles of circulating hospital strains is a key activity of a hospital infection control policy. The hospital environment and equipment may be reservoirs for carbapenem-resistant bacteria. Mobile phones have been shown to be a potential source for the transmission of bacteria in the healthcare environment.

Methods: Bacteria were cultured from seven common electronic devices. These included touchpads, chargers, hands-free headphones/microphones, laptops, digital wristwatches and computer mice which were used by healthcare workers and non-healthcare workers including family members and patient attendants. The Gram-negative bacteria were further analysed for phenotypic and genotypic (bla_{KPC}, bla_{NDM-1} genes) carbapenem resistance.

Results: 110 Gram-negative bacteria were isolated Mobile phones were found to be the most heavily contaminated devices and hands-free devices the least. 53.6% (n=59/110) Gram-negative bacteria were phenotypically carbapenem-resistant of which 36.37% (n=40) were metallo-β-lactamase positive. 40% (n=44/110) were genotypically resistant and 30% (n=33) were bla_{NDM-1} gene positive. 9% (n=10) bacteria had both bla_{NDM-1} and bla_{KPC} genes.

Conclusions: Carbapenem-resistant bacteria are widespread in India's hospital environment and present a challenge in healthcare. Electronic devices are a potential vehicle for the transmission of carbapenem-resistant bacteria. The results of the study support that hands-free electronic devices are less likely to be contaminated with carbapenem-resistant bacteria and that promoting the use of hands-free devices may help to reduce the spread of multidrug resistant bacteria in healthcare.

Introduction

Electronic devices such as mobile phones, chargers, touch screens, digital wristwatches, laptops, computer mice and hands-free mobile devices such as headphones/microphones are now routinely used by healthcare workers (HCWs) both on and off duty, in hospital and at home [1]. It has been shown that mobile phones are a potential source for the transmission of bacteria such as *Staphylococcus aureus*, coagulase-negative *Staphylococcus*, Gram-positive spore-bearers, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Citrobacter* spp., *Escherichia coli*, and diphtheroids, among

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HCWs [2,3]. The hands of HCWs, microflora emitted from the mouth while talking and nasal bacteria in exhaled breath have been postulated to be common sources of these bacteria. Moreover, the heat generated by constant handling of the phone and by the handset itself creates a suitable environment for bacterial growth. The presence of these bacteria and preventing their spread is a key issue in controlling healthcare-associated infections (HAIs) [4,5].

HAIs caused by carbapenem-resistant bacteria have become a global threat and the incidence is increasing [6,7]. Carbapenemase-producing bacteria are resistant not only to the carbapenem antibiotics such as ertapenem, meropenem, imipenem and doripenem, but can also be resistant to other groups of antibiotics [8]. Characterising carbapenem resistance requires the consideration of both carbapenemase production as well as other resistance mechanisms. This can enable clinicians to select the most appropriate antibiotics for treatment. Although testing for carbapenemase production is not always routinely carried out, healthcare infection control procedures or epidemiological investigations often require the identification of these enzymes in Gram-negative bacteria [9,10].

Common β-lactamase/carbapenemase enzymes contain either serine or a zinc motif at the active sites and are coded by genes such as bla_{IMP}, bla_{VIM}, bla_{NDM}, bla_{KPC}, and bla_{OXA-48}. Serine-containing carbapenemases are mediated by the bla_{KPC} gene. The zinc-containing carbapenemases are known as metallo-β-lactamases (MBL) and include bla_{NDM-1} (New Delhi Metallo-β-Lactamase). bla_{NDM-1}-positive strains are especially challenging because there is no routine, standardised phenotypic test for MBL detection and there is a likely high prevalence of unrecognised asymptomatic carriers as well as a lack of antibiotics for the treatment of multidrug-resistant bla_{NDM-1}-expressing bacteria. Also, plasmids carrying these genes can undergo extensive rearrangements and are transferable by horizontal transmission [11].

Studies on the bacteria present on hand-held and hands-free electronic devices are required given the widespread use of these devices and the rising incidence of infections caused by multidrug-resistant bacteria.

The National Institute of Tuberculosis and Respiratory Diseases (NITRD) is the premier tuberculosis/respiratory care hospital in Delhi, India. The hospital has a dedicated hospital infection control policy regarding hand hygiene and hygienic practice including, infection control bundles. The hospital carries out active surveillance of locally circulating bacteria routinely. It has a total staff of around 114, including doctors, nurses, paramedics and cleaning and sanitation workers who work in various shifts.

We conducted an observational study to investigate the phenotypic and genotypic (bla_{KPC} and bla_{NDM-1}) carbapenem-resistance characteristics of bacteria present on hand-held and hands-free electronic devices used by healthcare workers, their family members and the patient attendants.

Methods

Collection and processing of samples

This observational study was conducted in the Department of Microbiology of the NITRD, Delhi, over three months after obtaining due institutional ethical approval (NITRD/EC/2019/6612). Swab samples were collected from electronic devices of healthcare workers (HCWs) and non-health care workers (non-HCWs). Samples were collected from 112 HCWs and from 50 non-HCWs who frequented the hospital to assist patients or who were living on the hospital campus as family members of NITRD staff. Not all patients were accompanied by attendants. Swabs moistened with sterile water were rubbed over mobile phones, touchpads, chargers, hands-free headphones/microphones, laptops, digital wristwatches and computer mice. Care was taken to ensure that those surfaces which are in frequent contact with the hands were adequately rubbed. The swabs were cultured and bacteria were identified by Gram staining and biochemical reactions according to standard methods [12]. Bacteria isolated were stored in 20% glycerol broth solution.

Phenotypic detection of carbapenemase (serine carbapenemase/MBL) production in Gram-negative bacteria

Disks of imipenem (10 μg) and imipenem-EDTA (10/750 μg) were placed apart on Mueller Hinton agar plates. Bacteria with zone diameters of ≥23 mm, 20–22 mm and ≤ 19 mm around imipenem disks were designated sensitive, intermediately resistant and presumptively resistant, respectively. The zone diameters of the presumptively imipenem-resistant bacteria were then compared with the zone diameters obtained from the combined imipenem-EDTA disks. Zone differences of >7 mm and <7 mm was taken as indicative of the presence of presumptive metallo-β-lactamase (carbapenemase) enzyme and serine-β-lactamase enzyme, respectively [10].

Identification of bla_{KPC} and bla_{NDM-1} genes

This was done for the bacteria belonging to the family Enterobacteriaceae, *Pseudomonas* spp. and *Acinetobacter* spp. DNA was extracted in accordance with the methods described in the literature [13]. Briefly, two bacterial colonies were picked up from overnight growth on blood agar plates. These were placed in a test tube containing 25 μl of autoclaved double distilled water and heated to 95°C for 10 min in a water bath. The tubes were then centrifuged for 10 min at 10,000 rpm. The supernatant was collected and used for PCR. Uniplex touch-down PCR was set up with 25 μl of master mix solution containing 15 μl of nuclease-free water, 2.5 μl of 10× PCR buffer, 0.5 μl of 25 mM MgCl2, 0.5 μl of template DNA, 2 μl of 10 mM dNTP, 2 μl of 10 μM forward primer, 2 μl of 10 μM reverse primer and 0.5 μl of 5 U/μl *Taq* DNA polymerase. The DNA amplicons obtained were run on 1% agar gel. PCR was set up by using primers for the bla_{KPC} gene (FP- 5′-TGTCACTGTATCGCCGTC-3′; RP-5′-GTCAGTGCTCTACAGAAAACC-3′) with a touch-down range from 57°C to 63°C and for the bla_{NDM-1} gene (FP- 5′-GGTTTGGCGAT CTGGTTTTC-3′; RP- 5′-CGG AATGGCTCATCAC-GATC-3′) with a touch-down range from 54°C to 48°C. The amplicon size expected was of 1011 bp and 621 bp for the bla_{KPC} and bla_{NDM-1} gene, respectively [14]. To optimise the PCR, ribonuclease-free water was included as a negative control. Non-specific band amplicons were expected during PCR, as the collected samples were environmental in nature, but were ignored because no high-end sequencing techniques were used.

Statistical analysis was performed using Microsoft Excel® version 2017.

Results

Swabs were collected from the hand-held and hands-free electronic devices of 162 participants, 112 of whom were HCWs, and 50 were non-HCWs. A total of 330 swabs were collected, 215 of which were from devices of HCWs and 115 from those of non-HCWs. These 330 swabs yielded 684 bacteria (Table I). 67.5% of the bacteria found on HCW devices (n=462/684) and remaining 32.5% on non-HCW devices (n=222/684). Mobile phones were the most heavily contaminated (48%, n=328/684) and hands-free headphones/microphones were the least contaminated (2.2%, n=15/684). A mixture of bacteria was cultured from all devices. The bacteria cultured from the electronic devices are shown in Table I. Gram-positive spore-bearing bacilli were the most numerous. *Escherichia coli* was the commonest Gram-negative bacterium (10.7%, n=73/684). Overall, *Staphylococcus* spp., *Enterococcus* spp., *Micrococcus* spp., Gram-positive spore-bearers, Diphtheroids, *Escherichia* spp. and *Klebsiella* spp. were found in greater numbers on HCW devices than on non-HCW devices. There were 15 isolates of methicillin-resistant *Staphylococcus* spp. and these were found on all the types of electronic devices except chargers and hands-free headphones/microphones.

Among the 110 common Gram-negative bacteria bacteria grown (*Escherichia* spp., *Klebsiella* spp., *Proteus* spp., *Pseudomonas* spp. and *Acinetobacter* spp.), 65.5% (n=72/110) were found on HCW devices and the remaining 34.5% (n=38/110) on non-HCW devices.

53.6% (n=59/110) of the Gram-negative bacteria were phenotypically carbapenem-resistant of which 67.8% (n=40/59) were from HCW devices and the remaining 32.2% (n=19/59) from non-HCW devices. Also, 67.8% (n=40/59) of these bacteria were identified as presumptive metallo-β-lactamase positive and remaining 32.2% (n=19/59) as presumptive serine-β-lactamase positive (Table II). Overall, the proportions of metallo-β-lactamase positive bacteria on HCW and non-HCW devices were 34.7% (n=25/72) and 39.5% (n=15/38) respectively.

40% (n=44/110) of the Gram-negative bacteria were genotypically carbapenem-resistant of which 72.7% (n=32/44) were from HCW devices and the remaining 27.3% (n=12/44) from non-HCW devices. These bacteria were positive for only the bla_{NDM-1} gene (20.9%, n=23/110), or only bla_{KPC} gene (10%, n=11/110), or for both the genes (9.1%, n=10/110) (Table II). Overall, the proportions of bla_{NDM-1} gene positive bacteria were 34.7% (n=25/72) and 21.0% (n=8/38) on HCW and non-HCW devices respectively.

Table I
Bacteria cultured from hand-held and hands-free electronic devices (n=684)

Organism	HCW/non-HCW	Mobile phones	Touchpads	Chargers	Digital wristwatches	Laptop keyboards	Computer mouse	Hands-free mobile devices	Total	P-value
Methicillin-sensitive *Staphylococcus aureus* (n=35)	HCW	6	0	1	4	13	7	0	31	<0.05
	Non-HCW	1	0	1	0	2	0	0	4	
Methicillin-resistant *Staphylococcus aureus* (n=5)	HCW	2	0	0	2	1	0	0	5	-
	Non-HCW	0	0	0	0	0	0	0	0	
Coagulase-negative *Staphylococcus* spp. (n=148)	HCW	36	21	3	5	15	5	1	86	<0.05
	Non-HCW	45	3	3	1	8	1	1	62	
Methicillin-resistant Coagulase-negative *Staphylococcus* spp. (n=10)	HCW	4	1	0	1	2	2	0	10	-
	Non-HCW	0	0	0	0	0	0	0	0	
Micrococcus spp. (n=39)	HCW	23	7	1	0	0	0	0	31	<0.05
	Non-HCW	7	1	0	0	0	0	0	8	
Enterococcus spp. (n=8)	HCW	2	1	0	2	0	1	0	6	<0.05
	Non-HCW	1	1	0	0	0	0	0	2	
Gram-Positive Spore Bearers (n=306)	HCW	101	21	20	5	45	10	1	203	<0.05
	Non-HCW	44	3	34	2	10	2	8	103	
Diphtheroids (n=19)	HCW	12	0	2	0	0	2	0	16	<0.05
	Non-HCW	3	0	0	0	0	0	0	3	
Escherichia spp. (n=48)	HCW	11	3	2	4	11	1	1	33	<0.05
	Non-HCW	6	1	3	1	3	0	1	15	
Klebsiella pneumoniae (n=13)	HCW	5	1	0	1	3	0	0	10	<0.05
	Non-HCW	1	0	0	0	1	0	1	3	
Citrobacter spp. (n=4)	HCW	1	1	0	0	0	0	0	2	1
	Non-HCW	0	0	1	1	0	0	0	2	
Proteus spp. (n=8)	HCW	2	2	0	0	0	1	0	5	0.31
	Non-HCW	2	0	0	0	0	1	0	3	
Pseudomonas aeruginosa (n=32)	HCW	6	5	1	2	1	3	1	19	0.13
	Non-HCW	5	2	2	1	3	0	0	13	
Acinetobacter baumannii (n=9)	HCW	1	2	0	1	0	1	0	5	0.63
	Non-HCW	1	0	1	1	0	1	0	4	
Total	-	328	76	75	34	118	38	15	684	-

HCW: Healthcare worker; Non-HCW: Non-Healthcare worker.

Table II
Frequency distribution of various phenotypic and genotypic resistance patterns for the organisms (n=110)

Organism	Phenotypic Imipenem resistance	bla_{KPC} and bla_{NDM-1} (HCW+ Non-HCW)	Only bla_{NDM-1} (HCW+ Non-HCW)	Only bla_{KPC} (HCW+ Non-HCW)	Both genes absent (HCW+ Non-HCW)	Total (HCW+ Non-HCW)
Escherichia spp.	Sensitive	5 (4+1)	10 (7+3)	4 (3+1)	8 (5+3)	27 (19+8)
	Resistant	2 (2+0)	4 (3+1)	1 (1+0)	14 (8+6)	21 (14+7)
	MBL	*1 (1+0)*	*3 (2+1)*	*0 (0+0)*	*10 (5+5)*	*14 (8+6)*
	SBL	*1 (1+0)*	*1 (1+0)*	*1 (1+0)*	*4 (3+1)*	*7 (6+1)*
Klebsiella spp.	Sensitive	0 (0+0)	1 (0+1)	1 (1+0)	4 (3+1)	6 (4+2)
	Resistant	1 (1+0)	1 (1+0)	1 (0+1)	4 (4+0)	7 (6+1)
	MBL	*1 (1+0)*	*1 (1+0)*	*1 (0+1)*	*1 (1+0)*	*4 (3+1)*
	SBL	*0 (0+0)*	*0 (0+0)*	*0 (0+0)*	*3 (3+0)*	*3 (3+0)*
Proteus spp.	Sensitive	0 (0+0)	0 (0+0)	0 (0+0)	3 (1+2)	3 (1+2)
	Resistant	0 (0+0)	1 (1+0)	0 (0+0)	4 (3+1)	5 (4+1)
	MBL	*0 (0+0)*	*1 (1+0)*	*0 (0+0)*	*3 (2+1)*	*4 (3+1)*
	SBL	*0 (0+0)*	*0 (0+0)*	*0 (0+0)*	*1 (1+0)*	*1 (1+0)*
Pseudomonas spp.	Sensitive	2 (2+0)	3 (1+2)	1 (1+0)	7 (3+4)	13 (7+6)
	Resistant	0 (0+0)	2 (2+0)	2 (1+1)	15 (9+6)	19 (12+7)
	MBL	*0 (0+0)*	*1 (1+0)*	*1 (1+0)*	*11 (6+5)*	*13 (8+5)*
	SBL	*0 (0+0)*	*1 (1+0)*	*1 (0+1)*	*4 (3+1)*	*6 (4+2)*
Acinetobacter spp.	Sensitive	0 (0+0)	1 (1+0)	1 (0+1)	0 (0+0)	2 (1+1)
	Resistant	0 (0+0)	0 (0+0)	0 (0+0)	7 (4+3)	7 (4+3)
	MBL	*0 (0+0)*	*0 (0+0)*	*0 (0+0)*	*5 (3+2)*	*5 (3+2)*
	SBL	*0 (0+0)*	*0 (0+0)*	*0 (0+0)*	*2 (1+1)*	*2 (1+1)*
Grand total		10 (9+1)	23 (16+7)	11 (7+4)	66 (40+26)	110 (72+38)
MBL		*2 (2+0)*	*6 (5+1)*	*2 (1+1)*	*30 (17+13)*	*40 (25+15)*
SBL		*1 (1+0)*	*2 (2+0)*	*2 (1+1)*	*14 (11+3)*	*19 (15+4)*

HCW: Healthcare worker; Non-HCW: Non-Healthcare worker; MBL: - Metallo- β-lactamase enzyme positive; SBL: - Serine β -lactamase enzyme positive.

On comparing the phenotypic and genotypic resistance patterns (Table II), 33.6% (n=37/110) of the organisms showed concordance (phenotypically sensitive with no resistance gene or phenotypically resistant with either or both the genes). The resistance concordance was present in 13.6% (n=15/110) of the organisms. Amongst these 15 organisms, 80% (n=12/15) were from HCWs' devices and only 20% (n=3/15) from non-HCWs' devices. Whereas the percentage of bacteria positive for both metallo-β-lactamase and the bla_{NDM-1} gene (with or without the bla_{KPC} gene) was 7.3% (n=8/110), the percentage of those positive for both serine-β-lactamase and the bla_{KPC} gene was 2.7% (n=3/110). Amongst all the 110 Gram-negative bacteria isolated, there were only three bacteria (two *Escherichia* spp. and one *Klebsiella* spp.) which were phenotypically carbapenem (imipenem) resistant and also had both the resistance genes (bla_{NDM-1} and bla_{KPC}).

Discussion

A reduction in the rate of healthcare-associated infections (HAI) is one of the most important measurable outcomes of an effective hospital infection control policy. Monitoring antibiotic resistance rates of hospital bacteria is considered a key strategy in an infection control policy.

In this study, mobile phones had the highest number of isolated bacteria {48% (328/684)} whereas hands-free headphones/microphones were the least contaminated {2.2% (15/684)} (Table I). This observation could be explained by Gram-positive bacteria being common skin contaminants and are therefore frequently transmitted to surfaces of hand-held devices [15–17]. Also, among Gram-positive bacteria, spore-forming bacilli were common. These bacteria are present in the air and settle quickly on surfaces, thus contaminating them. These bacilli can occasionally cause serious infections, in healthy individuals and in immunocompromised patients [18]. Although this study did not investigate the potential benefit of using hands-free headphones/microphones, in terms of reducing healthcare-associated infections, the lower numbers of bacteria detected on hands-free devices compared with hand-held devices may potentially contribute to the reduction of transmission of micro-organisms in the hospital environment.

In this study, 53.6% (n=59/110) of the Gram-negative bacteria were phenotypically carbapenem-resistant of which 67.8% (n=40/59) were from HCW devices and the remaining 32.2% (n=19/59) from non-HCW devices. In a similar study by Ain N. *et al.*, the presence of imipenem resistance was calculated to be around 56.5% [19]. The presence of such a high proportion of resistant bacteria on hand-held electronic devices could be due to sharing devices. This may be a potential risk not only for HCWs and their family members but also for patients and their carers, especially in a respiratory care hospital in India. In such settings, the burden of fomite-borne transmission is already very high, and resistant bacteria could be transmitted to the home environment. Infections caused by antibiotic-resistant bacteria can be difficult to treat and can cause morbidity and mortality.

This study identified that 40% (n=44/110) of the Gram-negative bacteria were genotypically carbapenem-resistant

(both bla_{NDM-1} and bla_{KPC}) of which 72.7% (n=32/44) were from HCW devices. 30% (n=33/110) were bla_{NDM-1} gene positive of which 25 (34.7% of n=72) were on HCW devices and 8 (21.0% of n=38) on non-HCW devices. The presence of these bla_{NDM-1} gene positive bacteria on devices from both HCWs and non-HCWs is a concern, and suggests possible community transmission through such devices.

In this study, a significant percentage of bacteria showed concordant phenotypic and genotypic resistance patterns. It is noted that discordant results regarding this resistance pattern have been reported worldwide, as different methods of metallo-β-lactamase testing for routine and epidemiological purposes are used: either the combination (imipenem, imipenem-EDTA) disk diffusion method or the modified Hodge test [19,20]. The fact that such a high percentage of bacteria with bla_{NDM-1} confirmation was found in this study is a concern, as it suggests that these organisms may be endemic among HCWs and their family members.

This study has limitations. The incidence of HAIs to demonstrate a possible association between the use of hands-free devices and a reduction in HAIs was not attempted as the resources required to do this were not available. Also, additional molecular analysis such as 16S rRNA gene PCR amplification and sequencing, may have provided further insights into the role of HCWs potentially transmitting resistant bacteria to non-HCWs via sharing devices.

Conclusions

The study was carried out in Delhi which was reported as the origin of the first so-called New Delhi Metallo-β-lactamase [21]. The results of this study highlight the importance of antimicrobial resistance surveillance studies and the need to develop a surveillance policy. It provides an insight into the load of carbapenem-resistant bacteria on hand-held electronic devices used by HCWs and non-HCWs comprising the family members of HCWs and patient carers. The study supports the hypothesis that electronic devices are a potential vehicle of the transmission of carbapenem-resistant bacteria. Hands-free mobile devices were less likely to be contaminated with carbapenem-resistant bacteria than mobile phones and other electronic devices. Promoting the use of hands-free devices use may reduce the transfer of multidrug-resistant bacteria in the healthcare setting and could help to reduce HAIs.

CRediT author statement

Dr Manpreet Bhalla: Conceptualization, Methodology. **Dr Amit Aggarwal:** Data curation, Writing- Original draft preparation, Visualization, Investigation, Supervision. **Dr Hena Fatima Khan:** Writing- Reviewing and Editing.

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Conflict of interest statement

The authors declare that they have no conflicts of interest.

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